**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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SKECHERS

v.

NIKE, INC.

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# DECLARATION OF INGRID HSIEH-YEE, PH.D.

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## I. Introduction

I, Ingrid Hsieh-Yee, Ph.D., do hereby declare as follows:

**1.** Except where I have been informed by counsel regarding certain legal issues, as indicated below, I have personal knowledge of all of the matters about which I testify in this declaration.

**2.** I have been retained as an independent expert witness on behalf of Skechers U.S.A., Inc. to evaluate the authenticity and public availability of certain printed publications (identified below) which I am told will be submitted in connection with *inter partes* review (IPR) proceedings before the United States Patent and Trademark Office.

**3.** I am being compensated for my work in this matter at my customary hourly rate of $300. I am also being reimbursed for any reasonable expenses associated with my work and testimony in this investigation. My compensation is not contingent on the results of my study, the substance of my opinions, or the outcome of the IPR proceedings.

### A. Qualifications and Professional Experience

**4.** My complete qualifications and professional experience are described in my academic curriculum vitae (**Ex. U**). The following is a brief summary of my relevant qualifications and professional experience.

**5.** I was a professor in the Department of Library and Information Science at the Catholic University of America for 32 years and was conferred the title of Professor Emerita in December 2022. I have experience working in an academic library, a medical library, and a legislative library. I hold a Ph.D. and a Masters in Library and Information Studies from the University of Wisconsin-Madison.

**6.** I am an expert on library cataloging and classification and have published two editions on this subject, *Organizing Audiovisual and Electronic Resources for Access*: *A Cataloging Guide* (2000 and 2006). I taught a variety of courses, including Cataloging and Classification, Advanced Cataloging and Classification, Organization of Internet Resources, Organization of Information, Metadata, Digital Content Creation and Management, Internet Searches and Web Design, Information Literacy Instruction, Advanced Information Retrieval and Analysis Strategies, and The Information Professions in Society. I am familiar with metadata schema design and implementation. In my teaching, I covered the design and implementation of metadata in databases, search engines, digital repositories, digital libraries, and digital archives. I also covered how information organization affects the discovery and access to digital resources on the Internet. My research interests cover cataloging and classification, information organization, metadata, information retrieval, information architecture, digital collections, scholarly communication, social media, user interaction with information systems, and others.

## B. MARC, OCLC & Library Catalogs

**7.** I am very familiar with a library cataloging encoding standard known as the "Machine-Readable Cataloging" standard, also known as "MARC," which became the national standard for sharing bibliographic data in the United States by 1971 and the international standard by 1973. MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries. Experts in my field reasonably rely upon MARC records when forming their opinions.

**8.** A MARC record consists of several fields, each of which contains specific data about the work. Each field is identified by a standardized, unique, three-digit code corresponding to the type of data that follows. **Ex. V** is a true and correct copy of Parts VII to X of "Understanding MARC Bibliographic: Machine-Readable Cataloging" (http://www.loc.gov/marc/umb/um07to10.html), a brief description and tutorial published by the Library of Congress in 2009 that explains commonly used MARC fields. For example, the personal author of a work is recorded in Field 100, the title is recorded in Field 245, publisher information is recorded in Field 260, the physical volume and characteristics of a publication are recorded in Field 300, and topical subjects are recorded in Fields 650. More details of MARC21 format for Bibliographic Data are available on the Library of Congress website at https://www.loc.gov/marc/bibliographic/.

**9.** I am very familiar with library cataloging and processing practices and the relationships between OCLC (Online Computer Library Center) and library catalogs, and how libraries create and share their records to help the public discover and access information.

**10.** The Online Computer Library Center (OCLC) is the largest bibliographic network of the world, and its WorldCat database is "the world's most comprehensive database of information about library collections" (source: https://www.oclc.org/en/worldcat.html), containing more than 559 million records from thousands of member institutions (many of which are libraries of some type) in more than 100 countries. OCLC was founded in 1967 to promote and support library cooperation. According to the third article of the "Amended Articles of Incorporation of OCLC, Inc.," OCLC was created "to establish, maintain, and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary, and educational knowledge and information" (source: https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf).

**11.** OCLC members can contribute original cataloging records in MARC to the system or derive cataloging records from existing records, an activity referred to as "copy cataloging." When an OCLC-participating institution acquires a work, it can create an original MARC record for the work in OCLC's Connexion system (a system for catalogers to create and share MARC records), and the system will automatically generate a code for the date of record creation in the yymmdd format, and the creating library's OCLC symbol is recorded in subfield "a" of the 040 field. Once the MARC record is in Connexion, it becomes available to other OCLC members for adoption to their local online catalogs (*i.e.*, copy cataloging).

**12.** After a MARC record is created in Connexion, it also becomes searchable and viewable on WorldCat, which is a free web portal for users to explore more than 10,000 libraries worldwide. Records in WorldCat, however, are not presented in MARC fields. Instead, the data elements are labeled to help users interpret the records. Thus, the information stored in MARC records in Connexion is available to the interested public through the user-friendly WorldCat web portal.

**13.** Library online catalogs gained acceptance in the early 1980s and many libraries migrated their systems to the World Wide Web in the mid-1990s. Library online catalogs are based on MARC records that represent their collections in order to help the public understand what materials are publicly accessible in those libraries. Most libraries with online catalogs have made their catalogs freely

available on the Web. These online catalogs offer user-friendly search interfaces. Strong user interest in keyword searches and the popularity of Google have led to the "googlization" of library search systems. As a result, many library catalogs now provide a single search box for users to conduct keyword searches, with additional support for searches by author, title, subject terms, and other data elements such as ISBN (International Standard Book Number). Library catalogs these days also offer features for users to narrow their search results by language, year, format, and other elements. Many libraries display MARC records on their online catalogs with labels for the data elements to help the public interpret MARC records. Many libraries also offer the option to display MARC records in MARC fields.

**14.** Libraries create MARC records for works they acquire, including books, serials, motion pictures, and publications in other formats. MARC records are representations of materials held by libraries and are critical for the discovery and access to those materials. Monograph cataloging is fairly common in libraries, and most libraries make a newly cataloged monograph available to the public soon after the cataloging work is completed, usually within a week. Libraries can create original cataloging records or use an existing record in OCLC to create a copy cataloging record. As soon as the cataloging record is completed, it is added to the library's online catalog for users. If the record is an original record, it is also entered into OCLC WorldCat. If it is a copy cataloging record, the library's holding symbol

is attached to the existing original record in OCLC WorldCat to facilitate searching and interlibrary loan.

**15.** The cataloging of serials and the serial check-in process are discussed here to show how libraries usually provide access to newly received serial issues. According to the glossary of the *RDA: Resource Description and Access* cataloging standard, a serial is "[a] mode of issuance of a manifestation issued in successive parts, usually bearing numbering, that has no predetermined conclusion. A serial includes a periodical, monographic series, newspaper, etc." (source: MARC Discussion Paper No. 2020-DP16, available at https://www.loc.gov/marc/mac/2020/2020-dp16.html). Since the publisher of a serial makes new issues of the serial available successively, a customary cataloging practice is to create one bibliographic record for the serial, and the serial record (encoded in MARC) typically provides information on the beginning date and frequency of the serial, not the dates of individual issues. In other words, libraries typically do not create MARC records for individual issues of a serial. Instead, they rely on a serial check-in system to track the receipt of new issues. A common check-in practice is to date stamp a new issue when it arrives. This practice has become automated since the late 1990s, and libraries now vary in how they share the receipt date of a new serial issue with the public. Some libraries use a date stamp,

some affix a label to indicate the receipt date, some pencil in the receipt date, and some do not provide the information to the public.

**16.** The serial check-in process usually takes less than an hour, and one of the steps involves placing a date stamp on the new issue to document the date the issue is checked in. After that, the holdings information of the serial is updated in the library's catalog so that users know which issues are available for request or access. After serial check-in is completed, the new issue is placed on the shelf with the previous issues of the serial. Libraries with a public periodical room typically place new issues in the periodical room for easy user access. Because information presented in serials often reflects latest discovery, a general practice of libraries is to make new issues of serials available for user access soon after they are checked in, usually within a week.

**17.** I am personally familiar with many online catalogs, databases, and search engines. In preparing for this declaration, I used the following authoritative information systems to search for records:

- Google Scholar (https://scholar.google.com/)
- Internet Archive (https://archive.org/)
- OCLC FirstSearch, a subscription-based search system, subscription required for access (https://firstsearch.oclc.org/)

- Online catalog of the Cornell University Library (http://catalog.library.cornell.edu/)
- Online catalog of the North Carolina State University Libraries (https://catalog.lib.ncsu.edu/)
- Online catalog of the University of Massachusetts Dartmouth Library (https://lib.umassd.edu/)
- WorldCat (https://search.worldcat.org/)

### C. Scope of This Declaration

**18.** I have been asked to offer opinions on the authenticity and public availability dates of the following documents:

(1) Choi, W., & Powell, N. B. (2005, March). Three dimensional seamless garment knitting on V-bed flat knitting machines, *Journal of Textile and Apparel, Technology and Management*, *4*(3), 1-33, **Ex. A** ("*Choi*");

(2) Legner, M., & Stoll, H. (2003, September). 3D-products for fashion and technical textile applications from flat knitting machines, *Melliand International, 9*(3), 234, 238-241, **Ex. I** ("*Legner*");

(3) Hong, H., Filho, A. A., Fangueiro, R., & de Araujo, M. D., (1994, September), "The development of 3D shaped knitted fabrics for technical purposes on a flat knitting machine," *Indian Journal of*

*Fibre & Textile Research*, vol. 19, no. 3, pp. 189-194, available at the NIScPR Online Periodicals Repository at https://nopr.niscpr.res.in/bitstream/123456789/19312/1/IJFTR%2019%283%29%20189-194.pdf, **Ex. O** ("*Hong*").

(4) Ward, D. T. (2003, May). The future of knitting, *International Textile Bulletin*, vol. 49, 2nd issue 2003, 46-50, **Ex. W** ("*Ward*").

**19.** I am rendering my expert opinion on the authenticity of the documents referenced herein and on whether they were published. I will provide my opinion on when and how these documents were publicly disseminated or otherwise made publicly available to the extent that persons interested and ordinarily skilled in the subject matter or art, exercising reasonable diligence, could have located and retrieved these documents.

**20.** I am informed by counsel that an item is considered authentic if there is sufficient evidence to support a finding that the item is what it is claimed to be. I am also informed that authenticity can be established based on the contents of the documents themselves, such as the appearance, content, substance, internal patterns, protocols followed or other distinctive characteristics of the item.

**21.** I am informed by counsel that a given reference is "published" if it is publicly accessible upon a satisfactory showing that such a document has been disseminated or otherwise made publicly available to the extent that persons

interested and ordinarily skilled in the subject matter or art could locate it exercising reasonable diligence and obtain the document. I have also been informed by counsel that materials available in a library constitute "printed publications" if they are cataloged and indexed according to general library practices and protocols that make the references available and accessible to members of the interested public.

### D. Person of Ordinary Skill in the Art

**22.** I am told by counsel that the subject matter of the IPR proceedings generally involves machine knitting techniques.

**23.** I have been informed by counsel that a "person of ordinary skill in the art" (POSITA) is a hypothetical person who is presumed to be familiar with the relevant field and its literature at the time of the inventions. This hypothetical person is also a person of ordinary creativity, capable of understanding the scientific principles and literature applicable to the pertinent field.

**24.** It is my opinion that such a person would have been actively engaged in learning about the field, possibly through formal instruction and bibliographic resources. By at least the mid-2000's, such a person would have had access to a vast array of print and electronic resources, including at least those resources referenced below.

### E. Evidence Considered in Forming My Opinions

**25.** In the preparation of this declaration, I have reviewed the documents referenced below and any other documents I reference herein, and each of these is a type of material that experts in my field would reasonably rely upon when forming their opinions:

(1) The documents referenced above in Section I.B;

(2) Materials listed in **Appendix A** to this declaration.

## II. Authenticity and Public Availability of *Choi* (Ex. A)

### A. Authentication

**26.** **Ex. A** is a true and correct copy of "Three dimensional seamless garment knitting on V-bed flat knitting machines," ("*Choi*"), by W. Choi and N. B. Powell, *Journal of Textile and Apparel, Technology and Management*, 4(3), 1-33, that I received from counsel. Page 1 is the cover sheet that indicates this copy is obtained from ResearchGate. According to a research guide from the University of Michigan Library, "What is Research Gate?" (https://guides.lib.umich.edu/c.php?g=1165556&p=8603840),"ResearchGate.net is an academic profile and social networking site, and a popular hub on the web for sharing academic publications." The research guide further states that many researchers and scientists "post PDFs of their articles on ResearchGate, so it is a source of free scholarly articles" and the articles "are often indexed by Google

Scholar." This copy of *Choi* is presented as **Ex. A** in this declaration.

**27.** Page 1 is a ResearchGate cover page that shows the title, authors, and article date ("March 2005") of *Choi*. Page 2 (internal page 1) shows this article appears in "Volume 4, Issue 3, Spring 2005" of the *Journal of Textile and Apparel, Technology and Management* of "NC State University." This page also shows the title, authors, abstract, and author keywords ("Knitting, tubular, seamless, complete garment"), and the "Article Designation" at the bottom of this page indicates the article was "Refereed." **Ex. A** shows *Choi* has a total of 33 pages, including five tables, 40 figures (some colored), 52 references, and a glossary. The center column of each page shows "JTATM" that shows *Choi* appears in *Journal of Textile and Apparel, Technology and Management* ("JTATM").

**28.** Since JTATM is published as an electronic journal and no scanned copies can be obtained through interlibrary loan services, I searched Internet Archive for copies of *Choi* and records for this journal. **Ex. B** is a true and correct copy of *Choi* archived by Internet Archive on November 9, 2005. I personally located, identified, and obtained this copy. It is the type of material experts in my field would reasonably rely upon when forming their opinions.

**29.** The Internet Archive copy of *Choi* (**Ex. B**) shows this article has a total of 33 pages, including five tables, 40 figures (some colored), 52 references and a glossary. I have closely compared **Ex. A** and this archived copy and found them to

be identical.

**30.** **Ex. A** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. In addition, the full text of *Choi* is the same as that in the copy archived by Internet Archive. I therefore see no reason to question the authenticity of this copy of *Choi* (**Ex. A**).

**B. Internet Archive Records**

**31.** Internet Archive is a digital library that archives scholarly materials, cultural artifacts, and other web resources on the Internet and provides free public access to its collections. I have used Internet Archive in the past and am familiar with their Wayback Machine and their practice of assigning an extended URL to an archived resource in the format of http://www.archive.org/web/[Year in yyyy][Month in mm][Day in dd][Time code in hh:mm:ss]/[Archived URL] to show the point of time the archived file was captured. It is important for users to keep in mind that the archive date of a web resource archived by Internet Archive is usually *after* the first public availability date of the archived resource, because Internet Archive usually does not archive web resources the moment they appear on the Internet. The archive date, therefore, means that the archived file was available before, and definitely no later than, the archive date.

**32.** **Ex. C** is a true and correct copy of archived copies of the website of JTATM, the preview of page 1 of *Choi*, and the *Choi* article. I personally located, identified, and obtained these archived copies and assembled them into **Ex. C**. These copies are the type of material experts in my field would reasonably rely upon when forming their opinions.

**33.** Page 1 of **Ex. C** is a screenshot of a Wayback Machine calendar that shows the website for "Volume 4, Issue 3, Spring 2005" of *Journal of Textile and Apparel, Technology and Management* (http://www.tx.ncsu.edu/jtatm/volume4issue3/vo4_issue3_abstracts.htm) was archived 25 times between "19 Apr 2005" and "16 Jun 2012," and this particular copy was archived on "AUG 27 2005" and is available at https://web.archive.org/web/20050827064124/http://www.tx.ncsu.edu/jtatm/volume4issue3/vo4_issue3_abstracts.htm. The archive date of "20050827064124" indicates this webpage was archived on August 27, 2005, at 6 a.m., 41 minutes, and 24 seconds. The archive date means interested users would have been able to discover and access this website on the Internet by August 27, 2005.

**34.** Pages 2 to 9 are the PDF of the archived website of volume 4, issue 3 (spring 2005) of JTATM that displays the table of contents of this issue. Each article is represented in one row by the title, authors, abstract, and author keywords, together with a link to "Preview First Page" and a link to the "Complete Article."

The second row on page 2 of **Ex. C** shows *Choi* is included in this issue of JTATM. **Ex. C** shows that, by August 27, 2005, interested users would have been able to locate this website to discover the *Choi* article and would have been able to follow the links to preview page 1 of *Choi* and access the full text of *Choi*. A note on page 9 shows JTATM is published by "TATM, Department of Textile and Apparel, Technology and Management" and the date for "Last Site Revision" was "March 16, 2005." This website revision date means that, in fact, interested users would have been able to discover the website for volume 4, issue 3 of JTATM by March 16, 2005.

**35.** The "Preview First Page" link for *Choi*, reflected in Page 10 of **Ex. C,** is a screenshot of a Wayback Machine calendar that shows the first page of *Choi* (http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_first_145_05.pdf ) was archived three times between "9 Nov 2005" and "28 Jun 2010," and this particular copy was archived on "NOV 09 2005" and has been available at https://web.archive.org/web/20051109100812/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_first_145_05.pdf. Page 11 is the PDF of this archived copy that identifies the file as page 1 of *Choi* and shows the journal title, volume and issue numbers, issue date, and parent university of this journal. The content of this file is the same as the first page of *Choi* in **Ex. A** and **Ex. B**. The archive date of "20051109100812" indicates this file was archived on November 9, 2005, at 10 a.m.,

8 minutes and 12 seconds. The archive date means that interested users would have been able to discover and access this file on the Internet by November 9, 2005.

**36.** Page 12 of **Ex. C** is a screenshot of a Wayback Machine calendar that shows the complete article of *Choi* (http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_full_145_05.pdf) was archived eight times between "9 Nov 2005" and "16 Apr 2024" and this particular copy was archived on "NOV 09 2005" and has been available at https://web.archive.org/web/20051109095833/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_full_145_05.pdf. Pages 13 to 45 (internal numbers 1 to 33) are the PDF of this archived copy, and it shows the same content for *Choi* as **Ex. A**. The archive date of "20051109095833" indicates the complete article of *Choi* was archived on November 9, 2005, at 9 a.m., 58 minutes, and 33 seconds. The archive date means that interested users would have been able to discover and access the complete article of *Choi* on the Internet by November 9, 2005.

### C. Affidavit of Mr. Nathaniel E. Frank-White

**37.** My analysis of the archived copies in **Ex. C** is supported by the affidavit of Mr. Nathaniel E. Frank-White of the Internet Archive that I received from counsel. This affidavit includes four parts: the affidavit, Exhibit A, Exhibit B 001, and Exhibit B 002. I have assembled these parts to produce **Ex. N** and added the cover sheets for Exhibits B 001 and B 002 to identify those parts clearly. Mr. Frank-

White states that "[t]he Internet Archive is a website that provides access to a digital library of Internet sites and other cultural artifacts in digital form. Like a paper library, we provide free access to researchers, historians, scholars, and the general public" (Page 1, ¶ 2). He further explains that "[t]he Internet Archive assigns a URL on its site to the archived files in the format http://www.archive.org/web/[Year in yyyy][Month in mm][Day in dd][Time code in hh:mm:ss]/[Archived URL] aka an 'extended URL'. … The date indicated by an extended URL applies to a preserved instance of a file for a given URL …." (Page 1, ¶ 5). He also makes explicit that "in the case of a page constituted by a primary HTML file and other separate files (e.g., files with images, audio, multimedia, design elements, or other embedded content) linked within that primary HTML file, the primary HTML file and the other files will each have their own respective extended URLs and may not have been archived on the same dates" (Page 1, ¶ 5).

**38.** In Paragraph 6 Mr. Frank-White states that Exhibit A attached to the affidavit "are true and accurate copies of browser screenshots of the Internet Archive's records of the archived files for the URLs and the dates specified in the attached coversheet of each printout" (Page 1, ¶ 6).

**39.** Mr. Frank-White's Exhibit A (Pages 7 to 12 of **Ex. N**) confirms the authenticity and accuracy of the screenshots of the archived website of vol. 4, issue 3 (Spring 2005) of JTATM, presented as pages 1 to 9 of **Ex. C**.


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**40.** In Paragraph 7 of his affidavit Mr. Frank-White states that "Exhibit B are true and accurate copies of the Internet Archive's records of the archived files for the URLs and the dates specified in the following table." Folder B 001 is an archived copy of the first page of *Choi* (see page 13 of **Ex. N**), which is the same as the archived first page of *Choi* in **Ex. C** (page 11). The table in the affidavit shows the URL of this archived file is https://web.archive.org/web/20051109100812/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_first_145_05.pdf (page 2, ¶ 7), which is the same the URL included in **Ex. C** (page 10) for this file.

**41.** Folder B 002 is the complete article of *Choi* (see pages 16 to 48 of **Ex. N**), and it is the same as the archived copy of *Choi* included in **Ex. C** (pages 13 to 45). The URL of the archived copy of *Choi* on page 2 of the affidavit (¶ 7), https://web.archive.org/web/20051109095833/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_full_145_05.pdf, is the same as the URL included in **Ex. C** for the complete article (see page 12).

**42.** **Ex. N** presents the affidavit, Exhibit A, Exhibit B 001, and Exhibit 00B 002 provided by Mr. Frank-White, and confirms the screenshots in these archived files are true and accurate copies archived by the Internet Archive. The affidavit of Mr. Frank-White supports my analysis that the journal website of JTATM was publicly discoverable and accessible on the Internet no later than August 27, 2005. In

addition, this affidavit confirms my analysis that the first page of *Choi* and the complete article of *Choi* were publicly discoverable and accessible on the Internet no later than November 9, 2005.

**43.** As evidence that Internet Archive was in operation by August of 2005 when archives pages presented in **Ex. B** and **Ex. C** were on the Internet Archive, I obtained a record about the Internet Archive from the Library of Congress at https://www.loc.gov/item/2003541624. This record is presented as **Ex. D** in this declaration. It indicates Internet Archive is a "software, e-resource" and the record summary states that "The Internet Archive 'was founded [in 1996] to build an "Internet library,"' with the purpose of offering permanent access for researchers, historians, and scholars to historical collections that exist in digital format." **Ex. D** shows that Internet Archive has been in operation since 1996, meaning interested users would be able to use it to discover the archived records in **Ex. B** and **Ex. C** and use them to discover and access *Choi* in August and November of 2005 on the Internet.

### D. OCLC FirstSearch Record

**44.** As noted above, the WorldCat database on OCLC has more than 559 million records for publications in various formats. OCLC provides access to this database in three ways. The general public can use WorldCat, a free web portal, to explore the collections in more than 10,000 libraries worldwide. Librarians can use

OCLC Connexion to create and share library records for cataloging, collection management, and interlibrary loan services. Researchers and reference librarians can use OCLC FirstSearch to explore many proprietary databases, including the WorldCat database. The difference between WorldCat the free web portal and the WorldCat database on OCLC FirstSearch is that the latter provides more technical details than the former and requires a subscription for access. For example, the "Date of Entry" field on an OCLC FirstSearch record shows the date when the record was entered into the WorldCat database, indicating the date when the record became discoverable on WorldCat the free web portal, on OCLC Connexion, and on OCLC FirstSearch.

**45.** **Ex. E** is a true and correct copy of the OCLC FirstSearch record for JTATM that contains *Choi*. I personally located, identified, and obtained this record. It is the type of record experts in my field would reasonably rely upon when forming their opinions.

**46.** Page 1 shows this record represents "Journal of textile and apparel technology and management : JTATM" and the author of this publication is "North Carolina State University." It also shows the accession number of this record in the OCLC WorldCat database is "45649342" and 70 libraries hold this journal. Record details on pages 3 and 4 show "North Carolina State University.; Department of Textile and Apparel Technology and Management" as the corporate author of this

journal. The record also shows this academic unit of Raleigh, North Carolina, is the publisher, and the journal began in 2000, with a publication frequency of "Quarterly." The record shows the journal's ISSN is "1533-0915," its CODEN (a unique six-character, alphanumeric code that provides unambiguous identification of the titles of periodicals) is "JTATAJ" and its LCCN (Library of Congress Control Number) is "2001-212483." Details on page 4 identify this work as a periodical that is accessible on the World Wide Web. The "Document Type" field shows this work is identified as an "Internet Resource; Computer File; Serial." The "Date of Entry" field and the Database field show this record was entered into OCLC WorldCat on "20010103" (*i.e.*, January 3, 2001). According to OCLC documentation, the "Entry" field is the date of entry field that reflects the record creation date in MARC Field 008 (see https://help.oclc.org/Discovery_and_Reference/FirstSearch/Search/Expert_search_in_WorldCat_indexes/US_MARC_fields_displayed_in_a_WorldCat_detailed_record). This OCLC FirstSearch record informs my opinion that a serial record for JTATM was entered into the OCLC WorldCat database on January 3, 2001, making the journal discoverable from that date on.

**47.** As evidence that OCLC FirstSearch was in operation when the record for JTATM was added to this system on January 3, 2001, I obtained a report on OCLC FirstSearch. This report is presented as **Ex. F** in this declaration.

**48.** **Ex. F** is a true and correct copy of the *Library Systems Newsletter* of November 1991 (https://librarytechnology.org/document/4992/) that I obtained from the Library Technology Guide. The headline is "FirstSearch launched" and the article describes FirstSearch as a "new online reference tool for end-users" that enables patrons, as of November 1991, to search WorldCat, the OCLC Online Union Catalog, and five other databases. **Ex. F** shows that OCLC FirstSearch is a long-running search system that began operation in 1991, meaning it was available to interested users when the record for JTATM was entered into the WorldCat database on OCLC on January 3, 2001.

**E. Library Records of North Carolina State Universities**

**49.** As evidence of the public availability of JTATM at libraries, I obtained records from the North Carolina State University Libraries, because the corporate author of JTATM is a department of this university. **Ex. G** is a true and correct copy of the bibliographic and MARC records for JTATM. I personally located, identified, and obtained these records from the library online catalog of this university. They are the type of record experts in my field would reasonably rely upon when forming their opinions.

**50.** Pages 1 and 2 of **Ex. G** are the bibliographic record for JTATM that shows the journal title, corporate author, publication frequency ("Quarterly"), publisher, language, ISSN ("1533-0915"), OCLC number ("45649342"), LCCN

("2001212483"), and an online link to the journal. These details are the same as the details in the OCLC FirstSearch record (**Ex. E**).

**51.** Pages 3 and 4 are the MARC record. The first six digits of Field 008 show this record was created on "010103" (*i.e.*, January 3, 2001), and the "c20009999" code following the record creation date indicates this publication is a continuing resource that began publication in 2000 and has no end date of publication. Subfield "a" of Field 040 shows NSD (the National Serials Data Program of the Library of Congress) created the original record. Field 008 and 040 inform my opinion that the original serial record for JTATM was created by NSD and the North Carolina State University Libraries used it to create a copy cataloging record later.

**52.** Field 022 shows the ISSN of this electronic journal, Field 030 shows the journal's CODEN, Field 035 shows the record's OCLC number, and Field 042 shows the record was authenticated by "NSDP" (the National Serials Data Program). Field 130 shows a uniform title for the journal, Field 245 shows the title, subtitle, and corporate author statement, Field 246 shows a variant title, Field 264 shows the publisher has published this journal since 2000, Field 300 identifies this publication as an "online resource," Field 362 shows the journal began with "Vol. 1, issue 1" and Field 310 shows the publication frequency is "Quarterly." Field 538 shows the journal is accessible on the World Wide Web. Field 710 shows the corporate author

is included to help users discover this journal.

**53.** The MARC serial record for JTATM that contains *Choi* shows that it is a copy cataloging record based on a record created by the National Serials Data Program of the Library of Congress on January 3, 2001. This MARC record has made JTATM discoverable in the online catalog of the North Carolina State University Libraries after the original MARC record was created in January 3, 2001. Interested users would have been able to discover this journal in the library online catalog by the ISSN, LCCN, CODEN, uniform title, title, variant title, and corporate author.

**54.** As evidence that the North Carolina State University Libraries had an online catalog in operation in 2005, I searched Internet Archive for records. **Ex. H** is a true and correct copy of the catalog of NCSU Libraries archived by Internet Archive. I personally located, identified, and obtained this record. It is the type of record experts in my field would reasonably rely upon when forming their opinions.

**55.** Page 1 is a screenshot of a Wayback Machine calendar that shows the online catalog of NCSU Libraries on the Internet (http://catalog.lib.ncsu.edu/web2/tramp2.exe/log_in?LOGIN=guest&SERVERS=1home&SETTING_KEY=Files&item_category2_filter=all&SCREEN=home.html) was archived 31 times between "16 Dec 2005" and "25 Jul 2010" and this particular copy was archived on "DEC 16 2005" and has been available at

https://web.archive.org/web/20051216115305/http://catalog.lib.ncsu.edu/web2/tramp2.exe/log_in?LOGIN=guest&SERVERS=1home&SETTING_KEY=Files&item_category2_filter=all&SCREEN=home.html. Page 2 is the PDF of the archived copy of the web catalog that shows that, as of December 16, 2005, users could search the library catalog for books, ebooks, journals, movies and music, government documents, and other materials, and the catalog supported users to search by author, title, journal title, subject, keywords, ISSN, and other data elements. **Ex. H** informs my opinion that the online catalog of NCSU was available on the Internet no later than December 16, 2005, and interested users would have been able to use it to discover JTATM, an electronic journal published by the Department of Textile and Apparel, Technology and Management at the North Carolina State University.

**F. Citation Records**

**56.** Actual usage of a publication is reflected by other publications that make reference to it. I used Google Scholar to review citations to *Choi* and found two citations were published before the "November 10, 2006" critical date, and the earliest citation appeared in September 2005:

(1) Rissanen, T. (2005, September). From 15% to 0: Investigating the creation of fashion without the creation of fabric waste. *Creativity: Designer meets Technology Europe*; and

(2) Rangel, M. T. (2006, September). *Estimating Penalties for Violating the Minimum Wage and Hiring Illegal Immigrants: The Case of the US Apparel Manufacturing Industry* (Doctoral dissertation, Virginia Tech).

### G. Summary of My Opinion on *Choi*

**57.** JTATM is an electronic journal that is available on the Internet. The copy of *Choi* that I received from counsel (**Ex. A**) is authentic because the article shows no signs to raise suspicion about its authenticity, and this copy and the copy archived by Internet Archive (**Ex. B**) have the same content. **Ex. C** contains three archived records that show when the journal JTATM and the *Choi* article became publicly discoverable and accessible on the Internet. An archived copy of the vol. 4, issue 3 (Spring 2005) journal website shows that interested users would have been able to discover and access this website to discover *Choi* no later than August 27, 2005. Archived copies of the first page of *Choi* and the complete article show that interested users would have been able to discover and access these two archived files no later than November 9, 2005. An affidavit from Mr. Frank-White of Internet Archive (**Ex. N**) confirms that the archived records presented as **Ex. C** are "true and accurate copies archived by the Internet Archive."

**58.** JTATM and *Choi* are also discoverable at libraries. An OCLC FirstSearch record for JTATM (**Ex. E**) shows the record was entered into the OCLC

WorldCat database on January 3, 2001. This date means that, as of that date, this OCLC FirstSearch record became available to catalogers for copy cataloging, interlibrary loan, and collection management purposes. In addition, as of January 3, 2001, this OCLC FirstSearch record became discoverable for users of OCLC FirstSearch, which was launched in 1991, and also became discoverable for the general public on WorldCat, the free web portal, which was launched by OCLC in 1998. Records from the North Carolina State University Libraries (**Ex. G**) show their MARC record was based on a record created on January 3, 2001, by the National Serials Data Program of the Library of Congress. The library records show the Department of Textile and Apparel, Technology and Management of North Carolina State University is the corporate author of this journal, and interested users would have been able to discover this electronic journal in the library online catalog by its ISSN, LCCN, CODEN, uniform title, title, variant title, and corporate author. An archived copy of the online catalog of NCSU Libraries (**Ex. H**) shows that by December 16, 2005, interested users would have been able to access the online catalog on the Web to discover JTATM. Citation records show two citations were published before the November 6, 2006, critical date, and the earliest citation appeared in September 2005, supporting my opinion that *Choi* became publicly available no later than November 9, 2005.

## III. Authenticity and Public Availability of *Legner* (Ex. I)

### A. Authentication

**59.** **Ex. I** is a true and correct copy of "3D-products for fashion and technical textile applications from flat knitting machines," ("*Legner*"), by M. Legner and H. Stoll, *Melliand International,* vol. 9, issue 3, pp. 234, 238-241, that I received from counsel.

**60.** Page 1 is the cover that identifies this publication as *Melliand International*. Page 2 is the Table of Contents that shows this issue is "Volume 9, Issue 3" that has an issue date of "September 2003." The "Knitting" section shows IKME preview appears on page 234, and the *Legner* article begins on page 238. Pages 3 to 6 (internal pages 238 to 241) are the full text of *Legner* that shows this article has a total of four pages, including three figures in color. Page 7 of **Ex. I** is the "IKME preview" that features four upcoming presentations of machines and products, including "Stoll: flat knitting machines."

**61.** To authenticate **Ex. I**, I searched WorldCat for records of the journal containing *Legner*, and a WorldCat record at https://search.worldcat.org/title/33263976 shows that Cornell University Library is one of the 75 (at the time of last access) holding libraries. After verifying the holdings information in this library's online catalog, I requested a scanned copy of

*Legner* and the IKME preview page from Cornell University Library through a document vendor. This library copy is presented as **Ex. J** in this declaration.

**62.** Page 1 of **Ex. J** is the cover of No. 3 (September 2003) of *Melliand International* that carries a label of "Mann TS 1300 M37 v. 9, no. 3, 2003" and a date stamp of "A.R. MANN LIBRARY NOV 10 2003 ITHACA, NY 14853" that indicates this issue was received by the library on November 10, 2003. Page 2 is the table of contents of this issue. Page 3 (internal page 234) is the "IKME preview" page. Pages 4 to 7 (internal pages 238 to 241) are the full text of *Legner*. I have closely compared **Ex. I** with this copy from Cornell University Library and found them to contain the same content.

**63.** **Ex. I** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. In addition, this copy has the same content as the copy obtained from Cornell University Library (**Ex. J**). Based on my analysis of **Ex. I** and **Ex. J**, I see no reason to question the authenticity of **Ex. I**.

**B. Records of Cornell University Library**

**64.** **Ex. K** is a true and correct copy of the bibliographic and MARC records for *Melliand International* that contains *Legner*. Page 1 shows the journal title, language, publisher, subjects, ISSN ("0947-9163"), and publication frequency


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("Quarterly"). The "Availability" area on page 1 shows this journal is available at the Mann Library of Cornell University, its call number is "TS1300 .M37" and the library has "no.3 (1998), v.5-26 (1999-2020)".

**65.** Pages 4 and 5 are the MARC serial record. The first six digits of Field 008 show the record was created on "951010" (*i.e.*, October 10, 1995), and the "c19959999" code after the record creation date indicates this publication is a continuing resource that began publication in 1995 and has no end date of publication. Subfield "a" of Field 040 shows "WAP" is the library that created the original serial record. Field 008 and Field 040 inform my opinion that the Cornell University Library used the MARC record created by WAP on October 10, 1995, to create their copy cataloging record.

**66.** Field 022 shows the ISSN of this journal is "0947-9163," Field 245 shows the journal title, Field 260 shows IBP Business Press Publishers of Frankfurt am Main has published this journal since 1995, Field 362 shows the journal began with No. 1 in March 1995, and Field 310 shows the publication frequency is "Quarterly." Fields 500 show the title for the 245 field was taken from the cover, and "Frankfurt, Milan, New York, Hongkong" appears on the cover. Field 546 shows this journal is in English.

**67.** Subject of *Melliand International* is represented in Field 050 by a Library of Congress Classification (LCC) number of "TS1300" that represents


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periodicals of the "Textile industries" and in Fields 650 by three Library of Congress subject headings, with "Textile industry," "Textile fibers," and "Textile machinery" as the main topics, each followed by "Periodicals" as a form subdivision to indicate these topics are treated in a journal. These subject representations enable users to conduct subject searches to discover this journal.

**68.** The MARC record for *Melliand International* was first cataloged by a library on October 10, 1995, and the original record was used by the Cornell University Library to create their copy cataloging record. The date stamp on the scanned copy provided by this library shows vol. 9, no. 3 (September 2003) of *Melliand International* that contains *Legner* was received by the library on November 10, 2003, so it is my opinion that *Melliand International* would have been discoverable in the library's online catalog by November 10, 2003, if not earlier. Interested users would have been able to discover this journal by the ISSN, title, classification number, and subject headings.

**69.** As discussed above, a customary library practice is to put a newly received journal issue through the serial check-in process by date stamping the new issue, and then processing it promptly for user access, usually within a week after serial check-in is completed. It is therefore my opinion that after vol. 9, no. 3 of *Melliand International* was received by the Cornell University Library on November 10, 2003, the physical copy, after processing, would have become publicly

accessible by November 17, 2003.

**70.** As evidence that Cornell University Library had an online catalog in operation in the fall of 2003 when the journal issue containing *Legner* was received, I searched Internet Archive for records of the library catalog. **Ex. L** is a true and correct copy of "About the CU Library Catalog" archived by Internet Archive on August 16, 2003. I personally located, identified, and obtained this record. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

**71.** Page 1 is a screenshot of a Wayback Machine calendar that shows "About the CU Library Catalog" (http://campusgw.library.cornell.edu/newhelp/res_tools/catalog/about.html) was archived 35 times between "8 Jan 2001" and "17 Jun 2012" and this particular copy was archived on "AUG 16 2003" and has been available at https://web.archive.org/web/20030816231751/http://campusgw.library.cornell.edu/newhelp/res_tools/catalog/about.html. The archive date of "20030816231751" means the file was archived on August 16, 2003, at 11 p.m., 17 minutes, and 51 seconds. This archive date indicates that interested users would have been able to learn about this file by August 16, 2003.

**72.** Pages 2 and 3 are the PDF of the archived copy of "About the CU Library Catalog" that explains the catalog "is available for use 7 days per week and

24 hours per day" and "contains over 4.3 million bibliographic records that identify and locate materials in all 17 libraries on the Ithaca campus, the Geneva Experiment Station Library, and the CISER Data Archive" and the records cover materials of various formats, such as books, serials (journals, magazines, newspapers), and electronic resources. Page 3 shows that users can use telnet to access the CU Library Catalog on the Internet. Telnet is a program that lets users "use the power of the Internet to connect" to "databases, library catalogs, and other information resources around the world" (Chapter 6.1 "Mining the Net" of *Big Dummy's Guide to the Internet* by the Electronic Frontier Foundation, available at https://www.gutenberg.org/cache/epub/118/pg118-images.html). Technical specification of the TELNET Protocol is detailed in RFC 854 "Telnet Protocol Specification) at https://datatracker.ietf.org/doc/html/rfc854. **Ex. L** informs my opinion that by August 2003 Cornell University Library had already had an online catalog in operation, and users could access the catalog on site or on the Internet. The availability of the library online catalog for user access means that by November 10, 2003, when the journal issue containing *Legner* was received by the library, interested users would have been able to search the online catalog to discover *Melliand International* that contains *Legner*.

### C. Usage Records

**73.** Actual usage of a publication is reflected by other publications that


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make reference to it. I have reviewed citations to *Legner* on Google Scholar and compiled a list of citations from 2005 to 2011 to show usage. **Ex. M** shows the earliest citation was published in Spring 2005.

### D. Summary of My Opinion on *Legner*

**74.** The copy of *Legner* from counsel (**Ex. I**) is authentic because it contains no signs to raise suspicion about its authenticity, and the content of this copy is the same as the content of a copy obtained from the Cornell University Library (**Ex. J**). The MARC serial record of the library (**Ex. K**) shows that it was a copy cataloging record based on a record created on October 10, 1995. The date stamp on the Cornell University copy of *Legner* shows the issue containing *Legner* was received by the library November 10, 2003. It is therefore my opinion that *Melliand International* that contains *Legner* would have been discoverable in the library's online catalog by November 10, 2003, and the physical copy of vol. 9, no. 3 that contains *Legner*, after processing, would have become publicly accessible by November 17, 2003. An archived record of the library catalog obtained from Internet Archive (**Ex. L**) shows that by August 16, 2003, users would have been able to search the library catalog on site or on the Internet. This availability date of the online catalog means that after the journal issue containing *Legner* was received on November 10, 2003, users would have been able to use the library catalog to discover the journal and the issue available at the library. Citation records show that six citations to *Legner* were

published by 2011, and the earliest citation to *Legner* appeared in the spring of 2005 (**Ex. M**).

## IV. Authenticity and Public Availability of *Hong* (Ex. O)

### A. Authentication

**75.** **Ex. O** is a true and correct copy of "The development of 3D shaped knitted fabrics for technical purposes on a flat knitting machine," ("*Hong*"), by Hong et al., *Indian Journal of Fibre & Textile Research*, vol. 19, no. 3, pp. 189-194, that I obtained from the NIScPR Online Periodicals Repository (NOPR) of India, which is an online repository created to support users to "access full text articles from research journals published by CSIR-NISCAIR! Full text facility is provided for all nineteen research journals viz. ALIS, AIR, BVAAP, IJBB, IJBT, IJCA, IJCB, IJCT, IJEB, IJEMS, IJFTR, IJMS, IJNPR, IJPAP, IJRSP, IJTK, JIPR, JSIR & JST. NOPR also hosts three Popular Science Magazines viz. Science Reporter (SR), Vigyan Pragati (VP) & Science Ki Duniya (SKD) and a Natural Products Repository (NPARR)" (source: https://niscpr.res.in/resources/nopr#). When I began researching *Hong*, I searched Google Scholar by the title of *Hong* for records, and the record for this article led me to the full text of *Hong* at https://nopr.niscpr.res.in/bitstream/123456789/19312/1/IJFTR%2019%283%29%20189-194.pdf on the NOPR website. This NOPR copy is presented as **Ex. O** in this declaration.

**76.** **Ex. O** is a true and correct copy of *Hong* obtained from NOPR. Page 1 shows the title, authors, abstract, and keywords of this article, including "Flat knitting machine, Knitted fabrics, Loop structure, Technical textiles, Three-dimensional shaped knitted fabrics." The top of page 1 shows *Hong* was published in vol. 19 (with an issue date of September 1994) of *Indian Journal of Fibre & Textile Research* and runs from pages 189 to 194. **Ex. O** shows *Hong* has a total of six pages, including five sections, nine figures, 2 equations, and two references.

**77.** The copy of *Hong* from NOPR (**Ex. O**) is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. Moreover, **Ex. O** was found in the custody of the NIScPR Online Periodicals Repository, an online repository created to facilitate access to research journals published by the Council of Scientific and Industrial Research-National Institute of Science Communication and Policy Research (CSIR-NIScPR) of India, a place where, if authentic, it would likely be found. I therefore see no reason to question the authenticity of this copy of *Hong* (**Ex. O**).

**B. NOPR Metadata Record**

**78.** **Ex. P** is a true and correct copy of the metadata record for *Hong* that I obtained from the NIScPR Online Periodical Repository at


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https://nopr.niscpr.res.in/handle/123456789/19312. This is the type of record experts in my field would reasonably rely upon when forming their opinion.

**79.** The top of page 1 of the metadata record (**Ex. P**) explains the NIScPR Online Periodicals Repository supports full text access to articles in research journals published by CSIR-NIScPR and three other systems. It shows the identifier for the *Hong* article is https://nopr.niscpr.res.in/handle/123456789/19312. It also shows the title, authors, keywords, abstract, journal issue and pages of this article. The title, authors, keywords, abstract, and journal issue information match the information contained in **Ex. O**, confirming this record represents *Hong*. The metadata record shows *Hong* was published by NISCAIR-CSIR of India, in a journal whose ISSN (International Standard Serial Number) is "0971-0426 (Print)" and the issue has a "Sep-1994" issue date. The record also shows *Hong* appears in the "Special issue: IJFTR Vol. 19(3) [September 1994]" that can be accessed online at https://nopr.niscpr.res.in/handle/123456789/19198. Links in this record show *Hong* can be viewed online.

### C. Copy of Cornell University Library

**80.** To determine when *Hong* became available at libraries, I searched WorldCat by the title of *Hong*, and retrieved a WorldCat record for this article at https://www.worldcat.org/title/198134445 that showed 93 libraries (at the time of last access) held the journal containing *Hong*, including Cornell University Library.

After verifying the holdings information in the online catalog of the Cornell University Library, I requested a scanned copy of *Hong* from this library through a document delivery service. This library copy is presented as **Ex. Q** in this declaration.

**81.** **Ex. Q** is a true and correct copy of *Hong* obtained from Cornell University Library. Page 1 shows the cover of volume 19, no. 3 of *Indian Journal of Fibre & Textile Research* and identifies it as a "Special Issue on Recent Advances in Fabric Forming." This page shows volume 19, no. 3 has a "September 1994" issue date, its CODEN (a six-character alphanumeric code that provides unique and unambiguous identification of periodicals and non-serial publications) is "IJFRET," its ISSN is "0971-0426," the issue contains pages 107 to 228, and the publisher is the "Publications & Information Directorate, CSIR, New Delhi." The cover also carries a library stamp of "Albert R. Mann Library, MAR 24 1995, Ithaca, NY 1485…" Page 2 is the issue title page that shows the journal title and the theme of the special issue, the guest editor, and the publisher. Page 3 is the copyright page that shows this issue has a "1994" copyright date and the Council of Scientific & Industrial Research of New Delhi is the copyright holder. This page also shows *Indian Journal of Fibre & Textile Research* is issued quarterly. Pages 4 and 5 are the table of contents and page 4 shows *Hong* begins on page 189.

**82.** Pages 6 to 11 of **Ex. Q** are the full text of *Hong*. I have closely compared

this library copy with the copy obtained from the NIScPR Online Periodicals Repository (**Ex. O**) and found them to have the same content. The only difference is the library copy includes front matter of the issue containing *Hong*. This library copy is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. Moreover, **Ex. Q** was found in the custody of an academic library, a place where, if authentic, it would likely be found. I therefore see no reason to question the authenticity of this copy of *Hong* from the Cornell University Library (**Ex. Q**).

**D. Records of Cornell University Library**

**83.** **Ex. R** is a true and correct copy of the bibliographic and MARC records for *Indian Journal of Fibre & Textile Research* whose vol. 19, no. 3 contains *Hong*. I personally located, identified and obtained these records from the online catalog of the Cornell University Library by searching by the journal's ISSN for records. They are the type of records experts in my field would reasonably rely upon when forming their opinions on the public availability of a document.

**84.** Pages 1 and 2 of **Ex. R** are the bibliographic record for *Indian Journal of Fibre & Textile Research* at Cornell University Library. Page 1 shows the title, format, language, publisher, subjects, physical description, ISSN, frequency, other contributor, other title, index service, and note. The "Availability" area on the right

side shows this journal is held at the Mann Library and its call number is TS1300 .I391. It also shows the library holds "v.15-35 (1990-2010)" and issues are available for user request.

**85.** Pages 3 and 4 are the MARC record identified as the "Librarian View." The first six digits of Field 008 show this MARC serial record was created on "900719" (*i.e.*, July 19, 1990), and the "c19909999" code following this creation date indicates the journal is a continuing resource that began publication in 1990, and "9999" means the journal has no pre-established end date of publication. Subfields "a" and "c" of Field 040 show "DSI" created the original MARC serial record. According to the *MARC Code List for Organizations* (https://www.loc.gov/marc/organizations/org-search.php), "DSI" is the MARC organization code for the Smithsonian Institution. Data from Fields 008 and 040 inform my opinion that the library of the Smithsonian Institution created the original serial record for *Indian Journal of Fibre & Textile Research* on July 19, 1990, and the record was later used by Cornell University Library for copy cataloging.

**86.** Field 022 of the MARC record (**Ex. R**) shows "0971-0426" as the print journal's ISSN, Field 030 shows "IJFRET" as the journal's CODEN, Field 245 shows the journal title, Field 246 shows a variant title, and Field 260 shows Publications & Information Directorate, CSIR of New Delhi has been the journal publisher since 1990. Field 362 shows the journal began with volume 15, no. 1 in

March 1990, and Field 310 shows the current publication frequency is "Quarterly." The ISSN, CODEN, title, publisher, and publication frequency match the information shown in the front matter of the journal issue containing *Hong* (**Ex. Q**), confirming this record represents *Indian Journal of Fibre & Textile Research*. Field 510 shows this journal is selectively indexed by Chemical Abstracts. Field 710 shows the publisher is included in the MARC record to help users discover this journal. Field 780 shows the predecessor of this journal is "Indian Journal of Textile Research" and this earlier title is included in the MARC record to help users discover the current title.

**87.** Subject of this journal is represented in Field 050 by a Library of Congress Classification number of "TS1540" that represents general works on "Textile fibers," and in Fields 650 by three Library of Congress subject headings, including "Textile research ‡z India" ("‡z" indicates a geographic subdivision), "Textile fibers" and "Textile chemistry" as the main headings, each followed by a "Periodicals" as the form subdivision encoded in subfield "x" ("‡x") to indicate these three topics are treated in a journal. These subject representations enable users to conduct subject searches to locate this journal.

**88.** This MARC record (**Ex. R**) shows that *Indian Journal of Fibre & Textile Research* is a long-running journal. The Cornell MARC record for this journal is based on a serial record created by the library of the Smithsonian


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Institution, and the library's copy of *Hong* (**Ex. Q**) shows the journal issue containing *Hong* was received on March 24, 1995. These data inform my opinion that the Cornell MARC record has made this journal discoverable in their catalog by March 1995, if not earlier. Users interested in the subject of this journal would have been able to conduct subject searches by the Library of Congress Classification number and the Library of Congress subject headings in this record to discover this journal. They would also have been able to discover and access the journal by the journal title, variant title, ISSN, CODEN, and the publisher.

**89.** As discussed earlier, a common library practice is to create a record for a serial, without creating records for individual issues of the serial. When individual issues are received, they go through the serial check-in process, which usually takes less than an hour. After that, the newly received issues are placed on the shelf or in a periodical reading room for user access, usually on the same date of serial check-in or within a week after serial check-in. I know this is the customary library practice from personal experience as a cataloger, cataloging instructor and researcher of library catalogs and information systems. The date stamp on the Cornell University Library copy of *Hong* (**Ex. Q**) shows the issue was received by the library on March 24, 1995. It is therefore my opinion that this issue (and *Hong* contained therein) would have been publicly accessible as early as March 24, 1995, and no later than March 31, 1995, at Cornell University Library.

**90.** As evidence that Cornell University Library had an online catalog in operation in March 1995 when the journal issue containing *Hong* was received, I searched libraries.org, a directory of libraries throughout the world, for a profile of this university. I personally located, identified, and obtained this profile. This is the type of material experts in my field would reasonably rely upon when forming their opinions. This profile of Cornell University Library is presented as **Ex. S** in this declaration.

**91.** Page 2 of **Ex. S** shows Cornell University Library began using NOTIS as their online catalog in 1987 and changed to Voyager in 1999. These dates confirm that the library had an online catalog in place in March 1995 when the journal containing *Hong* was received. By at least that date, users were able to use the online catalog of the library to discover the journal containing *Hong*.

### E. Usage Record

**92.** Actual usage of a publication is reflected by the publications that make reference to it. The citation history on Google Scholar shows *Hong* has been cited 34 times. **Ex. T** is a list I compiled from Google Scholar to demonstrate usage of this article. This list includes four citations published between 2001 and 2005, and the earliest citation is a dissertation completed in 2001.

### F. Summary of My Opinion on *Hong*

**93.** The copy of *Hong* obtained from the publisher's repository, the

NIScPR Online Periodical Repository, is in a condition that does not raise suspicion of its authenticity. This article appears in a journal issue with a September 1994 issue date (**Ex. O**). The repository's metadata record for *Hong* shows this article can be accessed online (**Ex. P**). The Cornell University Library copy of *Hong* shows the library received their copy of the journal issue containing *Hong* on March 24, 1995 (**Ex. Q**). The bibliographic and MARC records for the journal containing *Hong* (**Ex. R**) show Cornell University Library created a copy cataloging record, using the MARC serial record created on July 19, 1990, by the library of the Smithsonian Institution. Since the copy of *Hong* from Cornell University Library was received on March 24, 1995, it is my opinion that the journal containing *Hong* became discoverable in this library's online catalog no later than that date. By at least that date, interested users could search for this journal by the title, variant title, ISSN, CODEN, publisher, subject headings and classification number. After processing, the journal issue containing *Hong* would become publicly accessible between March 24 and March 31 of 1995. Citation records (**Ex. T**) show the earliest citation to *Hong* was completed in 2001.

## V. Authenticity and Public Availability of *Ward* (Ex. W)

### A. Authentication

**94.** **Ex. W** is a true and correct copy of "The future of knitting," ("*Ward*"), by Derek Ward, *International Textile Bulletin*, vol. 49, 2nd issue of 2003, pages 46 to 50, that I received from counsel.

**95.** Page 1 is the cover that identifies this publication as the second issue of 2003 of *International Textile Bulletin*, which has issue date of "May 2003." Page 2 includes imprint information that indicates ITS Publishing of Schlieren-Zurich of Switzerland is the publisher, and this issue has a 2003 copyright date with the publisher as the copyright holder. Pages 2 also includes the table of contents, which continues on page 3 and shows this issue is "2nd Issue 2003 – Volume 49." Page 3 shows "The future of knitting" by Derek T. Ward begins on page 46 and is included in the "Fabric Forming" section. Pages 4 to 8 (internal pages 46 to 50) are the full text of *Ward*. **Ex. W** shows *Ward* has a total of five pages that present new developments in seven topic areas and includes four figures in color.

**96.** To authenticate **Ex. W**, I searched WorldCat for records of the journal containing *Ward*, and a WorldCat record at https://search.worldcat.org/title/39345790 shows the University of Massachusetts Dartmouth Library is one of 31 (at the time of last access) holding libraries. After verifying the holdings information in this library's online catalog, I requested a

scanned copy of *Ward* from the library through a document vendor. This library copy is presented as **Ex. X** in this declaration.

**97.** Page 1 of **Ex. X** is the cover of issue 2, 2003 of *International Textile Bulletin* that has an issue date of May 2003. The cover shows a library stamp of "UMass Dartmouth." Page 2 is the Editorial page that carries a date stamp of "JUN 18 2003 UMASS DARTMOUTH" that indicates this issue was received by the university library on June 18, 2003. The table of contents appears on pages 5 and 6, and the full text of *Ward* appears on pages 8 to 12 (internal pages 46 to 50). I have closely compared **Ex. W** with this copy from the University of Massachusetts Dartmouth Library and found them to contain the same content for *Ward*. The only difference is **Ex. X** includes an editorial page and two pages of advertisement.

**98.** **Ex. W** is in a condition that creates no suspicion about its authenticity. Specifically, this copy of *Ward* is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. In addition, this copy has the same content as the copy obtained from the University of Massachusetts Dartmouth Library (**Ex. X**). Based on my analysis of **Ex. W** and **Ex. X**, I see no reason to question the authenticity of counsel's copy of *Ward* (**Ex. W**).

### B. Records of University of Massachusetts Dartmouth Library

**99.** **Ex. Y** is a true and correct copy of the bibliographic and MARC records for *International Textile Bulletin* that contains *Ward*. Page 1 is the bibliographic record that shows the journal title, publisher, the location of this journal at "Claire T. Carney Library 5th Floor – Periodicals Collection (Shelved by Title)" and "v.44 (1998)-50 (2004)" as the library's holdings of this journal. Details of the bibliographic record on page 2 includes title, author, subjects, publisher, creation date, format, language, and type of this publication.

**100.** Page 3 is the MARC serial record. The first six digits of Field 008 show the record was created on "980624" (*i.e.*, June 24, 1998), and the "c19989999" code after the record creation date indicates this publication is a continuing resource that began publication in 1998 and has no end date of publication. Subfield "a" of Field 040 shows "LDL" (*i.e.*, the University of Nebraska at Lincoln) is the library that created the original serial record. Field 049 shows this journal is in the "SMU" collection (*i.e.*, the University of Massachusetts Dartmouth Library). Fields 008, 040 and 049 inform my opinion that the University of Massachusetts Dartmouth Library used the MARC record created by University of Nebraska at Lincoln on June 24, 1998, to create their copy cataloging record.

**101.** Field 245 shows the journal title, Field 246 shows "ITB" as a variant title to help users discover this journal, and Field 260 shows the publisher and the


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beginning year of publication. Field 362 shows the journal began with number 1 in 1998, and Field 310 shows the journal is published six times a year. Field 500 indicates the journal title recorded in Field 245 is from the cover. Field 515 explains that "[i]ssues for 1998- called also v. 44- " Field 710 shows International Textile Service is included in the record to help users discover this journal. Subjects are represented by two Library of Congress subject headings, with "Textile industry" and "Textile fabrics" as the main topics, each followed by "Periodicals" as a form subdivision to indicate these topics are treated in a journal. These subject representations enable users to conduct subject searches to discover this journal.

**102.** The MARC record for *International Textile Bulletin* was first cataloged by the University of Nebraska at Lincoln Library on June 24, 1998, and the University of Massachusetts Dartmouth Library used that record to create their copy cataloging record. The date stamp on the scanned copy provided by this library shows issue 2 of 2003 (May 2003) of *International Textile Bulletin* that contains *Ward* was received by the library on June 18, 2003, it is therefore my opinion that this journal would have been discoverable in the library's online catalog by that date, if not earlier. Interested users would have been able to discover this journal by the title, variant title, corporate author, and subject headings.

**103.** As discussed above, a customary library practice is to put a newly received journal issue through the serial check-in process by date stamping the new

issue, and then processing it promptly for user access, usually within a week after serial check-in is completed. It is therefore my opinion that after issue 2 of 2003 of *International Textile Bulletin* was received by the University of Massachusetts Dartmouth Library on June 18, 2003, the physical copy, after processing, would have become publicly accessible by June 25, 2003.

**104.** As evidence that the University of Massachusetts Dartmouth Library had an online catalog in operation in 2003 when the journal issue containing *Ward* was received, I searched Internet Archive for records of the library catalog. **Ex. Z** is a true and correct copy of an archived copy of the webpage of the University of Massachusetts Dartmouth Library, an archived copy of the library's catalog, and the library's profile from libraries.org, a directory of libraries throughout the world. I personally located, identified, and obtained these files for **Ex. Z**. They are the type of records experts in my field would reasonably rely upon when forming their opinions.

**105.** Page 1 is a copy of the webpage of the University of Massachusetts Dartmouth Library archived by Internet Archive and available at https://web.archive.org/web/20030528150843/http://www.lib.umassd.edu/. The "20030528150843" archive date means this file was archived on May 28, 2003, at 3 p.m., 8 minutes, 43 seconds. This archive date indicates that interested users would have been able to discover this library webpage by May 28, 2003.

**106.** The library webpage on page 1 shows the library provided research support and other services to the university community in May 2003, and "Voyager online catalog" is the first link under Research to support users to find various resources at the library. This page shows that by May 28, 2003, users would have been able to discover the library webpage and follow the "Voyage online catalog" link to explore the library collections.

**107.** The "Voyage online catalog" link led to an archived copy of the catalog presented on page 2 of **Ex. Z**, which is available at https://web.archive.org/web/20010405033833/http://voyager.lib.umassd.edu/. The "20010405033833" archive date means this online catalog was archived on April 5, 2001, at 3 a.m., 38 minutes, 33 seconds. This archive date indicates that interested users would have been able to discover this library catalog by April 5, 2001.

**108.** The archived library catalog identifies this file as "The University Library Catalog: a listing of books and materials" that shows that in April 2001 users could search the catalog by title, author, subject, basic keyword, and ranked keyword, and set limits on the search results by date, language, location, etc. to make the search results more manageable.

**109.** Page 3 of **Ex. Z** is a profile of the Claire T. Carney Library of the University of Massachusetts Dartmouth (https://librarytechnology.org/library/1242) that I obtained from libraries.org, which is a "directory of libraries throughout the

world." Page 4 shows the library began using the Voyager system in 1999, and changed its system to Alma in 2012, meaning Voyager was the library automation system in 2003. This technology profile is consistent with the archived copies of the library webpage (page 1) and the library catalog (page 2). **Ex. Z** shows that the library catalog of the University of Massachusetts Dartmouth was in operation in 2003, meaning users were able to use it in 2003 to discover the journal *International Textile Bulletin* and access the issues available at the library.

### C. Summary of My Opinion on *Ward*

**110.** The copy of *Ward* from counsel (**Ex. W**) is authentic because it contains no signs to raise suspicion about its authenticity, and **Ex. W** has the same content as the copy of *Ward* obtained from the University of Massachusetts Dartmouth Library (**Ex. X**). The date stamp on this library copy of *Ward* shows the issue containing this article was received by the library on June 18, 2003. The MARC serial record of the library (**Ex. Y**) shows that it was a copy cataloging record based on a record created on June 24, 1998. It is therefore my opinion that *International Textile Bulletin* that contains *Ward* would have been discoverable in the library's online catalog by June 18, 2003, and issue 2 of 2003 that contains *Ward*, after processing, would have become publicly accessible by June 25, 2003. Archived records of the library's webpage and catalog, together with a technology profile of the library (**Ex. Z**) show

that by May 2003 users were able to search the library catalog on site or on the Internet to discover the journal.

**111.** Based on the records and documents I have analyzed, it is my opinion that *International Textile Bulletin* would have been discoverable in the online catalog of the University of Massachusetts Dartmouth by June 2003, and issue 2 of 2003 of *International Textile Bulletin* that contains *Ward* would have become publicly accessible no later than June 25, 2003.

## VI. Conclusion

**112.** I hereby declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with the knowledge that willful false statements and the like so made are made under penalty of perjury.

Date: 9-19-2024 Executed: Ingrid Hsieh-Yee

Ingrid Hsieh-Yee, Ph.D.



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## Appendix A. Materials Considered

| # | Item |
|---|---|
| A | Choi, W., & Powell, N. B. (2005, March). Three dimensional seamless garment knitting on V-bed flat knitting machines, *Journal of Textile and Apparel, Technology and Management*, *4*(3), 1-33 ("*Choi*"); |
| B | Copy of *Choi* archived by Internet Archive on November 9, 2005, available at https://web.archive.org/web/20051109095833/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_full_145_05.pdf. |
| C | Website of *Journal of Textile and Apparel, Technology and Management*, volume 4, issue 3, archived by Internet Archive on August 27, 2005, available at https://web.archive.org/web/20050827064124/http://www.tx.ncsu.edu/jtatm/volume4issue3/vo4_issue3_abstracts.htm; First Page Preview of *Choi*, archived by Internet Archive on November 9, 2005 and available at https://web.archive.org/web/20051109100812/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_first_145_05.pdf; and complete article of *Choi*, archived by Internet Archive on November 9, 2005, and available at https://web.archive.org/web/20051109095833/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_full_145_05.pdf. |
| D | Library of Congress record on "Internet Archive," available at https://www.loc.gov/item/2003541624/. |
| E | OCLC FirstSearch record for *Journal of Textile and Apparel, Technology and Management*, available on OCLC FirstSearch (subscription required for access). |
| F | "FirstSearch Launched" *Library Systems Newsletter* (November 1991), available at https://librarytechnology.org/document/4992. |

| | |
|---|---|
| G | Bibliographic and MARC records for *Journal of Textile and Apparel, Technology and Management*, available at https://catalog.lib.ncsu.edu/catalog/NCSU308856 from the online catalog of the North Carolina State University Libraries. |
| H | Online catalog of NCSU Libraries, archived by Internet Archive on December 16, 2005, available at https://web.archive.org/web/20051216115305/http://catalog.lib.ncsu.edu/web2/tramp2.exe/log_in?LOGIN=guest&SERVERS=1home&SETTING_KEY=Files&item_category2_filter=all&SCREEN=home.html. |
| I | Legner, M., & Stoll, H. (2003, September). 3D-products for fashion and technical textile applications from flat knitting machines, *Melliand International, 9*(3), 234, 238-241 ("*Legner*"). |
| J | Library copy of *Legner* obtained from Cornell University Library. |
| K | Bibliographic and MARC records for *Melliand International* that contains *Legner*, available at https://catalog.library.cornell.edu/catalog/3155739 from the online catalog of the Cornell University Library. |
| L | The webpage of "About the CU Library Catalog" archived by Internet Archive on August 16, 2003, available at https://web.archive.org/web/20030816231751/http://campusgw.library.cornell.edu/newhelp/res_tools/catalog/about.html. |
| M | Citations to *Legner*, obtained from Google Scholar. |
| N | Affidavit of Nathaniel E Frank-White of Internet Archive. |
| O | Hong, H., Filho, A. A., Fangueiro, R., & de Araujo, M. D., (1994, |

| | |
|---|---|
| | September), The development of 3D shaped knitted fabrics for technical purposes on a flat knitting machine, *Indian Journal of Fibre & Textile Research*, vol. 19, no. 3, 189-194, available at the NIScPR Online Periodicals Repository at https://nopr.niscpr.res.in/bitstream/123456789/19312/1/IJFTR%2019%283%29%20189-194.pdf ("*Hong*"). |
| P | NIScPR Online Periodicals Repository metadata record for *Hong*, available at https://nopr.niscpr.res.in/handle/123456789/19312. |
| Q | Library copy of *Hong* obtained from Cornell University Library. |
| R | Bibliographic and MARC records for *Indian Journal of Fibre & Textile Research* that contains *Hong*, available at https://catalog.library.cornell.edu/catalog/1880348 from the online catalog of the Cornell University Library. |
| S | Profile of Cornell University Library, available at https://librarytechnology.org/library/54542 from libraries.org (a directory of libraries throughout the world). |
| T | Citations to *Hong* obtained from Google Scholar. |
| U | Hsieh-Yee curriculum vitae. |
| V | Understanding MARC Bibliographic (2009), available at https://www.loc.gov/marc/umb/um07to10.html from the Library of Congress MARC Standards website. |
| W | Ward, D. T. (2003, May). The future of knitting, *International Textile Bulletin*, vol. 49, 2nd issue 2003, 46-50 ("*Ward*"). |

| | |
|---|---|
| X | Copy of *Ward* obtained from University of Massachusetts Dartmouth Library. |
| Y | Bibliographic and MARC records for *International Textile Bulletin* that contains *Ward*, available at https://umassd.primo.exlibrisgroup.com/permalink/01MA_DM_INST/192qo47/alma9911586500001301 from the online catalog of the University of Massachusetts Dartmouth Library. |
| Z | Webpage of the University of Massachusetts Dartmouth Library archived by Internet Archive on May 28, 2003, available at https://web.archive.org/web/20030528150843/http://www.lib.umassd.edu/; the library's Voyager online catalog archived by Internet Archive on April 5, 2001, available at https://web.archive.org/web/20010405033833/http://voyager.lib.umassd.edu/; and a profile of the University of Massachusetts Dartmouth Library at https://librarytechnology.org/library/1242. |

# Exhibit A

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# Three dimensional seamless garment knitting on V-bed flat knitting machines

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JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

*Volume 4, Issue 3, Spring2005*

# THREE DIMENSIONAL SEAMLESS GARMENT KNITTING ON V-BED FLAT KNITTING MACHINES

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## ABSTRACT

*Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.*

*The purpose of this research is to review the principles of seamless knitting on V-bed machines and to compare the machines from two major flat-knitting machine suppliers, Shima Seiki and Stoll. This paper will also discuss characteristics and applications of complete garment knitting in various products. This research was accomplished through interviews and a review of the literature. It has implications for academicians and industrial personnel who require information in three dimensional knitting technology and related machinery.*

*Keywords: Knitting, tubular, seamless, complete garment*

## 1. INTRODUCTION

Seamless knitting technology creates one entire complete garment with minimal or no cutting and sewing process. This innovative technology eliminates post labor work, which saves production time and cost. In addition, the technology offers knitwear consumers more comfort and better fit by eliminating seams. Thus, seamless technology provides benefits to manufacturers as well as end users. Seamless knitting technology has entered the mainstream in the knitwear market.

Through this research, principles of seamless knitting techniques are discussed, and two major suppliers for V-bed machines, Shima Seiki and Stoll, and machine characteristics will be introduced. In addition, advantages and disadvantages of this type of production are revealed. In order to understand the seamless knitting technology, it is important to review the fundamentals of the knitting process. By a review of the evolution of the knitting process, an explanation of knitting methods, and the description of knitting machines' characteristics, the distinctiveness of seamless knitting will be better understood.



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This research was achieved through a review of the literature and additional primary data was collected through interviews, company visits, etc.

### 1.1. Knitting Fundamentals

To fully examine the developments in seamless knitting, a basic foundation of knitting construction and characteristics should be discussed. Knitting is defined as "the process of forming a fabric by the intermeshing of loops of yarn" [22] and knitting accounts for more than 30% of total fabric production [24]. The end use of knitted fabrics, created either in tubular or flat form, can be apparel and other products including sweaters, underwear, hosiery, socks and stockings.

Knitting is classified into two fields, weft knitting and warp knitting. In weft knitting, loops are formed in a horizontal direction whereas in warp knitting, loops are formed in a vertical direction [1] (Figure 1.1a and 1.1b). Weft knitting is more resilient, more open and has additional design possibilities as compared to warp knitting. Conversely, warp knitting has less resilience, more cover, lighter weight and higher productivity. Weft knitting can be divided into circular knitting and flat knitting according to type of fabric, type of needle, and form of needle bed. In the circular knitting machine, needles are set radically or parallel in one or more circular beds [3]. On the other hand, a flat knitting machine employs straight needle beds carrying independently operated needles, which are usually of the latch type [3].

Compared to flat knitting machines, circular weft knitting machines provide higher productivity. Thus, circular knitting machines have more rapid production speeds than weft knit flat bed machines. However, flat knitting machines have greater versatility in loop structure combinations and patterning because their machine cams can be changed after every course (even after every stitch), and they are able to knit one or both beds easily [52]. It should also be noted that electronic circular machines have the same capability.

J T A T M

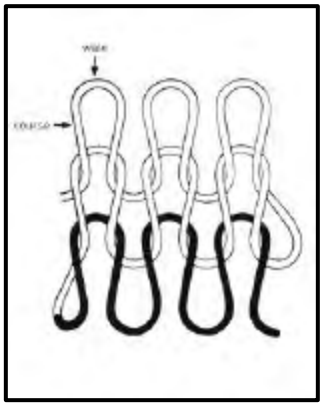



*Figure1.1a. Weft knitting*

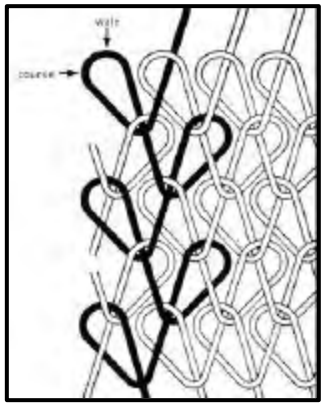



*Figure 1.1b. Warp knitting* (Black, 2002



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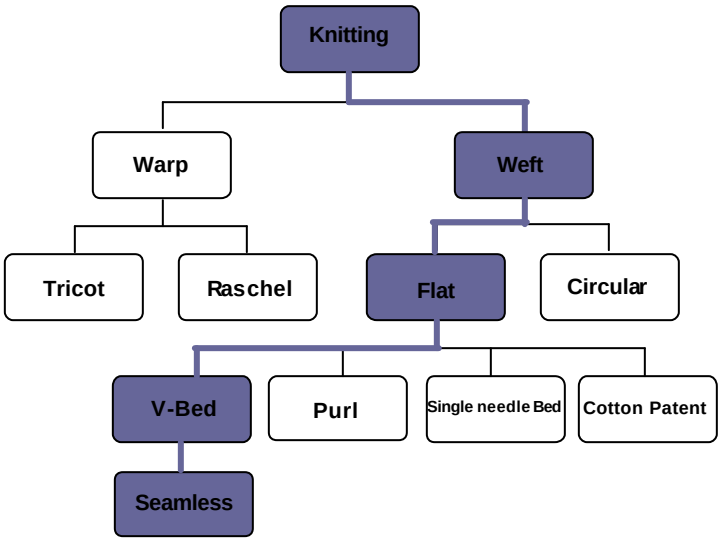



*Figure 1.1c. Knitting Classification Diagram*

Spencer defines cams as "the devices which convert the rotary machine drive into suitable reciprocating action for the needles" [42]. Figure 1.1d shows the knitting action of latch needles for the cam track on a V-bed knitting machine. According to the position of needle butts moving up and down through the cam system, the loop can be formed sequentially [34].

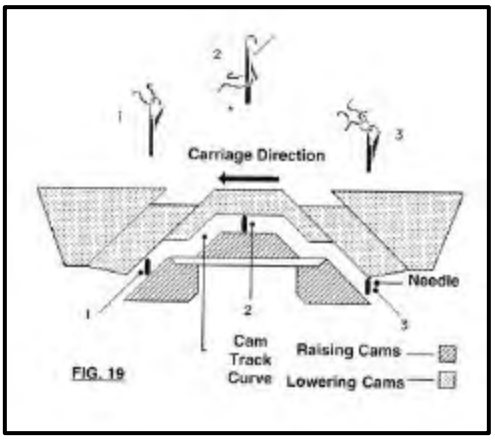



*Figure 1.1d. Knitting action of latch needle though cam track*
(Raz, 1991)

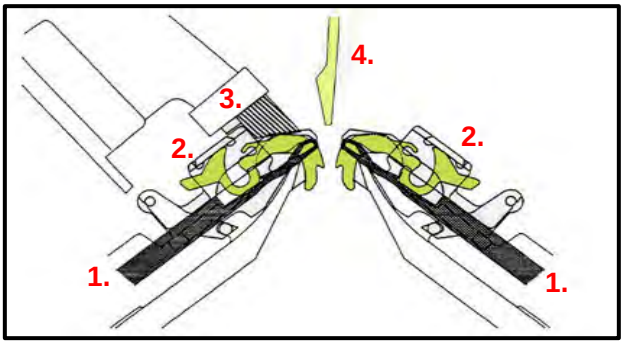
Figures 1.1e and 1.1f illustrate the basic knitting machine parts on a flat bed machine including a carriage, latch needles, sinkers, brushes, yarn carriers and take down rollers. A carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam [34].

The latch needle, the most widely used needle in weft knitting, is mainly composed of a needle hook, a latch, and a needle stem (Figure 1.1g). The major advantage of the latch needle is that it self acts or controls the loop so that individual movement and control of the needle permits loop selection to be accomplished [42]. The sinker is another primary element in knitting. Main purposes of the sinkers are loop formation, holding down, and knocking-over [42]. However, the role of sinkers on a V-bed knitting machine with latch needles is chiefly a holding-down function. Therefore, holding down sinkers are capable of tighter fabric structures with an improved appearance. The purpose of the brushes is to open the latches at the first course when the machine starts to knit and to avoid any closing of the latches [21]. The yarn carrier or yarn feeder is pulled along the needle bed by the carriage and introduces and feeds yarns required for knitting. The yarn carrier is assembled on a dovetail-profiled rail [34]. Take down rollers are needed to prevent the previous loop, which is located in the hook enclosure, from riding up with the needle ascension. This is very crucial for loop formation because without take down tension the previous loop will not slide under the latches and new loops will not be formed without the operation of the take down rollers [34].

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1. Latch needles
2. Sinkers
3. Brushes
4. Yarn Carrier (Feeder)

*Figure 1.1e. Knitting machine system on flat V-bed machine* (Shima Seiki Manual [37])

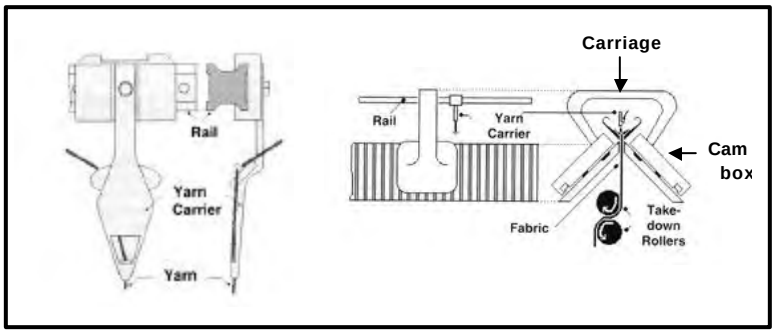



*Figure 1.1f. Yarn Carriers, Carriage and Take-down Rollers* (Raz, 1991)

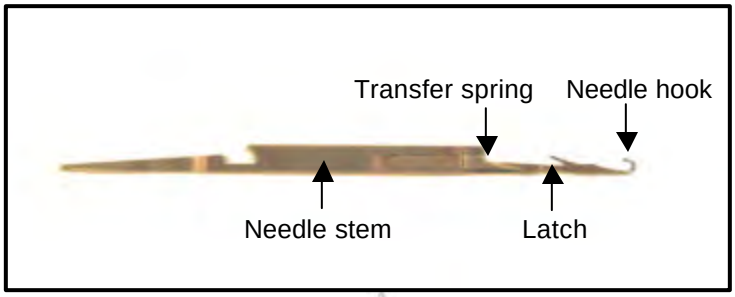



*Figure 1.1g. Latch needle on Shima Seiki Machine*

Flat bed machines have four different classes; (i) *V-bed flat machines* which have two inverted V-formed needle beds; (ii) *Purl machines* which have double ended needles; (iii) machines that have *a single bed* of needles which include most domestic models and a few hand manipulated intarsia machines [40]; and (iv) *Cotton patent machines* which are single-bed machines with bearded needles arranged vertically [1]. Bearded needles are the needles having an extended terminal hook or beard that can be flexed to close the hook [22].

## 1.2. Historical Events Contributing to the Development of Seamless Knitting

In the evolution of seamless knitting it is important to review the developments in knitting that directly affect three-dimensional knitting techniques. Kadolph and Langford [12] explain that historical remnants of knit fabrics have been dated from A.D. 250 in the Palestine area. Knitting was accomplished by a hand process until 1589, when William Lee in England invented a flat-bed weft-knitting frame to create hosiery [12]. The first operational V-bed flat knitting machine using latch needles was invented in 1863 by



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Issac W. Lamb [34]. William Cotton of Loughborough took out a patent in 1864 for his rotary-driven machine that used a flat bed to produce fully-fashioned garments [16]. According to Hunter [9], in the 1800's, the flat knitting machine was fitted with sinkers, which controlled loops in order to knit single jersey tubular articles such as gloves, socks and berets. In 1940, the manufacture of shaped knitted skirts was patented in the USA. This permitted darting on knitted skirts using a technique called "flechage" (See glossary). The flechage technique not only improved drape and fit, but cut production cost. In 1955, the Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaping of components. In the 1960's, the Shima Seiki company further explored the tubular-type knitting principle commercially to produce gloves. Also, in the mid1960's, engineers at Courtaulds in the UK established British patents on the idea of producing garments by joining tube knitting. However, the method was too advanced to be commercialized at that time. By 1995, Shima Seiki fully developed shaped seamless knitting [9]. Recently, by employing more advanced computerized systems, simpler programming was possible, and the computerized systems enabled the production of more complicated and sophisticated knitted structures and products. Table 1 introduces the historical events of seamless knitting.

| Year | Historical Events Contributing to Development of Seamless Knitting |
|---|---|
| 1589 | William Lee in England invented the first flat-bed frame to create hosiery. |
| 1863 | Issac W. Lamb invented the first operational V-bed flat knitting machine including the latch needles. |
| 1864 | William Cotton of Loughborough patented his rotary-driven machine that used a flat bed to produce fully-fashioned garments |
| 1800's | The flat knitting machine was fitted with sinkers, which controlled stitches in order to knit single jersey tubular articles such as gloves, socks and berets. |
| 1940 | The manufacture of shaped knitted skirts using a "flechage" technique was patented in the USA. |
| 1955 | The Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaped sections. |
| 1960's | Shima Seiki company further explored the tubular-type knitting principle to produce gloves commercially. |
| 1960's | Courtaulds established British patents on the idea of producing garments by joining tube knitting. |
| 1995 | Shima Seiki introduced seamless entire garment knitting at ITMA. |

*Table 1. Historical Events Contributing to Development of Seamless Knitting*

Seamless entire garment knitting was introduced in 1995, at ITMA, the International Textile Machinery Association [24]. Seamless knitting, or complete knitting, which produces one entire complete garment without a sewing or linking process, provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages. In Section 2, numerous advantages of seamless garment knitting are discussed.


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## 2. ADVANTAGES OF SEAMLESS GARMENT KNITTING

In general, V-bed knitting process has more flexible needle selection capability and more design possibilities compared to warp knitting process [2]. Through computerized flat bed knitting, more variety of knit patterns and structures can be created and designs can be instantly and efficiently changed through a computer-aided design system. Furthermore, seamless garment knitting makes it possible not only to create several types of tubular formed knitting but also to build diverse design structures on the tubular knitted garments simultaneously.

Complete garment knitting offers a variety of benefits in technical aspects as well as in the market demands. For benefits to the market, quick-response production and just-in-time production are possible. The required number of products can be quickly knitted in less time to meet the needs of the market. It also enables mass customization for many markets. Onal states "Mass customization is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology" [29]. In certain markets, seamless knitting could be considered for mass customization by rapid design changes according to customers' requirements through computerized knitting systems. Seamless knitting systems may be utilized for sampling prototype and for niche market limited production items.

For the focus of this paper, the benefits of seamless technology are mainly discussed. First, there is no longer the traditional labor-intensive cutting and sewing process because of eliminating seam production. Hence, the tubular-typed seamless knitting results in potential savings in terms of production time and cost. For instance, according to Melliand International, in the case of a complete woman's knit sweater, a time saving of about 35% can be achieved with seamless knitting [20]. Additionally, yarn consumption can be minimized by complete garment knitting as well as by effectively analyzing yarn feed through the computerized system on the machine [7]. The DSCS (Digital Stitch Control System) on Shima Seiki machine predetermines how much yarn is required for the each stitch. Loop size can be controlled accordingly and there is much less stress on the yarn at the sinker. According to Mowbray, this device not only permits a variety of types of yarns to be used but also offers maximum production efficiency because higher speeds can be achieved [26]. The range of gauges for complete garment machines varies from 5 gauge to 18 gauge. Seamless garment knitting technology adds flexibility through gauge conversion and multi-gauge knitting [20]. The capability of multi-gauge application allows the conversion of gauges in the same machine. As a result, it saves time and cost for investing in different machines for every gauge.

In garments, three-dimensional knitting is purported to give lightness and softness in knitwear because there is no linking and sewing production [39]. In addition, there are no bulky and annoying stitches at the underarm points, shoulders and neck lines [39]. For finished edges, the garment can have better trimmed edge lines through a machine binding-off process instead of a sewing or linking operation.

In decreasing the number of production processes such as the cutting or sewing steps, the risk of defects and damages can also be minimized. A single entire piece production method is claimed to provide more consistent product quality [20]. Consequently, seamless knitwear is promoted to look better, fit better and is believed to be much more comfortable than a traditional fully-fashioned piece of knitwear. Seamless knitting also allows knit designers to create design structures and patterns across the entire garment. Designers can easily program and style both more sophisticated design structures and shaped patterns through the computerized design system.



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Finally, in the global environment, according to Shima, seamless garment knitting puts less stress on the environment by minimizing waste disposal and reducing the need to grow as much as cotton, wool and other natural raw materials [26].

## 3. TECHNICAL ISSUES

Although seamless garment knitting technology provides a variety of advantages for the knitting industry, it still has several technical issues to be considered. The main problem in complete garment knitting has been fabric take-down [10]. To keep equal tension of each loop (i.e., stitch), diverse sinker systems and take-down tension systems have been utilized. Finally, the novel sinker systems such as a spring-type moveable sinker system and a computerized take-down tension system, appropriate to complete garment knitting, have been developed to solve the problem. Even though the systems have brought higher stability for knitting, there is the opinion of users that it still is not easy to control an exact take-down tension for the complete garment.

Complete garment knitting also has a problem caused by the alternate needle selection. The alternate needle selection knitting makes fabrics more open and less elastic than conventional fully-fashioned garments [27]. This problem occurs in the welt or the cuff areas. A welt in knitting means "a secure edge of a fabric. The welts are usually at the starting end of the fabric" [22]. To solve the looser fabric problem, it is critical to select appropriate yarns for the machine gauge; and in this context, elastic, flexible and durable yarns are recommended such as wool. For instance, a Yorkshire spinning company in the UK uses the elastic Spirol® lamb-wool on the cuffs and the collars, which can be knitted tighter like a fully-fashioned product [27]. In the current global knitting industry, natural fibers, such as wool, cashmere and angora, and manufactured fiber such as acrylic are mainly used to create seamless garments for outerwear [11]. Viscose and polyamide with Lycra® or other elastomerics are also utilized for complete garment knitting [11]. Cotton is also a popular fiber used in seamless apparel.

Another issue for complete garment knitting is that if the garment has a defect during knitting such as a hole or a barre' problem, the entire garment is useless and must be discarded. Pratt explains "Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric" [32]. Compared to fully-fashioned knitting, there would be more waste when the complete knitted garment has any defect. In cut and sewn production pattern pieces could be placed for cutting on a flat piece of fabric to avoid any defects.

## 4. APPLICATIONS OF SEAMLESS KNITTING

Seamless garment knitting on the V-bed machine has primarily been used for apparel. However, in recent years, this new three-dimensional knitting technique has been extended in other areas such as fashion, upholstery, industrial, automotive, and medical textiles.

### 4.1. Apparel (Figure 4.1)

A diverse range of seam-free products can be created such as hand gloves, hats, socks, and sweaters according to the machine gauge and types of machine. Additionally, patterns for knitted trousers and skirts are available on the complete knitting machines. As far as design structures, most knit structures knitted on fully-fashioned machines can be created on the seamless garment machines such as cable stitches and even intarsia structures.
(See glossary for structures.) [33]

### 4.2. Upholstery (Figure 4.2)

Several upholstery companies are utilizing three-dimensional seamless seat upholstery production. The Teknit Company offers three-dimensional knit upholstery for the office chair market. Teknit creates shaped three-dimensional polyester seat covers that compete against woven fabric, which


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requires a cutting and sewing process [43]. According to Teknit, lead times are substantially lower than conventional woven fabric and the office chairs covered with seamless knitted fabric are their fastest selling line. The company also has the capability of promoting rapid design changes by using sophisticated CAD systems [46]. Additionally, seamless shaped knitting with its inherent stretch characteristics follows the contours of the seat, providing better seat trimming [46]. It enhances appearance and enables users to feel more comfortable by eliminating ridges caused by a sewing or a linking process.

### 4.3. Automotives

Courtaulds and General Motors Corporation developed the three-dimensional knitting technique to produce seat covers in 1985 [40]. Marjorie Sorge proposed that automotive seat covers made by seamless knitting also provide great potential for the automotive market in that the three dimensional knitting process cuts lead time by eliminating cut-and-sew operations, brings down warranty costs and adds quality [40]. Lear Corporation which owns patents on three-dimensional knitting technologies claimed the ability to design new seats using a predictive computer model which reduced the time needed for seat design by 25% [31]. Seamless knitting for automotive also provides a potential for designing a more ergonomic seat through the ability to alter the knitted tube size.

### 4.4. Medical textiles

Recently, specialty textiles created by three-dimensional flat bed knitting machines have also been applied to medical textiles. Tubular typed knitted structures such as bandages, orthopedic supports, and medical compression stockings have been developed. In the future, it is expected that more advanced and sophisticated medical textiles created by seamless knitting technology would be produced. The incorporation of high performance fibers and additional sensors or electronics could provide further opportunities for seamless products in healthcare applications.

J T A T M



*Figure 4.1. Seam free garment created on Shima Seiki WholeGarment® Machine* (Shima Seiki, 2003)



*Figure 4.2. Claud 9™ Chair created by NeutralPosture®* (*NeutralPosture, 2004*)



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Each of these market applications has specific performance requirements and specialized aesthetics. In order to use this technology to fulfill these market needs, the principles of knitting and knitwear production, and the evolution of seamless knitting need to be reviewed.

## 5. EVOLUTION OF THE KNITTING PROCESS FROM CUT AND SEWN PRODUCTION TO SEAMLESS GARMENT KNITTING

As described in Table 1, the knitting industry has gradually developed since William Lee of Calverton successfully converted the actions of hand knitting with two needles into a mechanical process. Lee's work was the first attempt at mechanizing hosiery knitting in 1589 [16]. Since the invention of the frame-knitting machine, knitting technology has progressed from hand flat machines to complete garment-knitting machines. Section 5.1, 5.2, and 5.3 will explain the evolution of the knitwear process from cut-and-sew production to seamless knitting.

### 5.1. Cut and Sew Production

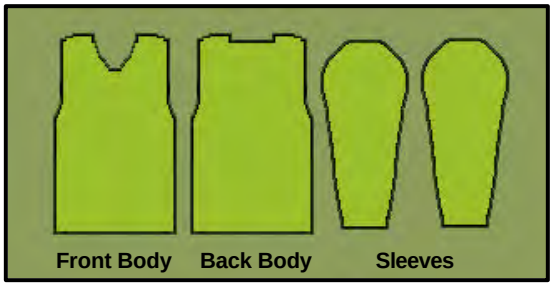



*Figure 5.1. Cut and sew production*
(Shaded area: Cutting Waste)

Cut and sew production is created by the use of one entire panel of fabric. Figure 5.1 shows the cutting layout for the front and rear body portions and also the sleeve portions required to create a sweater. Through the cutting and sewing process, the finished garment is created. However, this garment production process requires several post-knitting processes including cutting and sewing. Additionally, in this process, separately knitted trimmings and pockets need stitching. The Shima Seiki Company explains that with cut and sew production, up to 40% of the original fabric can be waste [39].

### 5.2. Fully-Fashioning

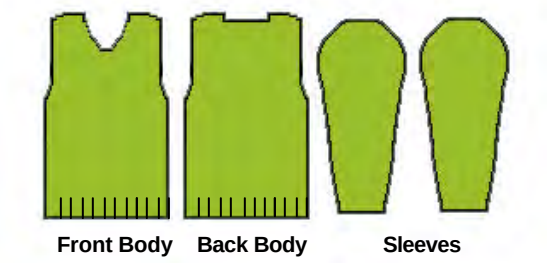


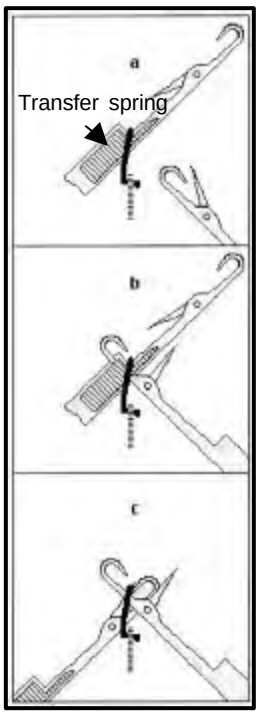

*Figure 5.2. Fully-fashioning production*

Fully-fashioned knitting means "shaped wholly or in part by widening or narrowing of piece of fabric by loop transference in order to increase or decrease of the number of wales" [3]. Thus, as the number of loops are increased or decreased, the fabric can get shaped areas as seen in Figure 5.2. To achieve fully-fashioned knitting, loop transference is necessary. The loop transference is the process that moves stitches (i.e., loops) from the needles on which they were made to other needles [49]. Figure 5.2a illustrates the mechanism of loop transference on a V-bed flat knitting machine.

In addition, the following stitch notation (Figure 5.2.1) describes how widening or narrowing occurs by loop transference on fully-fashioned machines. The fully-fashioning process allows the separate creation of shaped front and back body parts and sleeve parts by increasing or decreasing the number of loops (Figure 5.2); this eliminates the cutting operation. However, because all parts of the garment are knitted separately, the fully-fashioned knitting still requires a post sewing or linking process. Linking is defined as a process of joining side seams or edges of fabric pieces together with a row of knitting on a linking machine [19].



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a. The delivering needle is raised by a cam in the carriage. The loop is stretched over the transfer spring.

b. The receiving needle is raised slightly from its needle bed. The receiving needle enters the transfer spring of delivering needle and penetrates the loop that will be transferred.

c. The delivering needle retreats leaving the loop on the receiving needle. The transfer spring opens to permits the receiving needle to move back from its closure. Finally, loop transference is completed.

*Figure 5.2a. the mechanism of loop transference on V-bed flat knitting machine* (Raz, 1991)

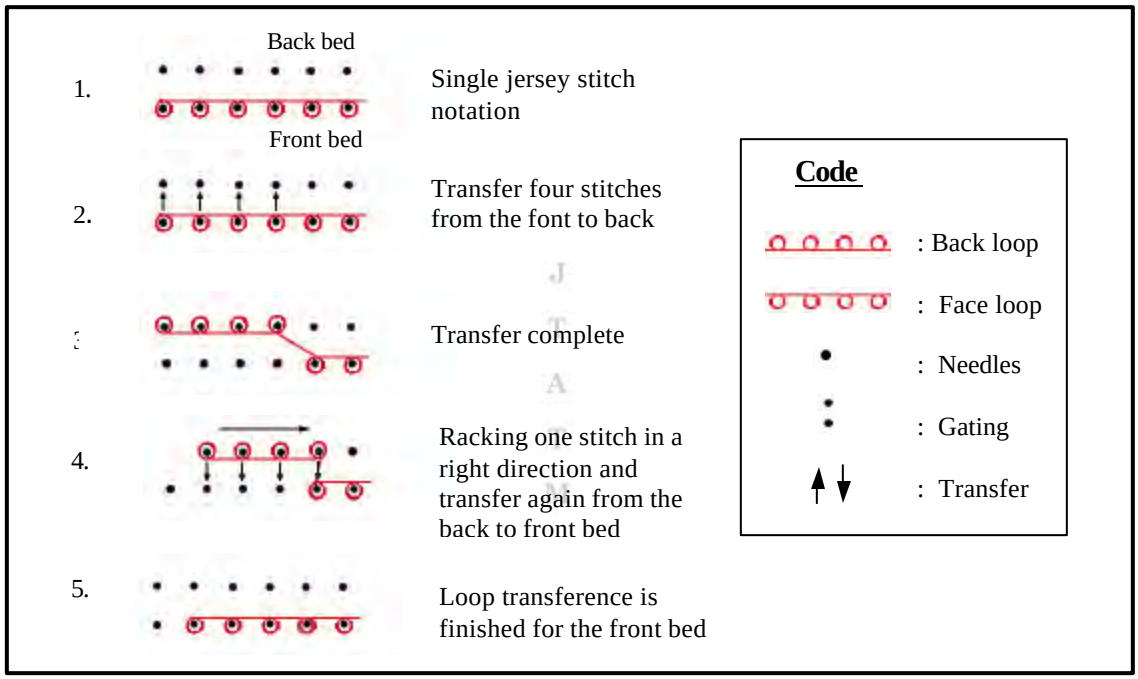



*Figure 5.2.1. Narrowing process by loop transference on flat V-bed machine*



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### 5.3. Seamless garment knitting



*Figure 5.3. Complete garment production by a seamless flat knitting machine*

"Seamless" garment knitting creates a complete garment by several different carriers (feeders) with minimal or no cutting and sewing processes (Figure 5.3). Thus, seamless knitting has the capability for production time and cost saving by removing post-knit processes such as the linking or sewing and cutting operation [39].

It also minimizes yarn consumption by reducing the cutting waste and can achieve higher productivity. Machine productivity in knitting is expressed in pattern rows per minute [41]. Complete garment knitting can be achieved either on a circular knitting machine or a flat (V-bed) knitting machine. However, seamless circular knitting machines are different from seamless flat knitting machines in that circular machines such as the Santoni create only a single tubular type of garment. Seamless flat knitting machines such as the Shima can create more than one knitted tube at the same time, and the tubes are joined together on the machine (Figure 5.3a). The complete garments knitted on circular machines may also need minimal cutting as seen in Figure 5.3a. In addition, the complete garments created by circular knitting machines still require minimal seam joining on one body tube and two sleeve tubes as well as the finished edges. Santoni has recently introduced the SM4 TL2 machine, which shapes the knitted tube and will eliminate the cutting process [35]. Consequently, seamless knitting on circular machines is not true seamless knitting.

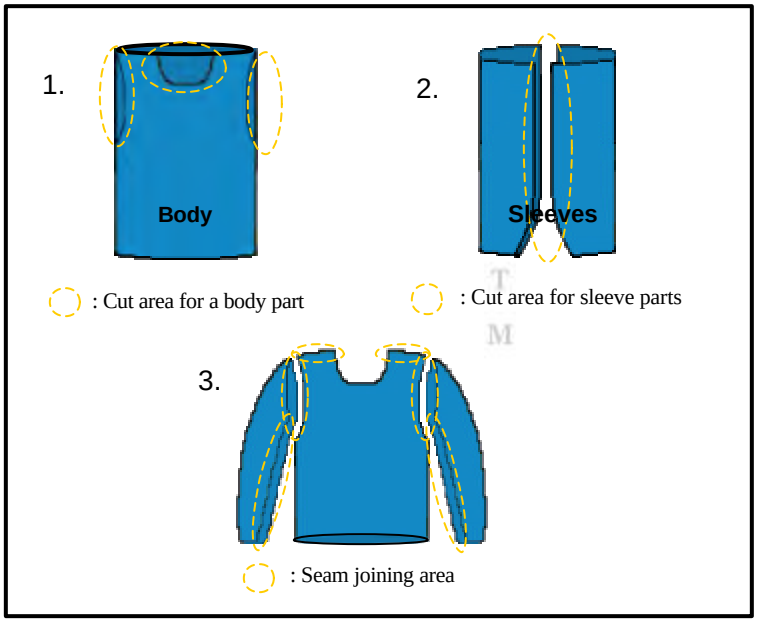



Figure 5.3a. *Complete garment production by a seamless circular knitting machine*



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In recent years, several companies have developed seamless or complete garment machines such as Santoni, Sangiacomo, and Orizio Santoni, part of the Lonati Group, is the biggest supplier of the circular knitting machinery. Lonati has recently acquired Sangiacomo, and its expanded seamless circular knitting technology is in the forefront of the industry. Santoni, whose customers include Nike, Adidas, Sara Lee et cetera [30], offers 14 different models of circular knitting machines, from 7 to 32 gauge. The machines produce swimwear, sportswear, outerwear, underwear et cetera. [35].

However, in the strict sense of the word, seamless flat V-bed knitting actually creates complete garments, which do not require any kind of cutting or sewing process. For Section 6, the knitting method of multi-tubular knitting techniques created on a V-bed knitting machine will be discussed.

## 6. V-BED MACHINE KNITTING OF SEAMLESS GARMENTS

As mentioned earlier, seamless garments on a flat V-bed machine can be created in three separate tubular forms by knitting one wider tube for the body part and two narrower tubes for the sleeve parts. Tubular knitting is created on both needle beds but front and back bed knitting are done alternately [23]. The continuously alternate knitting of all needles on front and back needle beds creates a single plain tube. Tubular type knitting is not a new technique. Since the 1800's, single jersey tubes have been produced on flat machines [8]. However, seamless garment knitting can be seen as a more advanced technique in that it can connect the three tubes together to create a sweater [6] and has the capability to increase and decrease the dimensions of the tubes [44]. Moreover, various structures such as plain, rib, and purl can be created within the seamless garment at the same time.

On the flat machine, the three tubes are knitted on a pair of front and back needle beds. The flat machine knits and transfers loops between the front needle bed and the back needle bed with different yarn carriers for one body tube (Feeder 2) and two sleeve tubes (Feeders 1 and 3) (Figure 6.1). The three-tube knitting continues to the underarm point. At the underarm point, the two carriers knitting sleeve parts (Feeders 1 and 3) are taken out of the knitting zone. The remaining carrier (Feeder 2) that knitted the main body part knits together the three tubes into one tube [10] (Figure 6.2). The tubes are joined at the underarm points, shoulders and neck points. In this manner, seamless garment knitting is accomplished. However, in order to make loop transference for performing shaping or design structures, loops should be formed by selecting alternate needles [17] (Figure 6.3).

Figure 6.4 reveals how loop transference occurs on complete garment knitting by using empty needles. By loop transference using the alternate needles, single jersey tubes as well as rib type tubes can be knitted on the complete garment machine. Figure 6.5 depicts how the 2X2 rib structure can be created on the complete garment V-bed knitting machine. However, due to the alternate needle selection on seamless machines, the garment tends to be more open and less elastic than a traditional fully-fashioned garment [27]. This requires the use of more elastic yarns on the seamless knitting machine compared to the other regular V-bed machines such as fully-fashioned machines.

In addition, the number of tubes knitted on the machine depends on the desired type of knitted product. The complete garment machine does not have to create three tubes all the time. For instance, to create a sweater, it requires three tubular typed forms. On the other hand, a seat cover may require only one type of tube for the complete cover, but could also provide an integrated attachment tube.


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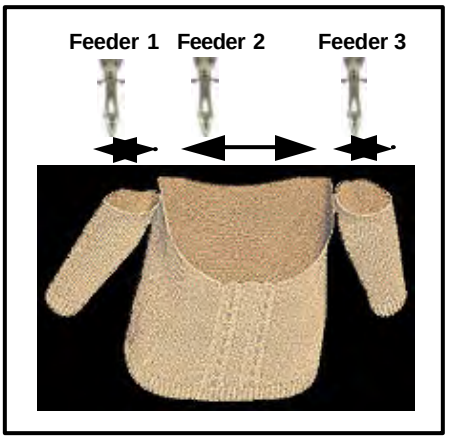



*Figure 6.1. Three-dimensional complete garment knitting until underarm point* (Shima Seiki)

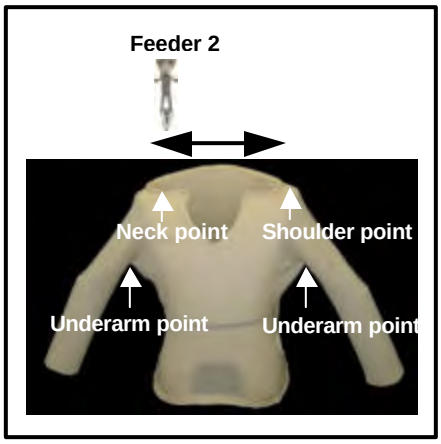



*Figure 6.2. Three-dimensional complete garment knitting after underarm point*

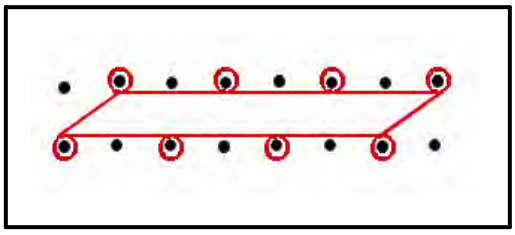


*Figure 6.3. Alternate stitch notation on complete garment knitting*

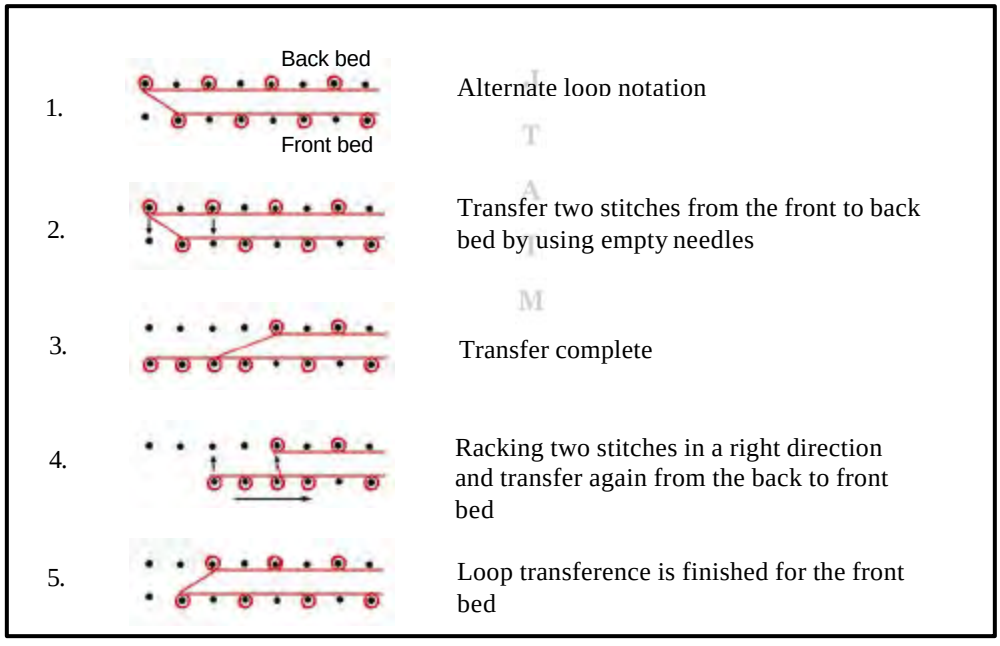
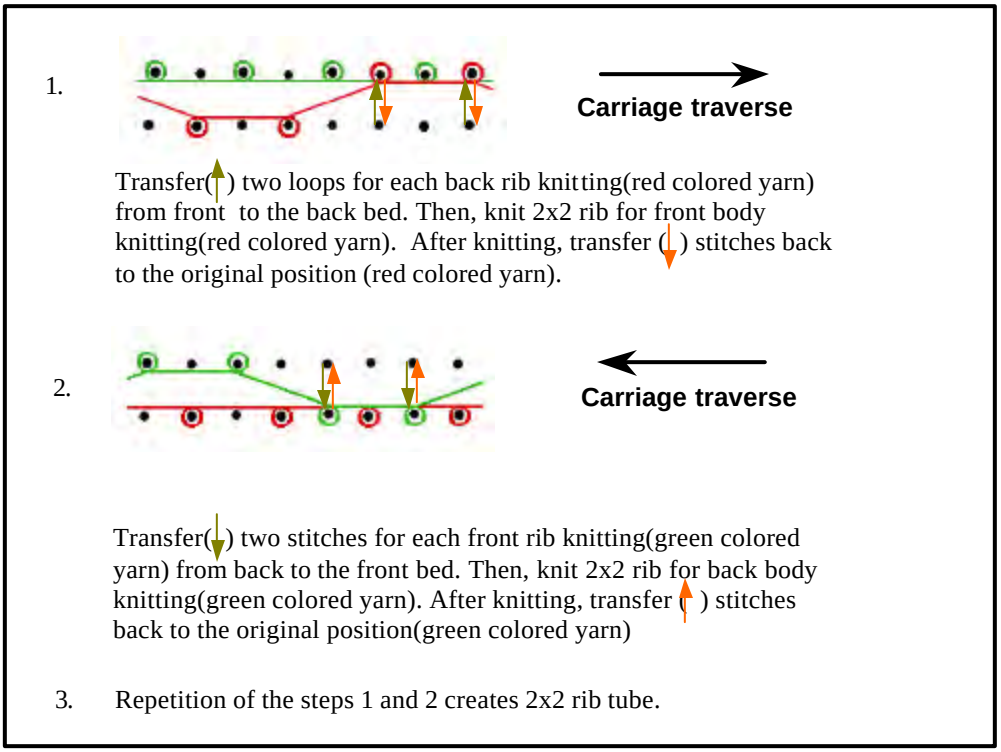



*Figure 6.4. Loop transference on complete garment knitting*



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** The upper figures show 2x2 rib tubular type knitting. Green colored yarn and red colored yarn represent the same yarn. In order that loop notation is seen easily, two different colors are*

*Figure 6.5. Tubular knitting of 2x2 rib on complete garment machine*

## 7. SEAMLESS MACHINES

For seamless flatbed knitting machines, two suppliers, Shima Seiki and Stoll, are the leaders in machine manufacturing. They offer solutions for the knitting of complete garments on computerized V-bed knitting machines. In Section 7, the two companies, Shima Seiki and Stoll, and their seamless knitting machine systems will be introduced and compared.

### 7.1. Shima Seiki

The Shima Seiki company invented the WholeGarment® machine and introduced the commercial complete garment knitting (SWG-V machine) in 1995 at ITMA (International Textile Machinery Association) [24]. Since the beginning of WholeGarment® machine production, about 3500 WholeGarment® machines have been manufactured and sold worldwide [11]. The seamless garment machines of Shima Seiki have different range of gauges from 5 to 18 gauge (needles per inch) and knitting widths ranging from 50 inches to 80 inches. Shima Seiki produces five versions of the innovative WHOLEGARMENT® machine that can produce a one-piece three-dimensional complete garment with no stitching, linking or sewing processes. Figure 7.1 illustrates the SWG-V WholeGarment® knitting machine system that shows various machine features such as a machine tuning screen, a computer controller, top tension devices, yarn carriage, et cetera.


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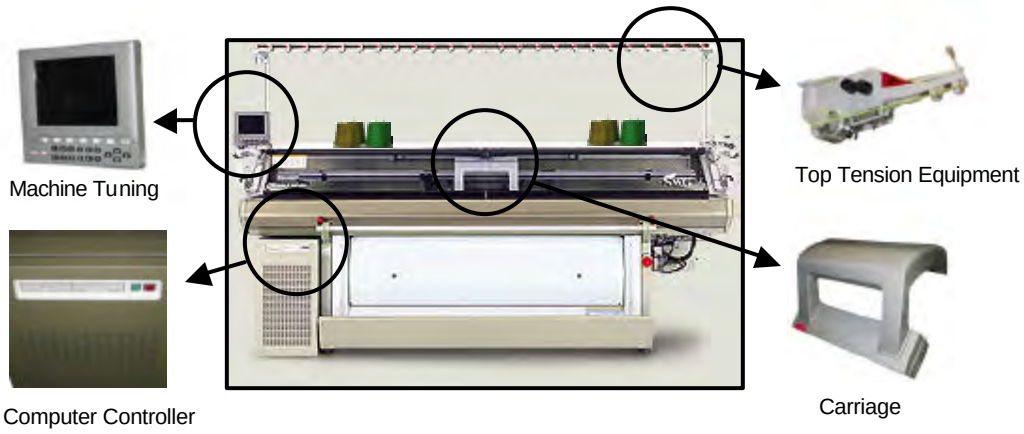



*Figure 7.1. SWG-V® machine*

### 7.1.1. Shima Seiki CAD system and machines

Figure 7.1.1 shows the Shima Seiki® knitting machine system. In general, knit patterns can be created on the CAD (Computer-Aided Design) system and all data can be saved to a diskette. The saved data can then be transferred to the Shima Seiki knitting machine and the machine can be operated. The machine-tuning screen allows operator interface with the settings of the machine. Finally, one complete three-dimensional garment can be knitted on the machine.

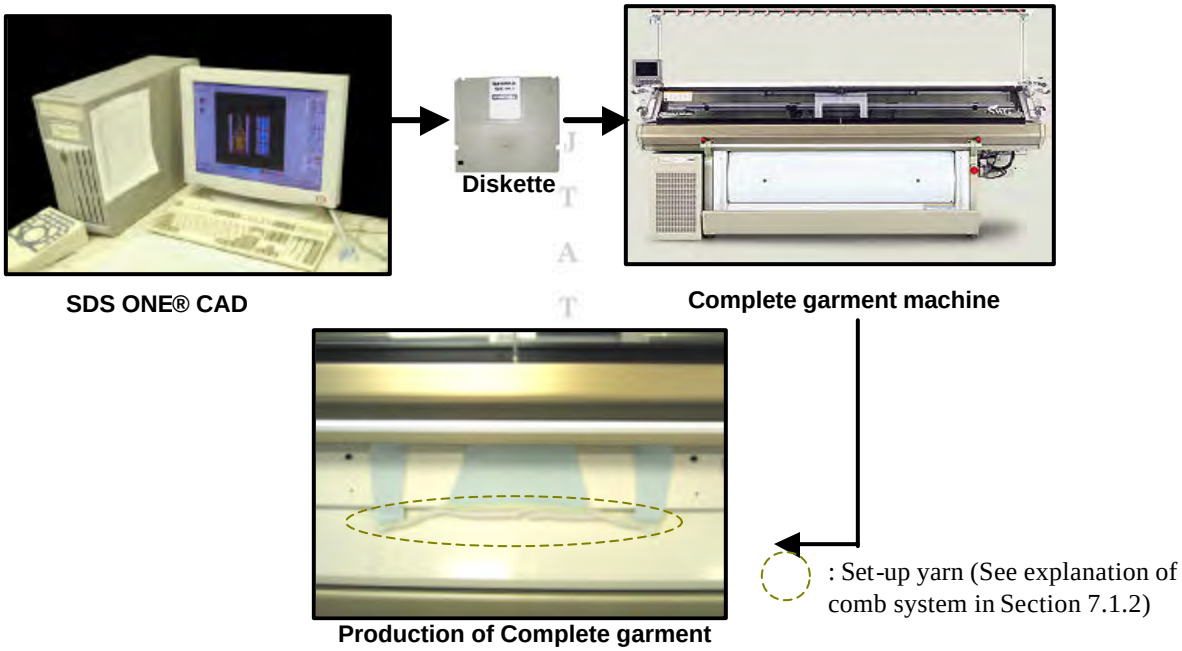


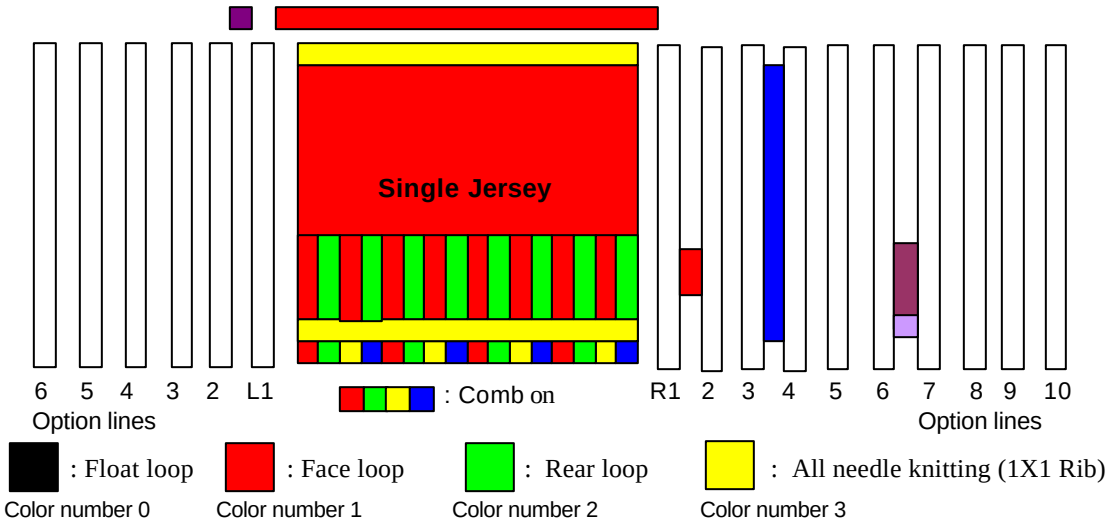

*Figure 7.1.1. Shima Seiki Knitting machine system*



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### 7.1.2. Shima Seiki CAD system

The Shima SDS ONE® CAD system is a totally integrated knit production system that allows all phases including planning, design, evaluation and production [44]. Specifically, the loop simulation program permits quick estimation of knit structures without any kind of actual sample making [8]. The program provides an opportunity to see knit problems and to try out diverse knit structures on the computer system before beginning the actual knitting. In the Shima CAD system, each different type of knitting loop is represented by different colored squares (Figure 7.1.2a). For example, as seen in the following figure 7.1.2a, color number 1(red) indicates a jersey (face loop) and color number 2 (green) indicates a reverse jersey (rear loop). Thus, the following red colored figure shows how a single jersey structure can be displayed on fully-fashioned CAD system of Shima Seiki machine.




* A Comb on a V-bed knitting machine is used to set up the yarn required to knit. The comb hooks the set-up yarn, and moves up and down, pulling down the set-up yarns connected with a knitted garment.
* Option line is used to control the data for a knit structure on the CAD system. For example, the right side of option line number 1 is utilized to decide repetition of a pattern area. Each option line represents specific functions of the machine knitting.

*Figure 7.1.2a. Shima Seiki CAD system for fully-fashioned*

The CAD patterning of the seamless garment knitting is more complicated than that of the fully-fashioned knitting due to alternate needle selection. The bottom figure (Figure 7.1.2b) depicts a single course notation of the tubular-formed knitting. In Figure 7.1.2b, the first row indicates front bed knitting (color number 1) and the second row indicates back bed knitting (color number 2). Accordingly, continuous knitting in a lateral direction between the front and back needle beds forms a tubular-typed fabric. In Figure 7.1.2c, it shows how loop transference for complete garment knitting can occur and how it can be displayed on the CAD system. The empty needles thus can be used for the loop transference. For the loop transference on complete garment knitting, at least two loops are transferred in a right or a left direction due to alternate needle selection such as Figure 7.1.2c. Note that only even number of loops can be transferred for seamless knitting on V-bed knitting machines.


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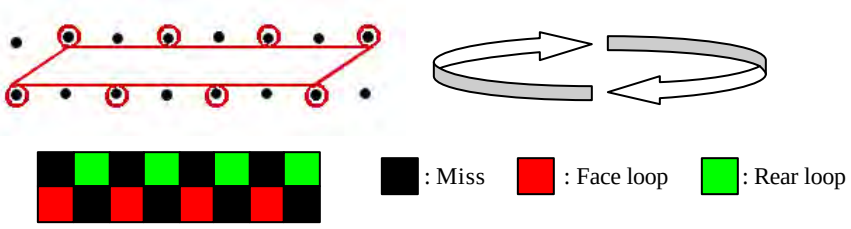



*Figure 7.1.2b. Stitch notation for seamless knitting and CAD design on Shima Seiki CAD system*




*Figure 7.1.2c. Loop transference on front bed for seamless garment knitting*

By utilizing the principle of the alternate stitch notation, two-dimensional design can be created on the CAD system as seen in Figure 7.1.2d. This represents a three-dimensional tubular typed garment. Figure 7.1.2d displays a whole garment designed on the Shima Seiki CAD system.

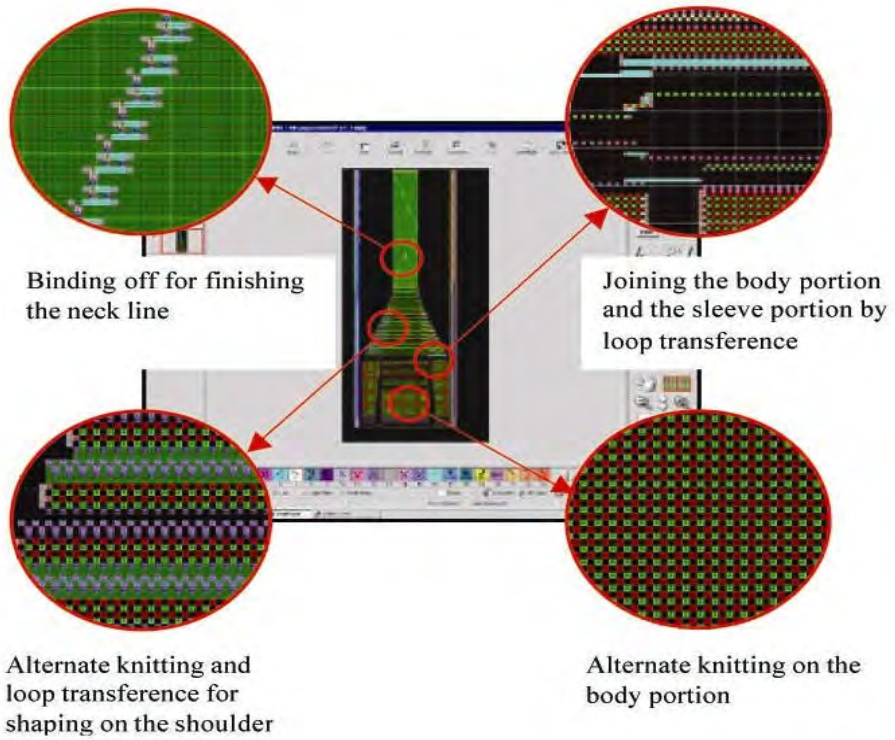



*Figure 7.1.2d. Design for complete garment on Shima Seiki CAD system*

Binding-off: The process that sequentially moves the stitches to the next loop from the edge [38]. This technique is generally utilized to finish edge lines.



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The interface between the knitwear designers and the knit technicians is critical to the success of new sample development. The designer's concept sketch must be realized through the capabilities of the machine governed by the technical expertise of the technician. Shima Seiki addresses this interpretative process through its enhanced Shima Seiki SDS ONE® CAD system. "Knit designs created in the paint program are simultaneously converted to knit programming data, so that designers and technicians can keep in close communication with each other over the same job" [39]. The combination of knit structures and yarn selections available in the design system will allow virtual simulation of potential garments without actual knitting.

Recently, Shima Seiki created a large pattern structure database of knitted parts including collars, plackets, cuffs et cetera. Knit and garment designs can be easily changed at will (Figure 7.1.2.e and 7.1.2f) [39]

### 7.1.3. Types of Shima Seiki Seamless knitting machines

Shima Seiki offers a line of machines capable of seamless knitting. These five different machines have special attributes, which can be selected according to application or end use. Gauge and needle type are the primary distinguishing factors.

#### 7.1.3.1. SWG-V®

The Shima Seiki's SWG-V® machine, which comes in 5 gauge and 7 gauge, is the first commercial application of Wholegarment® technology (See Figure 7.1) [39]. The SWG-V® machine uses a latch needle where the latch closes into the hook of needle as it pulls the yarn through a loop to form a new loop [33] (Figure 7.1.3.1a). The latch needles used in flat bed machines require an additional attachment, a transfer spring, in order to transfer a loop as can be seen in Figure 7.1.3.1a. However, due to the transfer spring, the needles cannot be located in the center of the needle groove, which results in a slightly asymmetrical loop formation. This will be discussed on Sections 7.1.3.4 and 7.1.3.5.

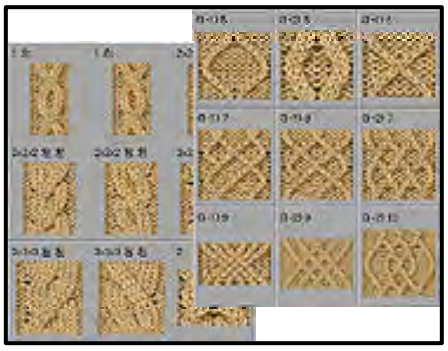


*Figure 7.1.2e. Structure pattern database*



*Figure 7.1.2f Virtual sampling* (Shima Seiki)



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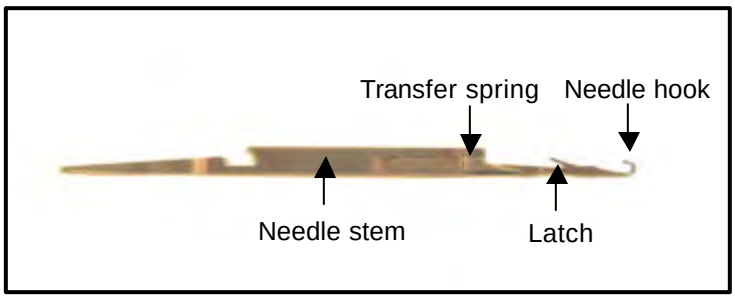



*Figure 7.1.3.1a.*
*Latch needle on SWG-V® machine*

Shima Seki introduced a version of the SWG-V® machine, with its enhanced technical capabilities such as the yarn carrier kickback device and increased memory capacity [39]. The New SWG-V® machine also has a special twin gauge needle configuration (Figure 7.1.3.1b) that includes a pair of needles working together in each needle slot. Complete garment knitting with loop transference requires two sets of needles, for the front and back of the garment, unlike a traditional single jersey tube that has only one set of needles [10]. Therefore, this twin needle configuration allows the needles to more effectively create widening or narrowing as well as diverse knit structures for complete garment knitting.



*Figure 7.1.3.1b. twin gauge needles*
(Shima Seiki)

### 7.1.3.2. SWG-X®

The SWG-X® machine is used to produce fine gauge knitwear, which has either 12 gauge or 15 gauge. Fine gauge knitting is produced by the slide needle and pull-down device, which independently controls takedown tension for front and back body portions. Specifically, the SWG-X® is configured for complete garment knitting with four separate needle beds and an additional loop presser bed [39]. This is the reason why the SWG-X® machine is the only machine that can knit complete garments without alternate needle technique. As can be seen in Figure 7.1.3.2, front body knitting can be achieved on needle beds 1 and 2, whereas back body knitting can be done between beds 3 and 4.

Actually, a machine that includes four needle beds and four cam plates is much more expensive to produce than a V-bed machine with two needle beds [10]. The reason Shima Seiki chose the more expensive four-bed route for fine gauge is in that if the machine was to take the half-gauge route for the fine gauge, the gauge would be just too fine for flat knitting technology [10]. The half gauge route on two needle beds for 12 or 15 gauge knitting is too fine to endure rigorous racking or transferring for complete garment knitting. The needle hook is also too small to accept the yarn required for 12 or 15 gauge knitting.



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This multi-needle bed configuration permits complete garment production with sufficient stitch density. Moreover, stitch transference can be more easily accomplished to create tubular ribs. In addition, various knit structures can be knitted at the same time with required stitch densities (Figure 7.1.3.2).

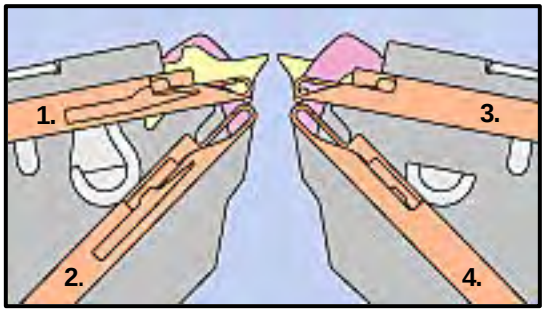



*Figure 7.1.3.2. Cross section Diagram of the SWG-X® four-needle bed configuration* (Shima Seiki)

### 7.1.3.3. SES-S.WG®

As with the SWG-V® machine, the SES-S.WG® has the capability to knit complete garments with latch needles. However, unlike the SWG-V's twin-needle configuration, the SES-S.WG® uses the standard latch needles and spring-type sinkers at the same pitch. This enables the machine to knit fine-gauge shaping as well as integral knitting, and it also makes possible multiple-gauge knitting. In multiple-gauge knitting, a number of different gauges can be knitted in a single course. Multiple-gauge knitting is different from fixed gauge knitting in that an assortment of gauge sizes may be knitted in a single garment [39] (Figure 7.1.3.3). The multiple gauges contain a combination of techniques, such as half-gauging, intarsia technique, using different numbers of yarn ends, and blocks of different gauges of needles each working with its corresponding count of yarn and yarn carriers [44]. Shima Seiki explains that this capacity responds to the change of seasons and trends without investing in a machine for every gauge. As a result, it saves time by eliminating the task of gauge conversion from one machine to another machine. Product variety can be greatly enhanced by achieving more interesting and sophisticated design patterns [39].

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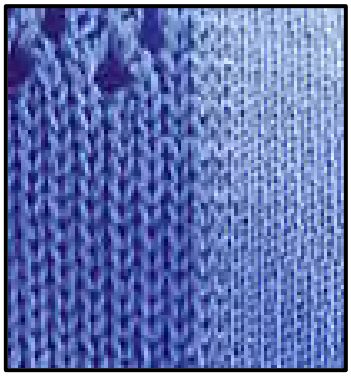


*Figure 7.1.3.3. multiple-gauge knitting sample with 12G and 7G mixed side by side* (Shima Seiki)



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### 7.1.3.4. SES-C.WG®

The SES-C.WG® is a flexible machine in that it can achieve quality knitting in a range of production styles. The SES-C.WG® machine has the capability to perform shaping and integral knitting similar to the other SES-series. In addition, this machine can knit coarser gauge complete knitwear. By using compound needles and a take down system featuring a pull-down device, the SES-C.WG® can produce a high-quality coarse gauge seamless garment. The compound needle, in which the hook and hook closing portions are separately controlled [22], is generally used in warp knitting machines [13] (Figure 7.1.3.4a). However, Shima Seiki applied the concept of compound needles to the flat bed machine.

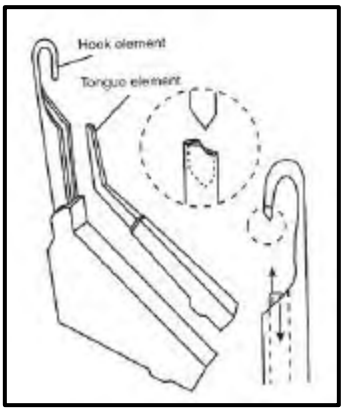



*Figure 7.1.3.4a. Compound needle* (Kadolph and Langford, 1998)

Compared to traditional latch needles, the compound needle is more complex and expensive to manufacture [44]. However, the compound needle gives higher operational stability, which is required for larger needle sizes. According to Shima Seiki, the compound needle offers significant reduction in needle stroke to allow for similar reductions in needle bed and carriage size [39]. Thus, the short stroke knitting helps reduce space in the carriage and permits smaller and lighter carriage [6]. According to John Ward [50], a technician at Shima Seiki USA Inc., the compound needle eliminates the necessity for a brush on the carriage, because the needle has a slider that opens and closes the hook of the needle unlike a latch needle. The slider moves up and down by the movement of the cam system, which is timed to work closely with the movement of the needle. This increases the stability of knitting, and there are no brushes to be worn out.

Another feature of the compound needle is that it does not have to be raised as high because there is no latch that must be cleared which increases knitting stability at higher speeds. However, one drawback of both the latch and the compound needle is that both needles have to be off center in the trick wall to allow for the transfer spring. This puts the needle hook closer to the knock-over bit on one side, resulting in a slightly imbalanced stitch. To solve the problem of imbalance, the Shima Seiki developed the slide needle [50]. The slide needle will be discussed in Section 7.1.3.5.

### 7.1.3.5. First®

This machine executes all types of production from fully fashioning and three-dimensional shaping to seamless production. All this capability is accomplished through the development of the slide needle instead of the latch needles, which uses a unique two-piece, slide mechanism [39] (Figure 7.1.3.5a).

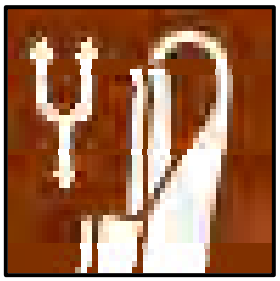


*Fig 7.1.3.5a. Slide needle* (Shima Seiki)

Shim Seiki points out "A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove. The slide needle thereby achieves perfectly symmetrical loop formation for knitting the highest possible



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quality fabrics (Figure 7.1.3.5b and 7.1.3.5c)" [39]. Accordingly, by using the slide needle, the machine provides better quality and stable knitting as well as higher productivity. However, in order to transfer loops by slide needles, the First® machine needs an additional transfer bed that can only move stitches [51]. The machine also requires an extra cam system to control the slider on the slide needle [51]. In consequence, the additional equipments make the machine with slide needles more expensive than a machine with latch needles.

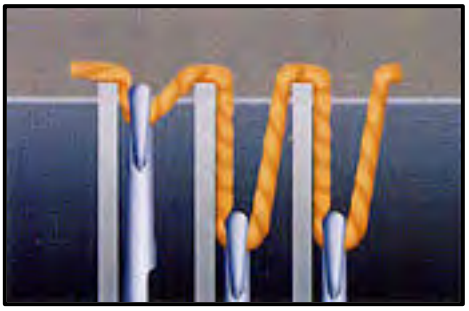


*Fig 7.1.3.5b. Conventional latch needles offset slots* (Shima Seiki)



*Fig 7.1.3.5c. Slide needles centered in slots*

Another distinctive feature of the First® machine is its takedown system. "Precision pull down of the garment is independently controlled by tiny pins mounted on front and rear panels which feature adjustable working width through individually controlled 1.5 inch wide sections. This precise control of takedown tension permits 3-dimensional shaping of complete garment items" [10].

The following Table 2 shows the five-versions of Shima Seiki WholeGarment® knitting system. All sources are cited from the Shima Seiki company website, www.shimaseiki.co.jp.

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**Shima Seiki WholeGarment® Systems**
(Sources from www.shimaseiki.co.jp, 2004)

| | First® | New SWG-V® | SWG-X® | New SES-S.WG® | New SES-C.WG® |
|---|---|---|---|---|---|
| Knitting Width | 126-181cm 50-72" | Max 183cm 72" | Max 172cm 68" | 183cm 72" | 203cm 80" |
| Gauge | 12 - 18 gauge | 5, 7 gauge | 12, 15 gauge | 8, 10, 12, 14, 16 gauge | 5 gauge(capable of producing 3G fabric) |
| Knitting Speed | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.1m/sec |
| Racking | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) |
| Knitting system | 3 or 4 system | Triple Knitran® system. Single carriage | 3 system (1 knitting system + 2 transfer system) | Triple Knitran® system. Single carriage | Ultra-compact 2-system (1 knitting system + 1 transfer system) |
| Transfer | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch |
| Sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system | Fixed sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system |
| Yarn Carriers | 12-16 | 13 | 12 | 13 | 16 |
| Take down device | Main/sub rollers, Changeable 31 levels | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear |
| Needle selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Full-jacquard solenoid selection |
| Needle | Slide needle | Latch needle | Slide needle | Latch needle (Standard layout of needles) | Compound Needle |
| Production | Everything from full-fashioning, rib shaping to 3-dimensional shaping, as well as seamless | | High quality fine gauge knitwear | Fine-gauge shaping and integral knitting, even multi-gauge knitting | Coarse gauge knitting |

*Table 2. The Shima Seiki WholeGarment® machine Systems*


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## 7.2. Stoll



*Figure 7.2. STOLL Knit and Wear® Machine* (Stoll)

The other major machinery producer for seamless knitting considered in this research is Stoll. The Stoll system is examined in comparison with the Shima Seiki based on research at Cotton Inc. with Emmett Hylton, Knitting Manager [5]. This section considers the CAD system, the knitting equipment and the seamless systems available. Seamless garment knitting systems from Stoll and Shima are similar, and a comparison of the complete garment knitting systems offered by Shima Seiki and Stoll are considered in this section. Stoll has manufactured flat knitting machines for more than 130 years and has today more than 1,100 employees worldwide [45]. The Stoll machine also markets complete garment knitting machines called "Knit and Wear®". The range of gauge for Stoll Knit and Wear® machine is from E2.5 to E9.2 gauge and the knitting width is from 72 inches to 84 inches. The Stoll Company also has a multiple gauge system, which permits different gauge areas to be knitted in one single course [45].

### 7.2.1. Stoll CAD system

According to Spencer [44], the Stoll SIRIX® (M1) CAD system is a complete design, patterning, and programming system, and it utilizes two windows to graphically develop knitting programs for the Stoll machines. In the Stoll CAD system, all knit structures are displayed by real modules. Figure 7.2.1 shows how 2X2 rib and single jersey can be displayed on the Stoll M1 CAD system.

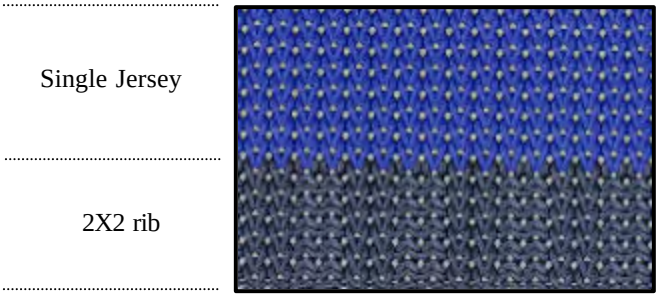



Figure 7.2.1. *2X2 Rib and single jersey displayed on the Stoll M1 CAD system*

As in the Shima CAD system, Stoll's M1 CAD system offers two different windows for designers and technicians who need different information for the same design (Figure 7.2.2). The technical window shows the developing design in the form of running yarn notations and technical data, while the design window presents design as a knitted structure [44]. Both windows can be easily displayed and automatically converted. Therefore, it is expected to minimize miscommunication between designers and technicians in knitting industry. By understanding the knit structures, it is possible to improve collaborative efforts and resulting samples.

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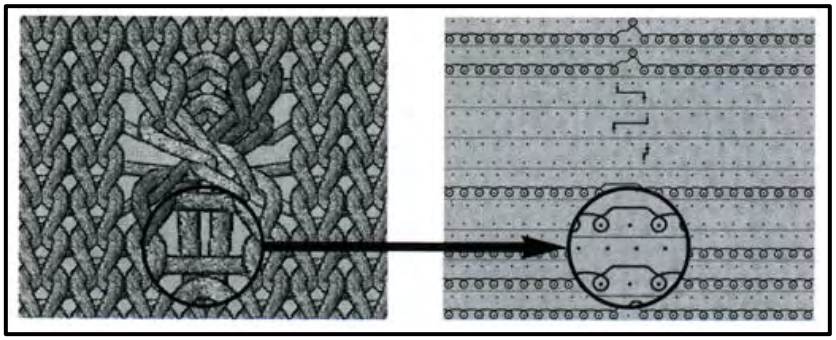


*Figure 7.2.2. Linked windows options of fabric design view and technical view*
(Spencer, 2001)

### 7.2.2. Types of Stoll seamless knitting machines

#### 7.2.2.1. CMS 330 and CMS 340 TC Knit and Wear® machines

CMS 330 TC and 340 TC knit and wear® machines have a 72-inch (183 cm) knitting width. The CMS 330 TC knit and wear® machines cover three systems and a gauge range from E6.2 to E7.2. E6.2 provides a range from E6 to E12 and E7.2 gives a range from E7 to E14. On the other hand, the CMS 340 TC knit and wear® machine has four systems that combine the knitting and the transfer system, and a gauge range from E2, 5.2 to E9.2. Technically, the CMS 330 TC machine is capable of producing fully fashioned, multiple gauge as well as intarsia fabrics. An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (or textures), so that both sides of the fabric are equal [48]. Its three systems yield a high level of production. The CMS 340 TC machine has the capability of multiple-gauge knitting such as Shima Seiki New SES-S.WG [45].

#### 7.2.2.2. CMS 330 TC-T Knit and Wear®

This machine offers a 72-inch (183 cm) knitting width and the range of the gauge is between E6.2 and E7.2. By using its three systems and two additional needle beds with transfer elements and independent racking front and rear, fine gauge knitting is possible in gauges E12 and E14 with all needles [45]. This machine is also capable of multiple-gauge knitting in order to create an interesting knit structure between finely knit areas knitted with all needles and coarser areas knitted only with every second needle [45].

#### 7.2.2.3. CMS 330 TC-C Knit and Wear®

CMS 330 TC-C knit and wear® machine has a three-system capability and a working width of 84 inches (213 cm). This width can easily produce coarse gauge knitwear in extra-large sizes. The gauge E2,5.2, in conjunction with knitting and transferring systems designed especially for this application and a new type of holding-down technology, allows the production of seamless garment knitting [45].

#### 7.2.2.4. CMS 340 TC-M Knit and Wear®

This machine is equipped with a new extra wide working width of 84 inches (213 cm) for producing triple XL sized seamless sweaters [13]. The four system model features a gauge range from E2, 5.2 to E7.2 (up to 14 cut) and the machine also offers gauge conversion capability. It also can be used efficiently for fully-fashioned, multiple-gauge and intarsia fabrics. Thus, it joins the advantages of the comb machines with those of multi piece knitting. Consequently, profitability can be enhanced and even multi-piece fully-fashioned knitting can be achieved [45]. For instance, two front pieces, two back pieces, and four sleeve pieces can be sequentially knitted in the necessary sizes. In two-piece knitting,



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the left fabric can be knitted by the two left knitting systems, and the right fabric can be knitted by the two right knitting systems (Figure 7.2.2.4). This figure also shows the two separate yarn carriages. Two-piece knitting significantly increases productivity compared to one-piece seamless knitting [45]. "This machine knits complete garment panels as multi-layer applications and also as racked and structured patterns in multi layer knits and an absolute novelty in the sector – two gauges in one fabric" [36]. In addition, this machine is capable of producing ultra-coarse gauge garments with the fabric appearance of 2-gauge with a hand-knitted look [13].

With new take-down technology, this machine offers a new shoulder solution, the so-called "French shoulder". This style of shoulder features the connection between the front and back body portions of the garment not in the middle of the shoulder but at the top of the back. This new knitting sequence demonstrates that the shoulder part of the garment can be produced with greater quality with a wide range of possible variations in terms of visual appearance and elasticity [45]. Table 3 shows the five-versions of the Stoll Knit-and-Wear® knitting system. All sources are cited from the Stoll website, www.stoll.de.

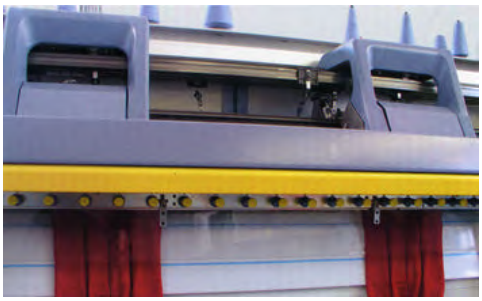


*Figure 7.2.2.4. Two piece fully fashioning* (Stoll)

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**Type of Knit–and–Wear® machines**
(Sources from www.stoll.de, 2004)

| | CMS 330 TC Knit and Wear | CMS 340 TC Knit and Wear | CMS 330 TC-T Knit and Wear | CMS 330 TC-C Knit and Wear | CMS 340 TC-M Knit and Wear |
|---|---|---|---|---|---|
| Knitting Width | 183 cm 72” | 183 cm 72” | 183 cm 72” | 213 cm 84” | 213 cm 84” |
| Gauge | E2,5.2- E7.2 | E2,5.2- E9.2 | E6.2-E7.2 | E2,5.2- E2,5.2 | E2,5.2- E7.2 |
| Knitting Speed | Max 1.2m/sec | Max 1.2m/sec | Max 1.2m/sec | Max 1m/sec | Max 1.2m/sec |
| Racking | Max 4” | Max 4” | Max 4” | Max 4” | Max 4” |
| Knitting system | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation (4 combined knitting/transfer systems) | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation | Independent knitting systems with split function for optimum system allocation (4 systems) |
| Transfer | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions |
| Sinker system | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down spring loaded sinkers: enables manufacturers to knit ultra coarse garment with a hand-made look (Mowbray, 2004). | Moveable holding-down sinkers |
| Yarn Carriers | 16 | 16 | 16 | 16 | 16 |
| Take down device | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb |
| Needle selection | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system |
| Production | Multi-gauge, Intarsia fabric | Multi-gauge, Flexible gauge | Fine gauge knitting, Multi-gauge | Coarse gauge knitting, | Coarser gauge knitting, Fully-Fashion, Multi-gauge, Intarsia fabric |

*Table 3. The Stoll knit and wear® machine system*


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### 7.3. Comparison of Complete Garment Knitting Systems between Shima Seiki & Stoll

Table 4 compares seamless garment knitting systems between two companies, Shima Seiki and Stoll. The characteristics of the machines are generally comparable except in a few features. The main difference between two offerings is that Shima Seiki machines employ three different types of needles for complete garment knitting such as latch needles, compound needles and slide needles, whereas Stoll machines employ only latch needles. Table 4 shows the machines of two companies have quiet similar characteristics.

**A comparison of complete garment knitting systems between Shima Seiki and Stoll**
(Sources from www.shimaseiki.co.jp and www.stoll.de, 2004)

| | Shima Seiki WholeGarment® Machines | Stoll Knit-and-Wear® Machines |
|---|---|---|
| Knitting Width | 50" – 80" (126 – 203 cm ) | 72" – 84" (183 – 213 cm) |
| Gauge | 5 - 18 gauge | 5 -18 gauge |
| Knitting Speed | Max 1.3m/sec | Max 1.2m/sec |
| Racking | Max 3" total | Max 4" total |
| Knitting System | 3 – 4 systems | 3 – 4 systems |
| Transfer | Simultaneous transfer | Simultaneous transfer |
| Sinker System | Spring-type movable full sinker system | Spring-type moveable holding-down sinker system |
| Yarn Carriers | Up to 16 | Up to 16 |
| Take-down Device | Main/sub take down rollers | Main/upper take down rollers |
| Needle Selection | Electric selection system | Electric selection system |
| Needle | Latch needles, Compound needles, Slide needles | Latch needles |
| CAD system | Integrated knit production system allowing planning, design, evaluation and production | Complete design, patterning, and programming system |

*Table 4. Comparisons of complete garment knitting systems between Shima Seiki and Stoll*


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## 8. CONCLUSIONS

Seamless garment knitting on V-bed machines creates one entire complete garment by using several different carriers eliminating the need for additional cut and sewn operations. The garment can be created in tubular forms: one wider tube for the body portion and two narrower tubes for the sleeve portions. Two leading companies, Shima Seiki and Stoll, manufacture seamless or complete garment V-bed knitting machines. Both companies develop various complete garment machines according to the machine gauge, types of needles, sinker systems, take down systems, and application of knit structures.

For seamless garment knitting, the machines have the capability not only to create shaped knitting, but also to make various knit design structures in the complete garment by utilizing alternate needle selection. Alternate needle selection, however, creates fabrics more open and less elastic than conventional fully-fashioned garments. Nevertheless, complete garment knitting provides major benefits for the market as well as for technical production. (See Table 5) Manufacturers do not have to rely on the cutting and sewing process. As a result, it is believed to offer savings in terms of production times and cost, and it minimizes yarn consumption. In addition, seamless garment knitting provides more consistent and homogeneous product quality, which gives lightness and comfort in the garments. It also offers knit designers more creative knit possibilities.

Three-dimensional seamless knitting with its diverse capabilities can be applied to numerous products such as fashion, upholstery, automotives, aerospace, medical textiles, et cetera. Seamless knitting is forecasted to continue growing and could be one of the largest next generation knitting technologies.

| **Potential benefits of seamless knitting** |
|---|
| 1. Minimizing or eliminating labor intensive cutting and sewing process |
| 2. Savings in production times and cost |
| 3. Minimal yarn consumption |
| 4. Higher productivity |
| 5. Multi-gauge knitting |
| 6. Lightness and softness |
| 7. No bulky and irritating stitches/seams |
| 8. More constant product quality |
| 9. Better trimmability for finished edge lines |
| 10. Better look, better fit and more comfortable |
| 11. More creative possibilities for knitwear designers |
| 12. Quick-response production for size and pattern changes |
| 13. Just-in-time production |
| 14. Mass customization |

*Table 5. Potential proposal for seamless garment knitting*



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## Glossary

Barre' : Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric.

Bearded needle: the needles having an extended terminal hook or beard that can be flexed to close the hook.

Binding-off: The process that sequentially moves the stitches to the next loop from the edge. This technique is usually utilized to finish edge lines.

Brushes: The aim of brushes is to open the latches at the first course when the machine starts to knit and to avoid closing of the latches.

Cable stitch: Cable stitch is a stitch formed by small groups of plain wales plaited with one another in ropelike fashion.

Carriage: Carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam.

Cam: The device which converts the rotary machine drive into suitable reciprocating action for the needles.

Circular knitting machine: Needles are set radically or parallel in one or more circular beds. Used without further qualification, the term generally refers to a weft-knitting machine of this type.

Comb: Comb on V-bed knitting machine is used to set up a yarn required to knit. The comb hooks the set-up yarn, and moves up


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and down, pulling down the set-up yarns connected with a garment.

Compound needle: The hook and hook closing portions are separately controlled. The compound needle gives higher operational stability at higher speed compared to latch needle.

Flat knitting machine: Flat knitting machine employs straight needle beds carrying independently operated, usually latch needles.

Flechage: Course shaping in knitting. A term increasingly used to define two and three-dimensional shaping of knitted fabric by increasing and/or decreasing the length of succeeding knitted courses to a pre-planned series. Beret knitting is also a term used to describe this process. The term is derived from the French for wedge. (http://www.resil.com/dictionary/f.htm)

Fully-fashioned knitting: Fully-fashioned knitting is shaped wholly or in part by widening or narrowing by loop transference to increase or decrease of the number of wales.

Gauge (cut): Gauge indicates the number of needles per inch.

Holding down: Holding down is one of functions of sinkers. It prevents previous loops from riding with needles. Thus, it gives tighter structures with improved appearance.

Intarsia fabric: An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (textures), so that both sides of the fabric are equal.

Interlock: a double-faced rib-based structure consisting of two 1X1 rib joined by interlocking sinker loops.

Interlock gating: The opposed alignment of one set of needles with the other on a knitting machine.

Knitting: The process of forming a fabric by the intermeshing of loops of yarn.

Knocking over: Knocking over is one of functions of sinkers. It supports the old loop as the new loop is drawn though it.

Latch needle: It has a latch or swinging fingers that closes into the hook of needle as it pulls the yarn through a loop to form a new loop.

Linking: Linking is a process of joining side seams or edges of a piece of fabrics together with a row of knitting on a linking machine.

Loop transference: Loop transference is the process that moves stitches from the needles on which they were made to other needles for the purpose of shaping or design.

Mass customization: It is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology.

Miss stitch: A knitting cycle where a needle or needles do not take a yarn and produce a float loop either intentionally or as the result of knitting fault.

Multiple-gauge knitting: Multiple-gauge knitting is a number of different gauges can be knitted in a single course.

Productivity: Machine productivity is expressed in pattern rows per minutes.

Racking: Racking is the lateral movement of a needle bed or point bar across a predetermined distance on a flat knitting machine.

Rib gating: The alternate alignment of one set of needles with the other on a machine equipped with two sets of needles arranged to knit rib fabrics.


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Sinker: Sinker helps loop formation, holding-down, and knocking-over on a machine.

Slide needle: A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove.

Take down rollers: Take down rollers are required in order that the previous loop which is located in the hook enclosure is prevented from the riding up with ascending needle.

Tubular knitting: Tubular knitting is created on both needle beds but front and back bed knitting are done alternately.

Warp knitting: Warp knitting is composed of loops formed in a vertical direction.

Weft knitting: Weft knitting is composed of loops formed in a horizontal direction.

Welt: Welt in knitting is a secure edge of a fabric. The welts are usually at the starting end of the fabric.

Yarn carrier (feeder): The yarn coming from a single yarn feeder is feeding the needle in a sequential order and by doing so connects the adjacent loops into a course.

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# THREE DIMENSIONAL SEAMLESS GARMENT KNITTING ON V-BED FLAT KNITTING MACHINES

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## ABSTRACT

*Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.*

*The purpose of this research is to review the principles of seamless knitting on V-bed machines and to compare the machines from two major flat-knitting machine suppliers, Shima Seiki and Stoll. This paper will also discuss characteristics and applications of complete garment knitting in various products. This research was accomplished through interviews and a review of the literature. It has implications for academicians and industrial personnel who require information in three dimensional knitting technology and related machinery.*

*Keywords: Knitting, tubular, seamless, complete garment*

## 1. INTRODUCTION

Seamless knitting technology creates one entire complete garment with minimal or no cutting and sewing process. This innovative technology eliminates post labor work, which saves production time and cost. In addition, the technology offers knitwear consumers more comfort and better fit by eliminating seams. Thus, seamless technology provides benefits to manufacturers as well as end users. Seamless knitting technology has entered the mainstream in the knitwear market.

Through this research, principles of seamless knitting techniques are discussed, and two major suppliers for V-bed machines, Shima Seiki and Stoll, and machine characteristics will be introduced. In addition, advantages and disadvantages of this type of production are revealed. In order to understand the seamless knitting technology, it is important to review the fundamentals of the knitting process. By a review of the evolution of the knitting process, an explanation of knitting methods, and the description of knitting machines' characteristics, the distinctiveness of seamless knitting will be better understood.



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This research was achieved through a review of the literature and additional primary data was collected through interviews, company visits, etc.

### 1.1. Knitting Fundamentals

To fully examine the developments in seamless knitting, a basic foundation of knitting construction and characteristics should be discussed. Knitting is defined as "the process of forming a fabric by the intermeshing of loops of yarn" [22] and knitting accounts for more than 30% of total fabric production [24]. The end use of knitted fabrics, created either in tubular or flat form, can be apparel and other products including sweaters, underwear, hosiery, socks and stockings.

Knitting is classified into two fields, weft knitting and warp knitting. In weft knitting, loops are formed in a horizontal direction whereas in warp knitting, loops are formed in a vertical direction [1] (Figure 1.1a and 1.1b). Weft knitting is more resilient, more open and has additional design possibilities as compared to warp knitting. Conversely, warp knitting has less resilience, more cover, lighter weight and higher productivity. Weft knitting can be divided into circular knitting and flat knitting according to type of fabric, type of needle, and form of needle bed. In the circular knitting machine, needles are set radically or parallel in one or more circular beds [3]. On the other hand, a flat knitting machine employs straight needle beds carrying independently operated needles, which are usually of the latch type [3].

Compared to flat knitting machines, circular weft knitting machines provide higher productivity. Thus, circular knitting machines have more rapid production speeds than weft knit flat bed machines. However, flat knitting machines have greater versatility in loop structure combinations and patterning because their machine cams can be changed after every course (even after every stitch), and they are able to knit one or both beds easily [52]. It should also be noted that electronic circular machines have the same capability.

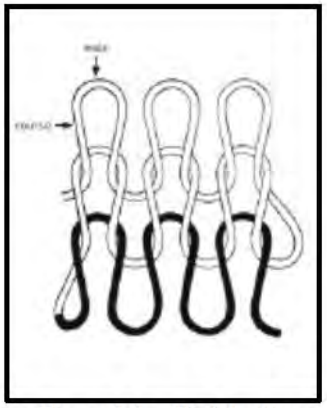


*Figure1.1a. Weft knitting*

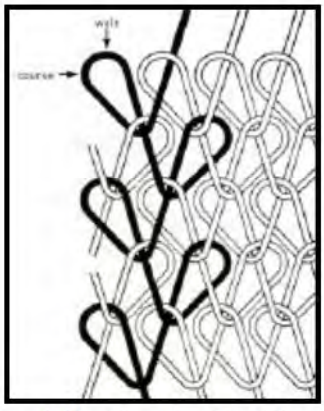


*Figure 1.1b. Warp knitting* (Black, 2002



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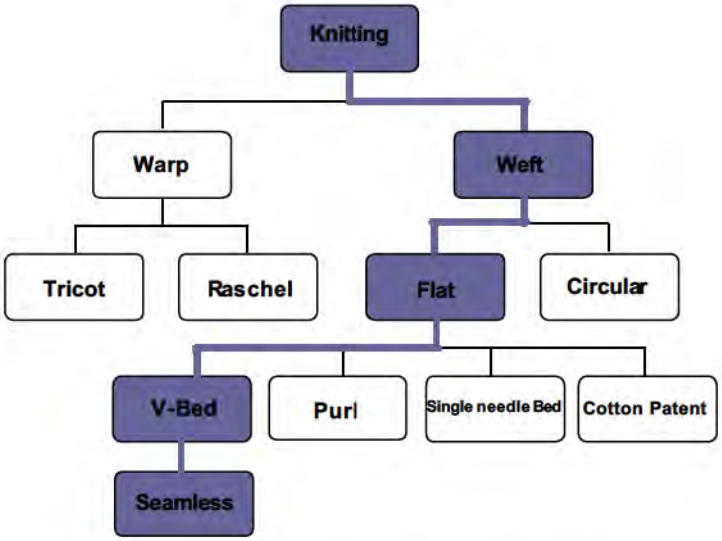



*Figure 1.1c. Knitting Classification Diagram*

Spencer defines cams as "the devices which convert the rotary machine drive into suitable reciprocating action for the needles" [42]. Figure 1.1d shows the knitting action of latch needles for the cam track on a V-bed knitting machine. According to the position of needle butts moving up and down through the cam system, the loop can be formed sequentially [34].

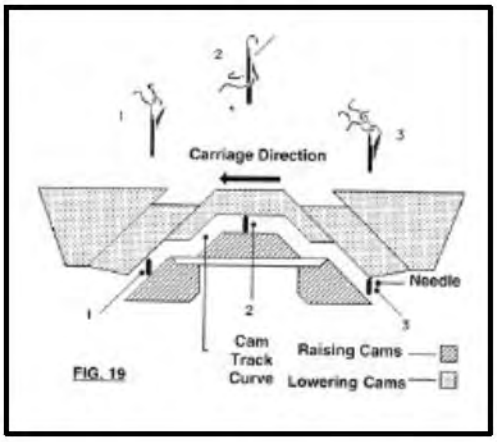


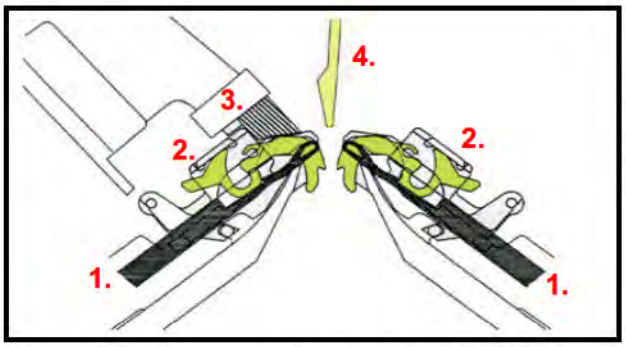

*Figure 1.1d. Knitting action of latch needle though cam track*
(Raz, 1991)

Figures 1.1e and 1.1f illustrate the basic knitting machine parts on a flat bed machine including a carriage, latch needles, sinkers, brushes, yarn carriers and take down rollers. A carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam [34].

The latch needle, the most widely used needle in weft knitting, is mainly composed of a needle hook, a latch, and a needle stem (Figure 1.1g). The major advantage of the latch needle is that it self acts or controls the loop so that individual movement and control of the needle permits loop selection to be accomplished [42]. The sinker is another primary element in knitting. Main purposes of the sinkers are loop formation, holding down, and knocking-over [42]. However, the role of sinkers on a V-bed knitting machine with latch needles is chiefly a holding-down function. Therefore, holding down sinkers are capable of tighter fabric structures with an improved appearance. The purpose of the brushes is to open the latches at the first course when the machine starts to knit and to avoid any closing of the latches [21]. The yarn carrier or yarn feeder is pulled along the needle bed by the carriage and introduces and feeds yarns required for knitting. The yarn carrier is assembled on a dovetail-profiled rail [34]. Take down rollers are needed to prevent the previous loop, which is located in the hook enclosure, from riding up with the needle ascension. This is very crucial for loop formation because without take down tension the previous loop will not slide under the latches and new loops will not be formed without the operation of the take down rollers [34].



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1. Latch needles
2. Sinkers
3. Brushes
4. Yarn Carrier (Feeder)

*Figure 1.1e. Knitting machine system on flat V-bed machine* (Shima Seiki Manual [37])

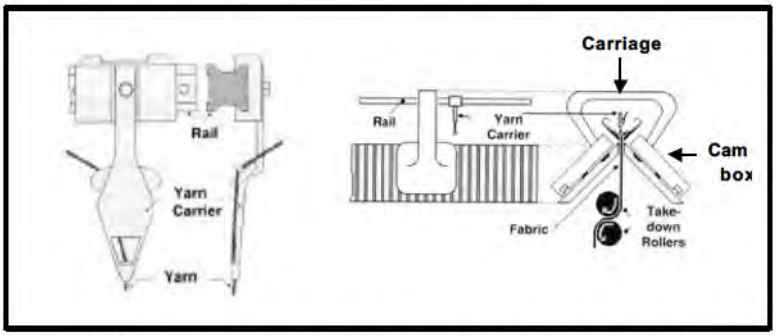



*Figure 1.1f. Yarn Carriers, Carriage and Take-down Rollers* (Raz, 1991)

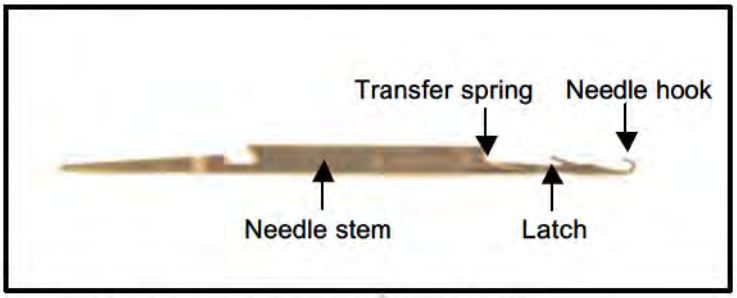



*Figure 1.1g. Latch needle on Shima Seiki Machine*

Flat bed machines have four different classes; (i) *V-bed flat machines* which have two inverted V-formed needle beds; (ii) *Purl machines* which have double ended needles; (iii) machines that have *a single bed* of needles which include most domestic models and a few hand manipulated intarsia machines [40]; and (iv) *Cotton patent machines* which are single-bed machines with bearded needles arranged vertically [1]. Bearded needles are the needles having an extended terminal hook or beard that can be flexed to close the hook [22].

## 1.2. Historical Events Contributing to the Development of Seamless Knitting

In the evolution of seamless knitting it is important to review the developments in knitting that directly affect three-dimensional knitting techniques. Kadolph and Langford [12] explain that historical remnants of knit fabrics have been dated from A.D. 250 in the Palestine area. Knitting was accomplished by a hand process until 1589, when William Lee in England invented a flat-bed weft-knitting frame to create hosiery [12]. The first operational V-bed flat knitting machine using latch needles was invented in 1863 by



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Issac W. Lamb [34]. William Cotton of Loughborough took out a patent in 1864 for his rotary-driven machine that used a flat bed to produce fully-fashioned garments [16]. According to Hunter [9], in the 1800's, the flat knitting machine was fitted with sinkers, which controlled loops in order to knit single jersey tubular articles such as gloves, socks and berets. In 1940, the manufacture of shaped knitted skirts was patented in the USA. This permitted darting on knitted skirts using a technique called "flechage" (See glossary). The flechage technique not only improved drape and fit, but cut production cost. In 1955, the Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaping of components. In the 1960's, the Shima Seiki company further explored the tubular-type knitting principle commercially to produce gloves. Also, in the mid1960's, engineers at Courtaulds in the UK established British patents on the idea of producing garments by joining tube knitting. However, the method was too advanced to be commercialized at that time. By 1995, Shima Seiki fully developed shaped seamless knitting [9]. Recently, by employing more advanced computerized systems, simpler programming was possible, and the computerized systems enabled the production of more complicated and sophisticated knitted structures and products. Table 1 introduces the historical events of seamless knitting.

| Year | Historical Events Contributing to Development of Seamless Knitting |
|---|---|
| 1589 | William Lee in England invented the first flat-bed frame to create hosiery. |
| 1863 | Issac W. Lamb invented the first operational V-bed flat knitting machine including the latch needles. |
| 1864 | William Cotton of Loughborough patented his rotary-driven machine that used a flat bed to produce fully-fashioned garments |
| 1800's | The flat knitting machine was fitted with sinkers, which controlled stitches in order to knit single jersey tubular articles such as gloves, socks and berets. |
| 1940 | The manufacture of shaped knitted skirts using a "flechage" technique was patented in the USA. |
| 1955 | The Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaped sections. |
| 1960's | Shima Seiki company further explored the tubular-type knitting principle to produce gloves commercially. |
| 1960's | Courtaulds established British patents on the idea of producing garments by joining tube knitting. |
| 1995 | Shima Seiki introduced seamless entire garment knitting at ITMA. |

*Table 1. Historical Events Contributing to Development of Seamless Knitting*

Seamless entire garment knitting was introduced in 1995, at ITMA, the International Textile Machinery Association [24]. Seamless knitting, or complete knitting, which produces one entire complete garment without a sewing or linking process, provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages. In Section 2, numerous advantages of seamless garment knitting are discussed.



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## 2. ADVANTAGES OF SEAMLESS GARMENT KNITTING

In general, V-bed knitting process has more flexible needle selection capability and more design possibilities compared to warp knitting process [2]. Through computerized flat bed knitting, more variety of knit patterns and structures can be created and designs can be instantly and efficiently changed through a computer-aided design system. Furthermore, seamless garment knitting makes it possible not only to create several types of tubular formed knitting but also to build diverse design structures on the tubular knitted garments simultaneously.

Complete garment knitting offers a variety of benefits in technical aspects as well as in the market demands. For benefits to the market, quick-response production and just-in-time production are possible. The required number of products can be quickly knitted in less time to meet the needs of the market. It also enables mass customization for many markets. Onal states "Mass customization is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology" [29]. In certain markets, seamless knitting could be considered for mass customization by rapid design changes according to customers' requirements through computerized knitting systems. Seamless knitting systems may be utilized for sampling prototype and for niche market limited production items.

For the focus of this paper, the benefits of seamless technology are mainly discussed. First, there is no longer the traditional labor-intensive cutting and sewing process because of eliminating seam production. Hence, the tubular-typed seamless knitting results in potential savings in terms of production time and cost. For instance, according to Melliand International, in the case of a complete woman's knit sweater, a time saving of about 35% can be achieved with seamless knitting [20]. Additionally, yarn consumption can be minimized by complete garment knitting as well as by effectively analyzing yarn feed through the computerized system on the machine [7]. The DSCS (Digital Stitch Control System) on Shima Seiki machine predetermines how much yarn is required for the each stitch. Loop size can be controlled accordingly and there is much less stress on the yarn at the sinker. According to Mowbray, this device not only permits a variety of types of yarns to be used but also offers maximum production efficiency because higher speeds can be achieved [26]. The range of gauges for complete garment machines varies from 5 gauge to 18 gauge. Seamless garment knitting technology adds flexibility through gauge conversion and multi-gauge knitting [20]. The capability of multi-gauge application allows the conversion of gauges in the same machine. As a result, it saves time and cost for investing in different machines for every gauge.

In garments, three-dimensional knitting is purported to give lightness and softness in knitwear because there is no linking and sewing production [39]. In addition, there are no bulky and annoying stitches at the underarm points, shoulders and neck lines [39]. For finished edges, the garment can have better trimmed edge lines through a machine binding-off process instead of a sewing or linking operation.

In decreasing the number of production processes such as the cutting or sewing steps, the risk of defects and damages can also be minimized. A single entire piece production method is claimed to provide more consistent product quality [20]. Consequently, seamless knitwear is promoted to look better, fit better and is believed to be much more comfortable than a traditional fully-fashioned piece of knitwear. Seamless knitting also allows knit designers to create design structures and patterns across the entire garment. Designers can easily program and style both more sophisticated design structures and shaped patterns through the computerized design system.



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Finally, in the global environment, according to Shima, seamless garment knitting puts less stress on the environment by minimizing waste disposal and reducing the need to grow as much as cotton, wool and other natural raw materials [26].

## 3. TECHNICAL ISSUES

Although seamless garment knitting technology provides a variety of advantages for the knitting industry, it still has several technical issues to be considered. The main problem in complete garment knitting has been fabric take-down [10]. To keep equal tension of each loop (i.e., stitch), diverse sinker systems and take-down tension systems have been utilized. Finally, the novel sinker systems such as a spring-type moveable sinker system and a computerized take-down tension system, appropriate to complete garment knitting, have been developed to solve the problem. Even though the systems have brought higher stability for knitting, there is the opinion of users that it still is not easy to control an exact take-down tension for the complete garment.

Complete garment knitting also has a problem caused by the alternate needle selection. The alternate needle selection knitting makes fabrics more open and less elastic than conventional fully-fashioned garments [27]. This problem occurs in the welt or the cuff areas. A welt in knitting means "a secure edge of a fabric. The welts are usually at the starting end of the fabric" [22]. To solve the looser fabric problem, it is critical to select appropriate yarns for the machine gauge; and in this context, elastic, flexible and durable yarns are recommended such as wool. For instance, a Yorkshire spinning company in the UK uses the elastic Spirol® lamb-wool on the cuffs and the collars, which can be knitted tighter like a fully-fashioned product [27]. In the current global knitting industry, natural fibers, such as wool, cashmere and angora, and manufactured fiber such as acrylic are mainly used to create seamless garments for outerwear [11]. Viscose and polyamide with Lycra® or other elastomerics are also utilized for complete garment knitting [11]. Cotton is also a popular fiber used in seamless apparel.

Another issue for complete garment knitting is that if the garment has a defect during knitting such as a hole or a barre' problem, the entire garment is useless and must be discarded. Pratt explains "Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric" [32]. Compared to fully-fashioned knitting, there would be more waste when the complete knitted garment has any defect. In cut and sewn production pattern pieces could be placed for cutting on a flat piece of fabric to avoid any defects.

## 4. APPLICATIONS OF SEAMLESS KNITTING

Seamless garment knitting on the V-bed machine has primarily been used for apparel. However, in recent years, this new three-dimensional knitting technique has been extended in other areas such as fashion, upholstery, industrial, automotive, and medical textiles.

### 4.1. Apparel (Figure 4.1)

A diverse range of seam-free products can be created such as hand gloves, hats, socks, and sweaters according to the machine gauge and types of machine. Additionally, patterns for knitted trousers and skirts are available on the complete knitting machines. As far as design structures, most knit structures knitted on fully-fashioned machines can be created on the seamless garment machines such as cable stitches and even intarsia structures.
(See glossary for structures.) [33]

### 4.2. Upholstery (Figure 4.2)

Several upholstery companies are utilizing three-dimensional seamless seat upholstery production. The Teknit Company offers three-dimensional knit upholstery for the office chair market. Teknit creates shaped three-dimensional polyester seat covers that compete against woven fabric, which



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requires a cutting and sewing process [43]. According to Teknit, lead times are substantially lower than conventional woven fabric and the office chairs covered with seamless knitted fabric are their fastest selling line. The company also has the capability of promoting rapid design changes by using sophisticated CAD systems [46]. Additionally, seamless shaped knitting with its inherent stretch characteristics follows the contours of the seat, providing better seat trimming [46]. It enhances appearance and enables users to feel more comfortable by eliminating ridges caused by a sewing or a linking process.

### 4.3. Automotives

Courtaulds and General Motors Corporation developed the three-dimensional knitting technique to produce seat covers in 1985 [40]. Marjorie Sorge proposed that automotive seat covers made by seamless knitting also provide great potential for the automotive market in that the three dimensional knitting process cuts lead time by eliminating cut-and-sew operations, brings down warranty costs and adds quality [40]. Lear Corporation which owns patents on three-dimensional knitting technologies claimed the ability to design new seats using a predictive computer model which reduced the time needed for seat design by 25% [31]. Seamless knitting for automotive also provides a potential for designing a more ergonomic seat through the ability to alter the knitted tube size.

### 4.4. Medical textiles

Recently, specialty textiles created by three-dimensional flat bed knitting machines have also been applied to medical textiles. Tubular typed knitted structures such as bandages, orthopedic supports, and medical compression stockings have been developed. In the future, it is expected that more advanced and sophisticated medical textiles created by seamless knitting technology would be produced. The incorporation of high performance fibers and additional sensors or electronics could provide further opportunities for seamless products in healthcare applications.

J T A T M



*Figure 4.1. Seam free garment created on Shima Seiki WholeGarment® Machine* (Shima Seiki, 2003)



*Figure 4.2. Claud 9™ Chair created by NeutralPosture® (NeutralPosture, 2004)*



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Each of these market applications has specific performance requirements and specialized aesthetics. In order to use this technology to fulfill these market needs, the principles of knitting and knitwear production, and the evolution of seamless knitting need to be reviewed.

## 5. EVOLUTION OF THE KNITTING PROCESS FROM CUT AND SEWN PRODUCTION TO SEAMLESS GARMENT KNITTING

As described in Table 1, the knitting industry has gradually developed since William Lee of Calverton successfully converted the actions of hand knitting with two needles into a mechanical process. Lee's work was the first attempt at mechanizing hosiery knitting in 1589 [16]. Since the invention of the frame-knitting machine, knitting technology has progressed from hand flat machines to complete garment-knitting machines. Section 5.1, 5.2, and 5.3 will explain the evolution of the knitwear process from cut-and-sew production to seamless knitting.

### 5.1. Cut and Sew Production

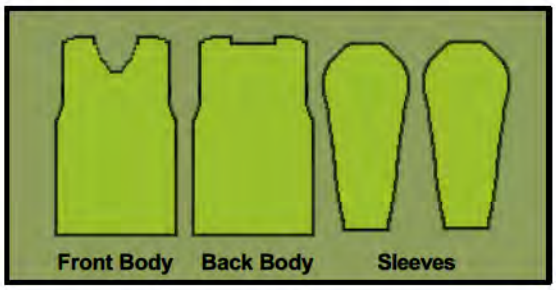



*Figure 5.1. Cut and sew production*
(Shaded area: Cutting Waste)

Cut and sew production is created by the use of one entire panel of fabric. Figure 5.1 shows the cutting layout for the front and rear body portions and also the sleeve portions required to create a sweater. Through the cutting and sewing process, the finished garment is created. However, this garment production process requires several post-knitting processes including cutting and sewing. Additionally, in this process, separately knitted trimmings and pockets need stitching. The Shima Seiki Company explains that with cut and sew production, up to 40% of the original fabric can be waste [39].

### 5.2. Fully-Fashioning

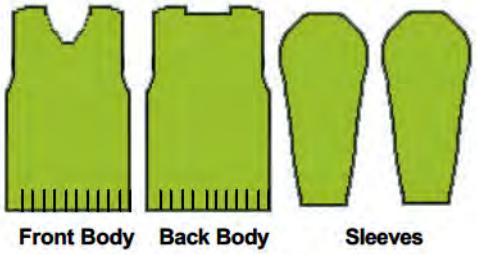


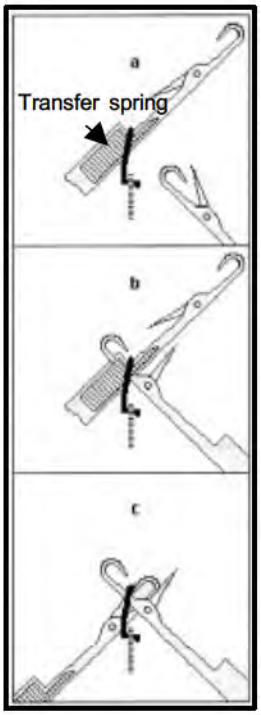

*Figure 5.2. Fully-fashioning production*

Fully-fashioned knitting means "shaped wholly or in part by widening or narrowing of piece of fabric by loop transference in order to increase or decrease of the number of wales" [3]. Thus, as the number of loops are increased or decreased, the fabric can get shaped areas as seen in Figure 5.2. To achieve fully-fashioned knitting, loop transference is necessary. The loop transference is the process that moves stitches (i.e., loops) from the needles on which they were made to other needles [49]. Figure 5.2a illustrates the mechanism of loop transference on a V-bed flat knitting machine.

In addition, the following stitch notation (Figure 5.2.1) describes how widening or narrowing occurs by loop transference on fully-fashioned machines. The fully-fashioning process allows the separate creation of shaped front and back body parts and sleeve parts by increasing or decreasing the number of loops (Figure 5.2); this eliminates the cutting operation. However, because all parts of the garment are knitted separately, the fully-fashioned knitting still requires a post sewing or linking process. Linking is defined as a process of joining side seams or edges of fabric pieces together with a row of knitting on a linking machine [19].



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a. The delivering needle is raised by a cam in the carriage. The loop is stretched over the transfer spring.

b. The receiving needle is raised slightly from its needle bed. The receiving needle enters the transfer spring of delivering needle and penetrates the loop that will be transferred.

c. The delivering needle retreats leaving the loop on the receiving needle. The transfer spring opens to permits the receiving needle to move back from its closure. Finally, loop transference is completed.

*Figure 5.2a. the mechanism of loop transference on V-bed flat knitting machine* (Raz, 1991)

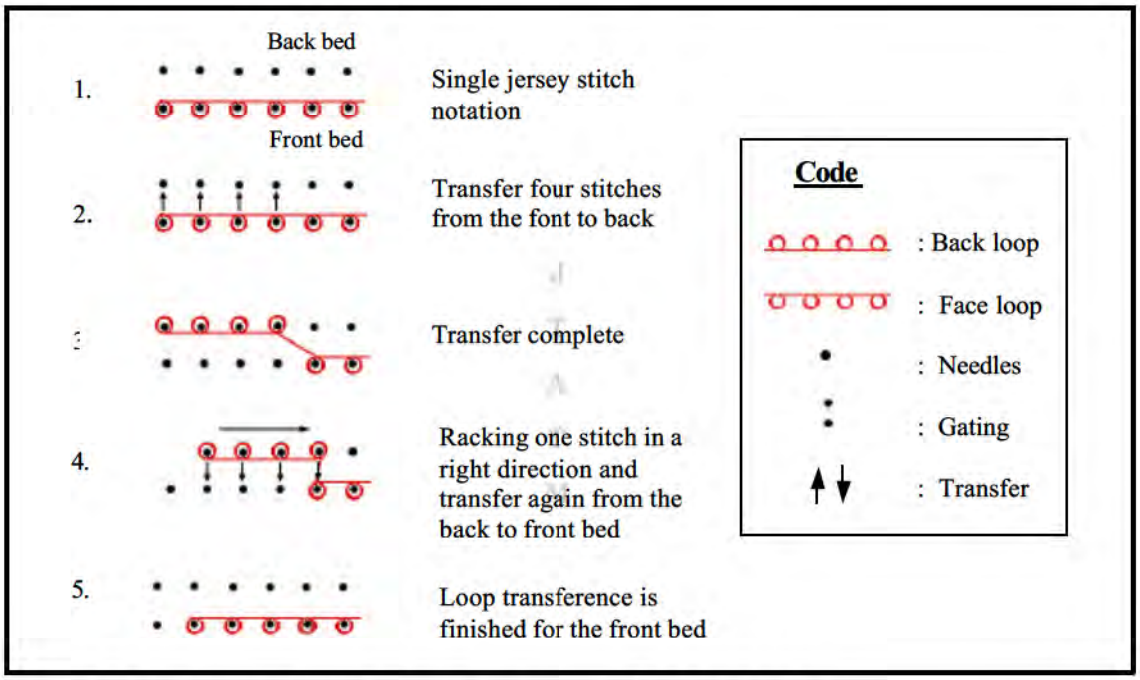



*Figure 5.2.1. Narrowing process by loop transference on flat V-bed machine*



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### 5.3. Seamless garment knitting



*Figure 5.3. Complete garment production by a seamless flat knitting machine*

"Seamless" garment knitting creates a complete garment by several different carriers (feeders) with minimal or no cutting and sewing processes (Figure 5.3). Thus, seamless knitting has the capability for production time and cost saving by removing post-knit processes such as the linking or sewing and cutting operation [39].

It also minimizes yarn consumption by reducing the cutting waste and can achieve higher productivity. Machine productivity in knitting is expressed in pattern rows per minute [41]. Complete garment knitting can be achieved either on a circular knitting machine or a flat (V-bed) knitting machine. However, seamless circular knitting machines are different from seamless flat knitting machines in that circular machines such as the Santoni create only a single tubular type of garment. Seamless flat knitting machines such as the Shima can create more than one knitted tube at the same time, and the tubes are joined together on the machine (Figure 5.3a). The complete garments knitted on circular machines may also need minimal cutting as seen in Figure 5.3a. In addition, the complete garments created by circular knitting machines still require minimal seam joining on one body tube and two sleeve tubes as well as the finished edges. Santoni has recently introduced the SM4 TL2 machine, which shapes the knitted tube and will eliminate the cutting process [35]. Consequently, seamless knitting on circular machines is not true seamless knitting.

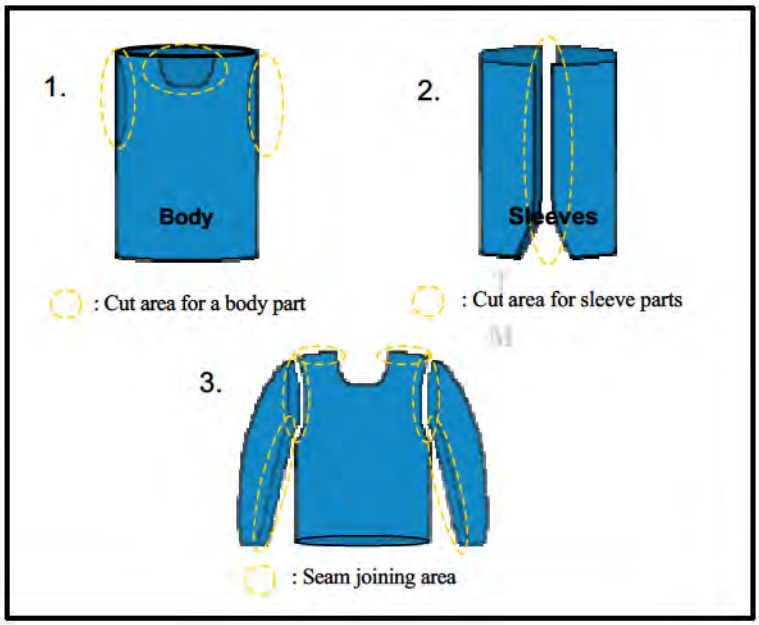



Figure 5.3a. *Complete garment production by a seamless circular knitting machine*



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In recent years, several companies have developed seamless or complete garment machines such as Santoni, Sangiacomo, and Orizio Santoni, part of the Lonati Group, is the biggest supplier of the circular knitting machinery. Lonati has recently acquired Sangiacomo, and its expanded seamless circular knitting technology is in the forefront of the industry. Santoni, whose customers include Nike, Adidas, Sara Lee et cetera β0], offers 14 different models of circular knitting machines, from 7 to 32 gauge. The machines produce swimwear, sportswear, outerwear, underwear et cetera. [35].

However, in the strict sense of the word, seamless flat V-bed knitting actually creates complete garments, which do not require any kind of cutting or sewing process. For Section 6, the knitting method of multi-tubular knitting techniques created on a V-bed knitting machine will be discussed.

## 6. V-BED MACHINE KNITTING OF SEAMLESS GARMENTS

As mentioned earlier, seamless garments on a flat V-bed machine can be created in three separate tubular forms by knitting one wider tube for the body part and two narrower tubes for the sleeve parts. Tubular knitting is created on both needle beds but front and back bed knitting are done alternately [23]. The continuously alternate knitting of all needles on front and back needle beds creates a single plain tube. Tubular type knitting is not a new technique. Since the 1800's, single jersey tubes have been produced on flat machines [8]. However, seamless garment knitting can be seen as a more advanced technique in that it can connect the three tubes together to create a sweater [6] and has the capability to increase and decrease the dimensions of the tubes [44]. Moreover, various structures such as plain, rib, and purl can be created within the seamless garment at the same time.

On the flat machine, the three tubes are knitted on a pair of front and back needle beds. The flat machine knits and transfers loops between the front needle bed and the back needle bed with different yarn carriers for one body tube (Feeder 2) and two sleeve tubes (Feeders 1 and 3) (Figure 6.1). The three-tube knitting continues to the underarm point. At the underarm point, the two carriers knitting sleeve parts (Feeders 1 and 3) are taken out of the knitting zone. The remaining carrier (Feeder 2) that knitted the main body part knits together the three tubes into one tube [10] (Figure 6.2). The tubes are joined at the underarm points, shoulders and neck points. In this manner, seamless garment knitting is accomplished. However, in order to make loop transference for performing shaping or design structures, loops should be formed by selecting alternate needles [17] (Figure 6.3).

Figure 6.4 reveals how loop transference occurs on complete garment knitting by using empty needles. By loop transference using the alternate needles, single jersey tubes as well as rib type tubes can be knitted on the complete garment machine. Figure 6.5 depicts how the 2X2 rib structure can be created on the complete garment V-bed knitting machine. However, due to the alternate needle selection on seamless machines, the garment tends to be more open and less elastic than a traditional fully-fashioned garment [27]. This requires the use of more elastic yarns on the seamless knitting machine compared to the other regular V-bed machines such as fully-fashioned machines.

In addition, the number of tubes knitted on the machine depends on the desired type of knitted product. The complete garment machine does not have to create three tubes all the time. For instance, to create a sweater, it requires three tubular typed forms. On the other hand, a seat cover may require only one type of tube for the complete cover, but could also provide an integrated attachment tube.



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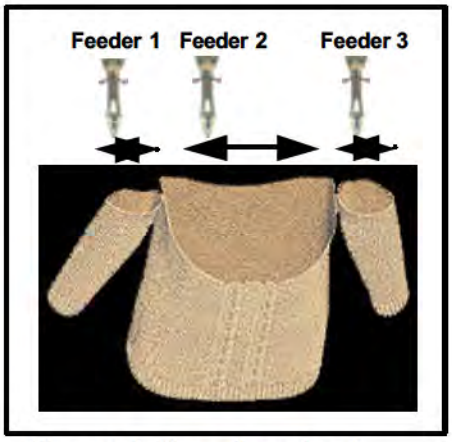



*Figure 6.1. Three-dimensional complete garment knitting until underarm point* (Shima Seiki)

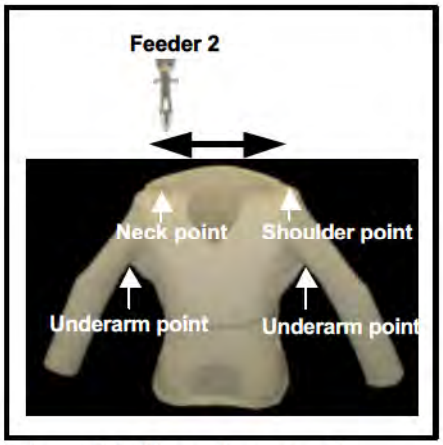



*Figure 6.2. Three-dimensional complete garment knitting after underarm point*

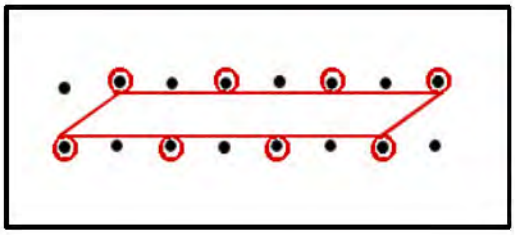


*Figure 6.3. Alternate stitch notation on complete garment knitting*

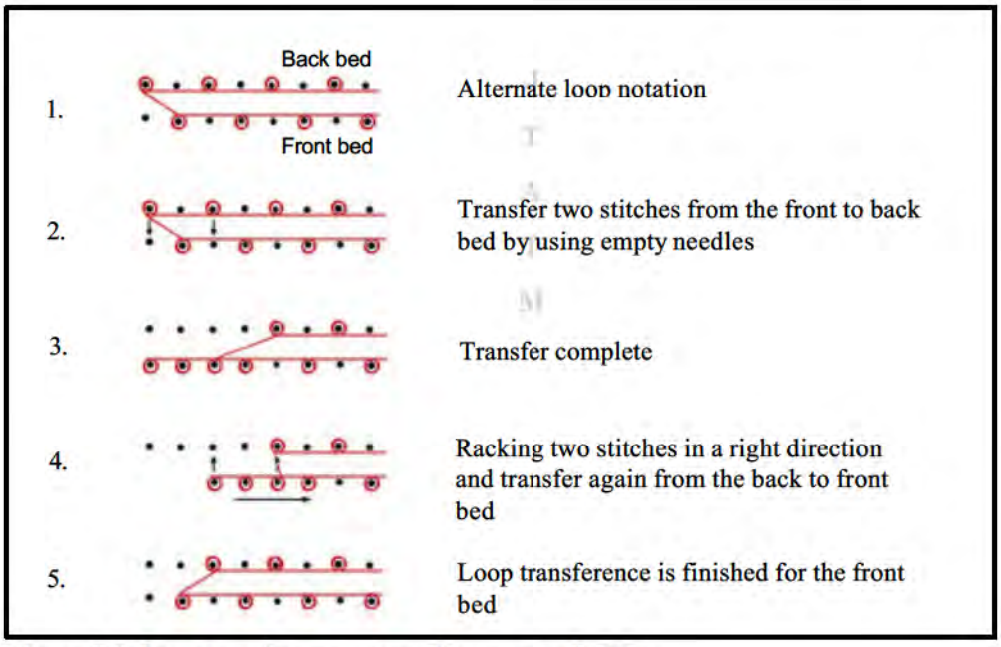
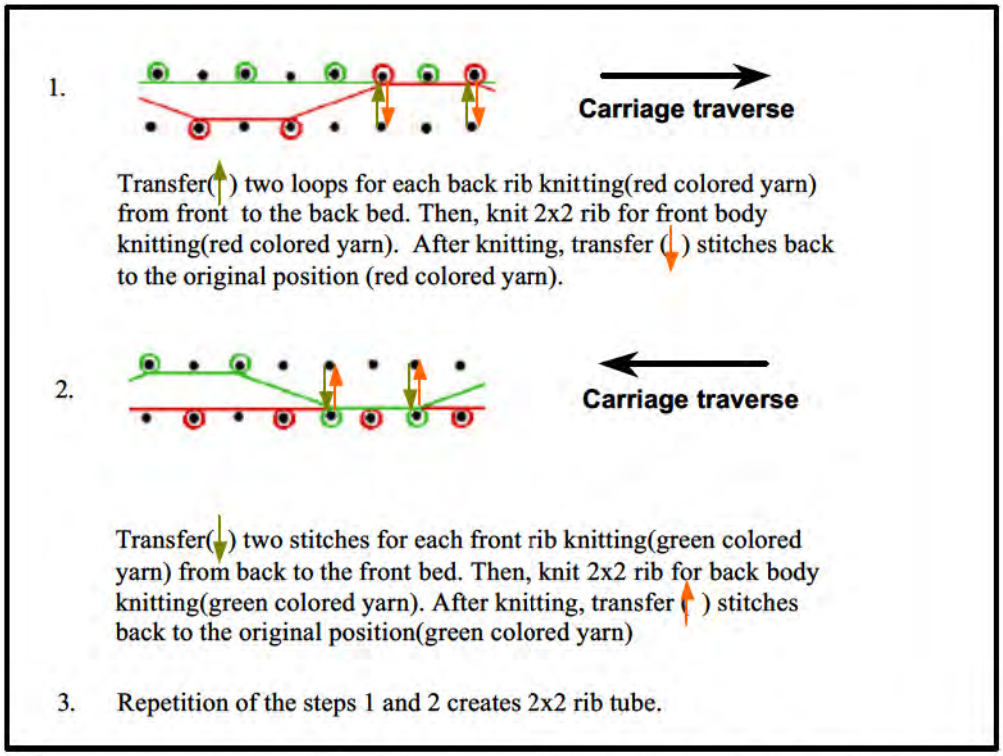



*Figure 6.4. Loop transference on complete garment knitting*



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** The upper figures show 2x2 rib tubular type knitting. Green colored yarn and red colored yarn represent the same yarn. In order that loop notation is seen easily, two different colors are*

*Figure 6.5. Tubular knitting of 2x2 rib on complete garment machine*

## 7. SEAMLESS MACHINES

For seamless flatbed knitting machines, two suppliers, Shima Seiki and Stoll, are the leaders in machine manufacturing. They offer solutions for the knitting of complete garments on computerized V-bed knitting machines. In Section 7, the two companies, Shima Seiki and Stoll, and their seamless knitting machine systems will be introduced and compared.

### 7.1. Shima Seiki

The Shima Seiki company invented the WholeGarment® machine and introduced the commercial complete garment knitting (SWG-V machine) in 1995 at ITMA (International Textile Machinery Association) [24]. Since the beginning of WholeGarment® machine production, about 3500 WholeGarment® machines have been manufactured and sold worldwide [11]. The seamless garment machines of Shima Seiki have different range of gauges from 5 to 18 gauge (needles per inch) and knitting widths ranging from 50 inches to 80 inches. Shima Seiki produces five versions of the innovative WHOLEGARMENT® machine that can produce a one-piece three-dimensional complete garment with no stitching, linking or sewing processes. Figure 7.1 illustrates the SWG-V WholeGarment® knitting machine system that shows various machine features such as a machine tuning screen, a computer controller, top tension devices, yarn carriage, et cetera.



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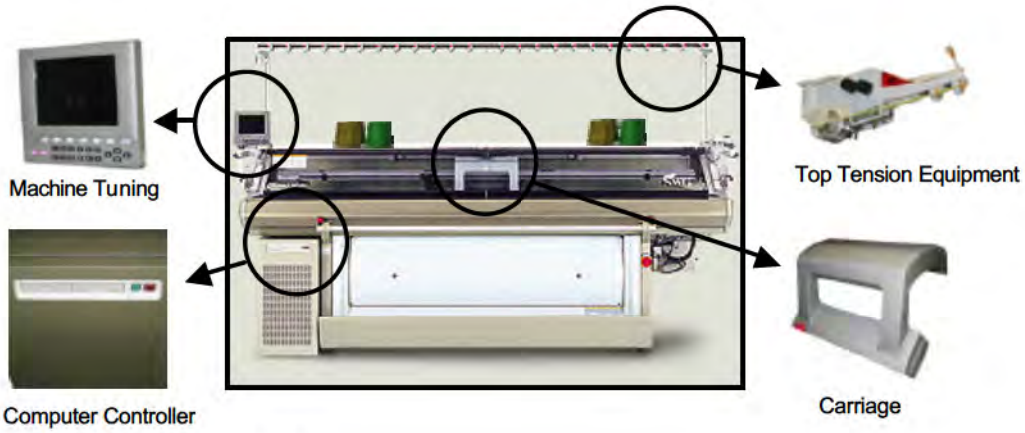



*Figure 7.1. SWG-V® machine*

### 7.1.1. Shima Seiki CAD system and machines

Figure 7.1.1 shows the Shima Seiki® knitting machine system. In general, knit patterns can be created on the CAD (Computer-Aided Design) system and all data can be saved to a diskette. The saved data can then be transferred to the Shima Seiki knitting machine and the machine can be operated. The machine-tuning screen allows operator interface with the settings of the machine. Finally, one complete three-dimensional garment can be knitted on the machine.

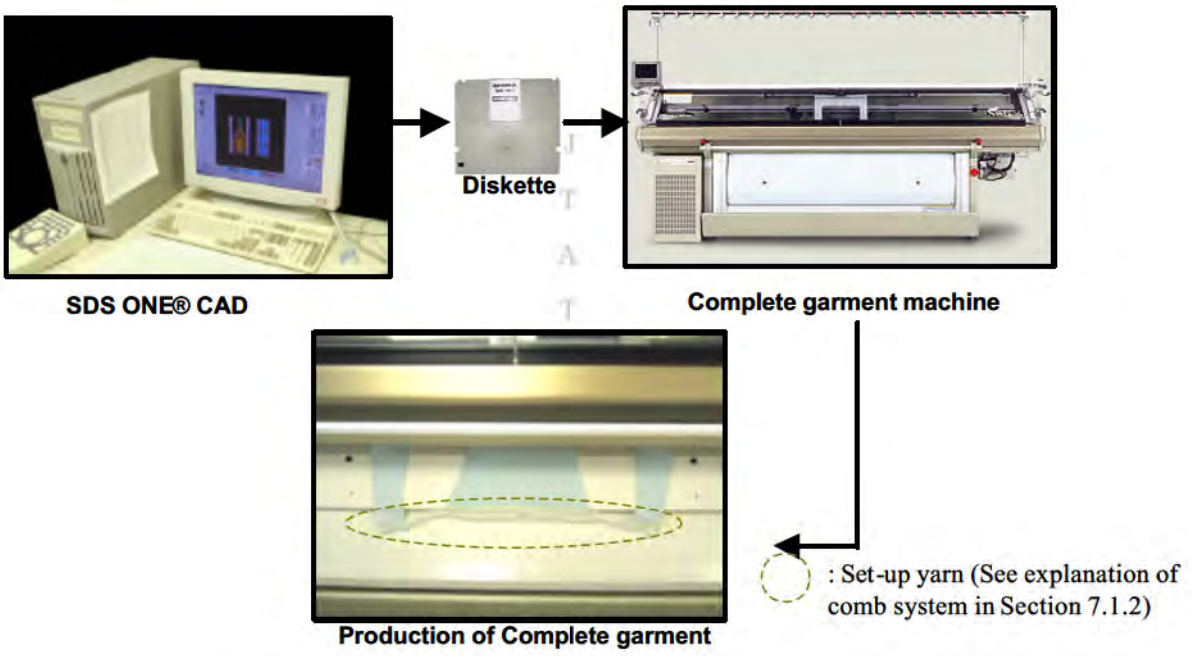


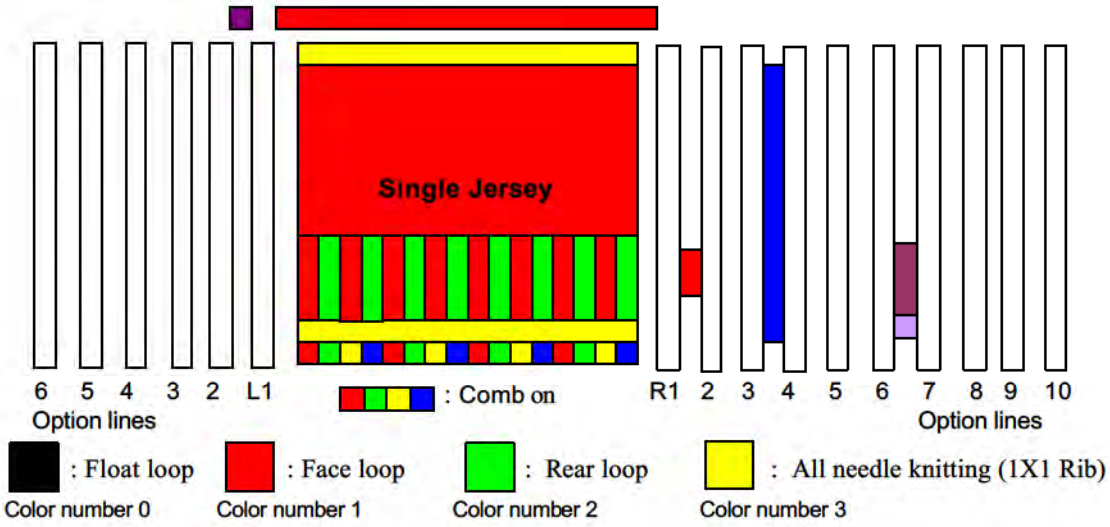

*Figure 7.1.1. Shima Seiki Knitting machine system*



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### 7.1.2. Shima Seiki CAD system

The Shima SDS ONE® CAD system is a totally integrated knit production system that allows all phases including planning, design, evaluation and production [44]. Specifically, the loop simulation program permits quick estimation of knit structures without any kind of actual sample making [8]. The program provides an opportunity to see knit problems and to try out diverse knit structures on the computer system before beginning the actual knitting. In the Shima CAD system, each different type of knitting loop is represented by different colored squares (Figure 7.1.2a). For example, as seen in the following figure 7.1.2a, color number 1(red) indicates a jersey (face loop) and color number 2 (green) indicates a reverse jersey (rear loop). Thus, the following red colored figure shows how a single jersey structure can be displayed on fully-fashioned CAD system of Shima Seiki machine.




* A Comb on a V-bed knitting machine is used to set up the yarn required to knit. The comb hooks the set-up yarn, and moves up and down, pulling down the set-up yarns connected with a knitted garment.
* Option line is used to control the data for a knit structure on the CAD system. For example, the right side of option line number 1 is utilized to decide repetition of a pattern area. Each option line represents specific functions of the machine knitting.

*Figure 7.1.2a. Shima Seiki CAD system for fully-fashioned*

The CAD patterning of the seamless garment knitting is more complicated than that of the fully-fashioned knitting due to alternate needle selection. The bottom figure (Figure 7.1.2b) depicts a single course notation of the tubular-formed knitting. In Figure 7.1.2b, the first row indicates front bed knitting (color number 1) and the second row indicates back bed knitting (color number 2). Accordingly, continuous knitting in a lateral direction between the front and back needle beds forms a tubular-typed fabric. In Figure 7.1.2c, it shows how loop transference for complete garment knitting can occur and how it can be displayed on the CAD system. The empty needles thus can be used for the loop transference. For the loop transference on complete garment knitting, at least two loops are transferred in a right or a left direction due to alternate needle selection such as Figure 7.1.2c. Note that only even number of loops can be transferred for seamless knitting on V-bed knitting machines.



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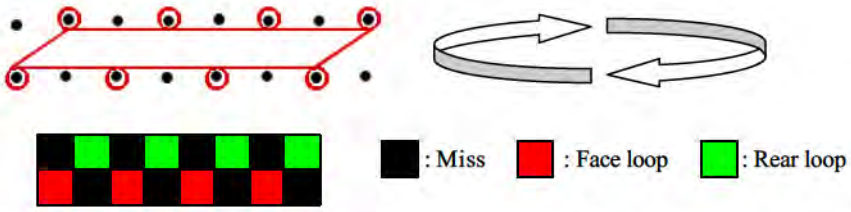



*Figure 7.1.2b. Stitch notation for seamless knitting and CAD design on Shima Seiki CAD system*

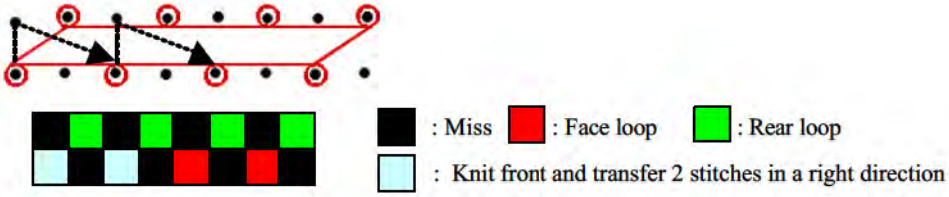



*Figure 7.1.2c. Loop transference on front bed for seamless garment knitting*

By utilizing the principle of the alternate stitch notation, two-dimensional design can be created on the CAD system as seen in Figure 7.1.2d. This represents a three-dimensional tubular typed garment. Figure 7.1.2d displays a whole garment designed on the Shima Seiki CAD system.

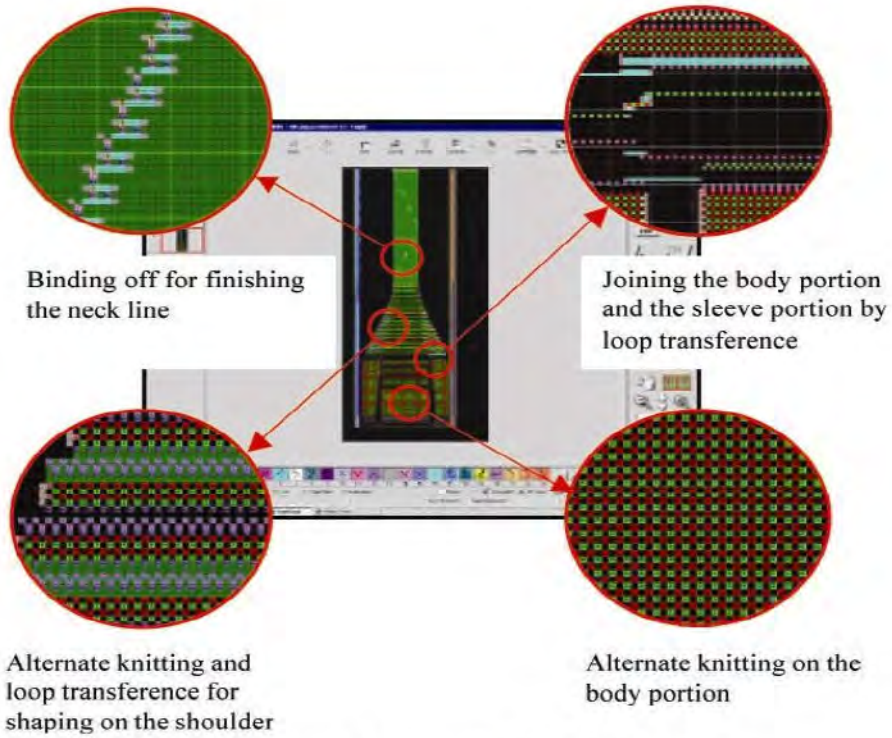



*Figure 7.1.2d. Design for complete garment on Shima Seiki CAD system*

Binding-off: The process that sequentially moves the stitches to the next loop from the edge [38]. This technique is generally utilized to finish edge lines.



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The interface between the knitwear designers and the knit technicians is critical to the success of new sample development. The designer's concept sketch must be realized through the capabilities of the machine governed by the technical expertise of the technician. Shima Seiki addresses this interpretative process through its enhanced Shima Seiki SDS ONE® CAD system. "Knit designs created in the paint program are simultaneously converted to knit programming data, so that designers and technicians can keep in close communication with each other over the same job" [39]. The combination of knit structures and yarn selections available in the design system will allow virtual simulation of potential garments without actual knitting.

Recently, Shima Seiki created a large pattern structure database of knitted parts including collars, plackets, cuffs et cetera. Knit and garment designs can be easily changed at will (Figure 7.1.2.e and 7.1.2f) [39]

### 7.1.3. Types of Shima Seiki Seamless knitting machines

Shima Seiki offers a line of machines capable of seamless knitting. These five different machines have special attributes, which can be selected according to application or end use. Gauge and needle type are the primary distinguishing factors.

#### 7.1.3.1. SWG-V®

The Shima Seiki's SWG-V® machine, which comes in 5 gauge and 7 gauge, is the first commercial application of Wholegarment® technology (See Figure 7.1) [39]. The SWG-V® machine uses a latch needle where the latch closes into the hook of needle as it pulls the yarn through a loop to form a new loop [33] (Figure 7.1.3.1a). The latch needles used in flat bed machines require an additional attachment, a transfer spring, in order to transfer a loop as can be seen in Figure 7.1.3.1a. However, due to the transfer spring, the needles cannot be located in the center of the needle groove, which results in a slightly asymmetrical loop formation. This will be discussed on Sections 7.1.3.4 and 7.1.3.5.

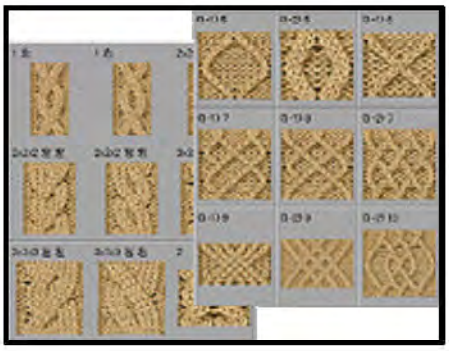


*Figure 7.1.2e. Structure pattern database*



*Figure 7.1.2f Virtual sampling* (Shima Seiki)



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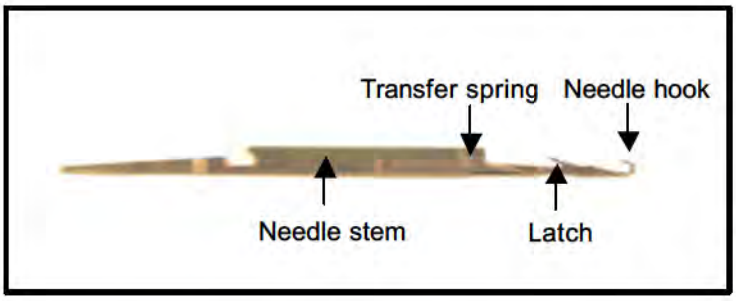



*Figure 7.1.3.1a.*
*Latch needle on SWG-V® machine*

Shima Seki introduced a version of the SWG-V® machine, with its enhanced technical capabilities such as the yarn carrier kickback device and increased memory capacity [39]. The New SWG-V® machine also has a special twin gauge needle configuration (Figure 7.1.3.1b) that includes a pair of needles working together in each needle slot. Complete garment knitting with loop transference requires two sets of needles, for the front and back of the garment, unlike a traditional single jersey tube that has only one set of needles [10]. Therefore, this twin needle configuration allows the needles to more effectively create widening or narrowing as well as diverse knit structures for complete garment knitting.

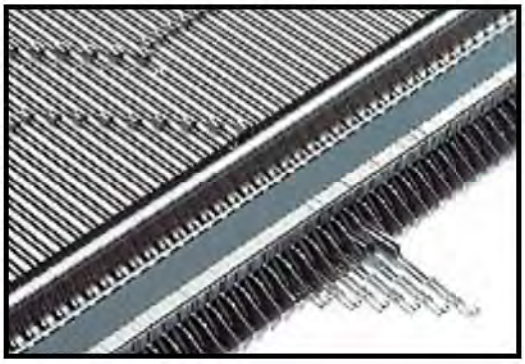


*Figure 7.1.3.1b. twin gauge needles*
(Shima Seiki)

### 7.1.3.2. SWG-X®

The SWG-X® machine is used to produce fine gauge knitwear, which has either 12 gauge or 15 gauge. Fine gauge knitting is produced by the slide needle and pull-down device, which independently controls takedown tension for front and back body portions. Specifically, the SWG-X® is configured for complete garment knitting with four separate needle beds and an additional loop presser bed [39]. This is the reason why the SWG-X® machine is the only machine that can knit complete garments without alternate needle technique. As can be seen in Figure 7.1.3.2, front body knitting can be achieved on needle beds 1 and 2, whereas back body knitting can be done between beds 3 and 4.

Actually, a machine that includes four needle beds and four cam plates is much more expensive to produce than a V-bed machine with two needle beds [10]. The reason Shima Seiki chose the more expensive four-bed route for fine gauge is in that if the machine was to take the half-gauge route for the fine gauge, the gauge would be just too fine for flat knitting technology [10]. The half gauge route on two needle beds for 12 or 15 gauge knitting is too fine to endure rigorous racking or transferring for complete garment knitting. The needle hook is also too small to accept the yarn required for 12 or 15 gauge knitting.



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This multi-needle bed configuration permits complete garment production with sufficient stitch density. Moreover, stitch transference can be more easily accomplished to create tubular ribs. In addition, various knit structures can be knitted at the same time with required stitch densities (Figure 7.1.3.2).

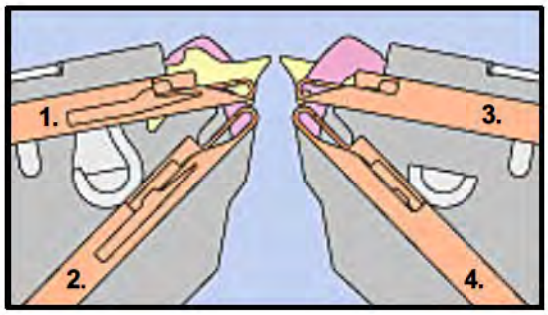



*Figure 7.1.3.2. Cross section Diagram of the SWG-X® four-needle bed configuration* (Shima Seiki)

### 7.1.3.3. SES-S.WG®

As with the SWG-V® machine, the SES-S.WG® has the capability to knit complete garments with latch needles. However, unlike the SWG-V's twin-needle configuration, the SES-S.WG® uses the standard latch needles and spring-type sinkers at the same pitch. This enables the machine to knit fine-gauge shaping as well as integral knitting, and it also makes possible multiple-gauge knitting. In multiple-gauge knitting, a number of different gauges can be knitted in a single course. Multiple-gauge knitting is different from fixed gauge knitting in that an assortment of gauge sizes may be knitted in a single garment [39] (Figure 7.1.3.3). The multiple gauges contain a combination of techniques, such as half-gauging, intarsia technique, using different numbers of yarn ends, and blocks of different gauges of needles each working with its corresponding count of yarn and yarn carriers [44]. Shima Seiki explains that this capacity responds to the change of seasons and trends without investing in a machine for every gauge. As a result, it saves time by eliminating the task of gauge conversion from one machine to another machine. Product variety can be greatly enhanced by achieving more interesting and sophisticated design patterns [39].



*Figure 7.1.3.3. multiple-gauge knitting sample with 12G and 7G mixed side by side* (Shima Seiki)



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### 7.1.3.4. SES-C.WG®

The SES-C.WG® is a flexible machine in that it can achieve quality knitting in a range of production styles. The SES-C.WG® machine has the capability to perform shaping and integral knitting similar to the other SES-series. In addition, this machine can knit coarser gauge complete knitwear. By using compound needles and a take down system featuring a pull-down device, the SES-C.WG® can produce a high-quality coarse gauge seamless garment. The compound needle, in which the hook and hook closing portions are separately controlled [22], is generally used in warp knitting machines [13] (Figure 7.1.3.4a). However, Shima Seiki applied the concept of compound needles to the flat bed machine.

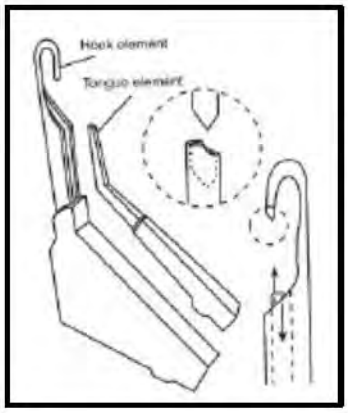



*Figure 7.1.3.4a. Compound needle* (Kadolph and Langford, 1998)

Compared to traditional latch needles, the compound needle is more complex and expensive to manufacture [44]. However, the compound needle gives higher operational stability, which is required for larger needle sizes. According to Shima Seiki, the compound needle offers significant reduction in needle stroke to allow for similar reductions in needle bed and carriage size [39]. Thus, the short stroke knitting helps reduce space in the carriage and permits smaller and lighter carriage [6]. According to John Ward [50], a technician at Shima Seiki USA Inc., the compound needle eliminates the necessity for a brush on the carriage, because the needle has a slider that opens and closes the hook of the needle unlike a latch needle. The slider moves up and down by the movement of the cam system, which is timed to work closely with the movement of the needle. This increases the stability of knitting, and there are no brushes to be worn out.

Another feature of the compound needle is that it does not have to be raised as high because there is no latch that must be cleared which increases knitting stability at higher speeds. However, one drawback of both the latch and the compound needle is that both needles have to be off center in the trick wall to allow for the transfer spring. This puts the needle hook closer to the knock-over bit on one side, resulting in a slightly imbalanced stitch. To solve the problem of imbalance, the Shima Seiki developed the slide needle [50]. The slide needle will be discussed in Section 7.1.3.5.

### 7.1.3.5. First®

This machine executes all types of production from fully fashioning and three-dimensional shaping to seamless production. All this capability is accomplished through the development of the slide needle instead of the latch needles, which uses a unique two-piece, slide mechanism [39] (Figure 7.1.3.5a).



*Fig 7.1.3.5a. Slide needle* (Shima Seiki)

Shim Seiki points out "A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove. The slide needle thereby achieves perfectly symmetrical loop formation for knitting the highest possible



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quality fabrics (Figure 7.1.3.5b and 7.1.3.5c)" [39]. Accordingly, by using the slide needle, the machine provides better quality and stable knitting as well as higher productivity. However, in order to transfer loops by slide needles, the First® machine needs an additional transfer bed that can only move stitches [51]. The machine also requires an extra cam system to control the slider on the slide needle [51]. In consequence, the additional equipments make the machine with slide needles more expensive than a machine with latch needles.

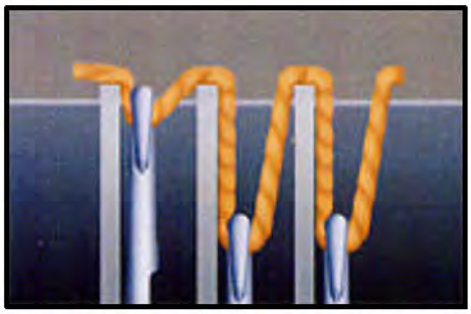


*Fig 7.1.3.5b. Conventional latch needles offset slots* (Shima Seiki)

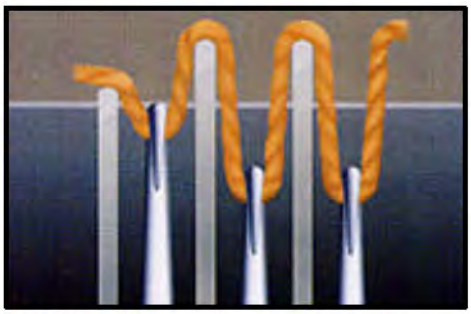


*Fig 7.1.3.5c. Slide needles centered in slots*

Another distinctive feature of the First® machine is its takedown system. "Precision pull down of the garment is independently controlled by tiny pins mounted on front and rear panels which feature adjustable working width through individually controlled 1.5 inch wide sections. This precise control of takedown tension permits 3-dimensional shaping of complete garment items" [10].

The following Table 2 shows the five-versions of Shima Seiki WholeGarment® knitting system. All sources are cited from the Shima Seiki company website, www.shimaseiki.co.jp.



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**Shima Seiki WholeGarment® Systems**
(Sources from www.shimaseiki.co.jp, 2004)

| | First® | New SWG-V® | SWG-X® | New SES-S.WG® | New SES-C.WG® |
|---|---|---|---|---|---|
| Knitting Width | 126-181cm 50-72" | Max 183cm 72" | Max 172cm 68" | 183cm 72" | 203cm 80" |
| Gauge | 12 - 18 gauge | 5, 7 gauge | 12, 15 gauge | 8, 10, 12, 14, 16 gauge | 5 gauge(capable of producing 3G fabric) |
| Knitting Speed | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.1m/sec |
| Racking | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) |
| Knitting system | 3 or 4 system | Triple Knitran® system. Single carriage | 3 system (1 knitting system + 2 transfer system) | Triple Knitran® system. Single carriage | Ultra-compact 2-system (1 knitting system + 1 transfer system) |
| Transfer | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch |
| Sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system | Fixed sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system |
| Yarn Carriers | 12-16 | 13 | 12 | 13 | 16 |
| Take down device | Main/sub rollers, Changeable 31 levels | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear |
| Needle selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Full-jacquard solenoid selection |
| Needle | Slide needle | Latch needle | Slide needle | Latch needle (Standard layout of needles) | Compound Needle |
| Production | Everything from full-fashioning, rib shaping to 3-dimensional shaping, as well as seamless | | High quality fine gauge knitwear | Fine-gauge shaping and integral knitting, even multi-gauge knitting | Coarse gauge knitting |

*Table 2. The Shima Seiki WholeGarment® machine Systems*



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## 7.2. Stoll



*Figure 7.2. STOLL Knit and Wear® Machine* (Stoll)

The other major machinery producer for seamless knitting considered in this research is Stoll. The Stoll system is examined in comparison with the Shima Seiki based on research at Cotton Inc. with Emmett Hylton, Knitting Manager [5]. This section considers the CAD system, the knitting equipment and the seamless systems available. Seamless garment knitting systems from Stoll and Shima are similar, and a comparison of the complete garment knitting systems offered by Shima Seiki and Stoll are considered in this section. Stoll has manufactured flat knitting machines for more than 130 years and has today more than 1,100 employees worldwide [45]. The Stoll machine also markets complete garment knitting machines called "Knit and Wear®". The range of gauge for Stoll Knit and Wear® machine is from E2.5 to E9.2 gauge and the knitting width is from 72 inches to 84 inches. The Stoll Company also has a multiple gauge system, which permits different gauge areas to be knitted in one single course [45].

### 7.2.1. Stoll CAD system

According to Spencer [44], the Stoll SIRIX® (M1) CAD system is a complete design, patterning, and programming system, and it utilizes two windows to graphically develop knitting programs for the Stoll machines. In the Stoll CAD system, all knit structures are displayed by real modules. Figure 7.2.1 shows how 2X2 rib and single jersey can be displayed on the Stoll M1 CAD system.

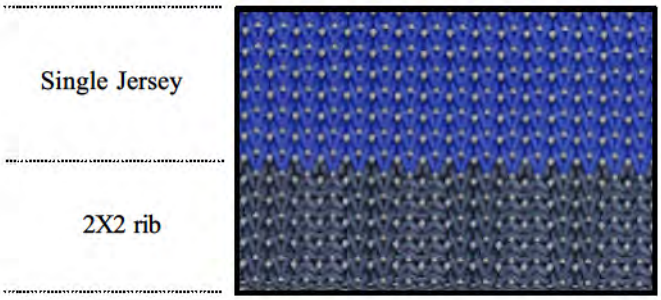



Figure 7.2.1. *2X2 Rib and single jersey displayed on the Stoll M1 CAD system*

As in the Shima CAD system, Stoll's M1 CAD system offers two different windows for designers and technicians who need different information for the same design (Figure 7.2.2). The technical window shows the developing design in the form of running yarn notations and technical data, while the design window presents design as a knitted structure [44]. Both windows can be easily displayed and automatically converted. Therefore, it is expected to minimize miscommunication between designers and technicians in knitting industry. By understanding the knit structures, it is possible to improve collaborative efforts and resulting samples.



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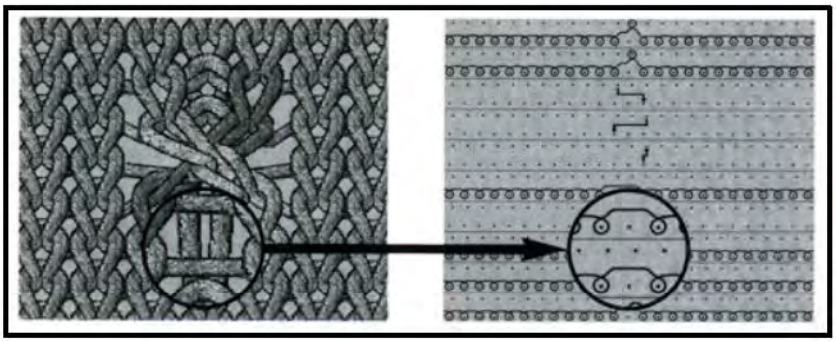


*Figure 7.2.2. Linked windows options of fabric design view and technical view*
(Spencer, 2001)

### 7.2.2. Types of Stoll seamless knitting machines

#### 7.2.2.1. CMS 330 and CMS 340 TC Knit and Wear® machines

CMS 330 TC and 340 TC knit and wear® machines have a 72-inch (183 cm) knitting width. The CMS 330 TC knit and wear® machines cover three systems and a gauge range from E6.2 to E7.2. E6.2 provides a range from E6 to E12 and E7.2 gives a range from E7 to E14. On the other hand, the CMS 340 TC knit and wear® machine has four systems that combine the knitting and the transfer system, and a gauge range from E2, 5.2 to E9.2. Technically, the CMS 330 TC machine is capable of producing fully fashioned, multiple gauge as well as intarsia fabrics. An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (or textures), so that both sides of the fabric are equal [48]. Its three systems yield a high level of production. The CMS 340 TC machine has the capability of multiple-gauge knitting such as Shima Seiki New SES-S.WG [45].

#### 7.2.2.2. CMS 330 TC-T Knit and Wear®

This machine offers a 72-inch (183 cm) knitting width and the range of the gauge is between E6.2 and E7.2. By using its three systems and two additional needle beds with transfer elements and independent racking front and rear, fine gauge knitting is possible in gauges E12 and E14 with all needles [45]. This machine is also capable of multiple-gauge knitting in order to create an interesting knit structure between finely knit areas knitted with all needles and coarser areas knitted only with every second needle [45].

#### 7.2.2.3. CMS 330 TC-C Knit and Wear®

CMS 330 TC-C knit and wear® machine has a three-system capability and a working width of 84 inches (213 cm). This width can easily produce coarse gauge knitwear in extra-large sizes. The gauge E2,5.2, in conjunction with knitting and transferring systems designed especially for this application and a new type of holding-down technology, allows the production of seamless garment knitting [45].

#### 7.2.2.4. CMS 340 TC-M Knit and Wear®

This machine is equipped with a new extra wide working width of 84 inches (213 cm) for producing triple XL sized seamless sweaters [13]. The four system model features a gauge range from E2, 5.2 to E7.2 (up to 14 cut) and the machine also offers gauge conversion capability. It also can be used efficiently for fully-fashioned, multiple-gauge and intarsia fabrics. Thus, it joins the advantages of the comb machines with those of multi piece knitting. Consequently, profitability can be enhanced and even multi-piece fully-fashioned knitting can be achieved [45]. For instance, two front pieces, two back pieces, and four sleeve pieces can be sequentially knitted in the necessary sizes. In two-piece knitting,



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the left fabric can be knitted by the two left knitting systems, and the right fabric can be knitted by the two right knitting systems (Figure 7.2.2.4). This figure also shows the two separate yarn carriages. Two-piece knitting significantly increases productivity compared to one-piece seamless knitting [45]. "This machine knits complete garment panels as multi-layer applications and also as racked and structured patterns in multi layer knits and an absolute novelty in the sector – two gauges in one fabric" [36]. In addition, this machine is capable of producing ultra-coarse gauge garments with the fabric appearance of 2-gauge with a hand-knitted look [13].

With new take-down technology, this machine offers a new shoulder solution, the so-called "French shoulder". This style of shoulder features the connection between the front and back body portions of the garment not in the middle of the shoulder but at the top of the back. This new knitting sequence demonstrates that the shoulder part of the garment can be produced with greater quality with a wide range of possible variations in terms of visual appearance and elasticity [45]. Table 3 shows the five-versions of the Stoll Knit-and-Wear® knitting system. All sources are cited from the Stoll website, www.stoll.de.



*Figure 7.2.2.4. Two piece fully fashioning* (Stoll)

J
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M



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**Type of Knit–and–Wear® machines**
(Sources from www.stoll.de, 2004)

| | CMS 330 TC Knit and Wear | CMS 340 TC Knit and Wear | CMS 330 TC-T Knit and Wear | CMS 330 TC-C Knit and Wear | CMS 340 TC-M Knit and Wear |
|---|---|---|---|---|---|
| Knitting Width | 183 cm 72" | 183 cm 72" | 183 cm 72" | 213 cm 84" | 213 cm 84" |
| Gauge | E2,5.2- E7.2 | E2,5.2- E9.2 | E6.2-E7.2 | E2,5.2- E2,5.2 | E2,5.2- E7.2 |
| Knitting Speed | Max 1.2m/sec | Max 1.2m/sec | Max 1.2m/sec | Max 1m/sec | Max 1.2m/sec |
| Racking | Max 4" | Max 4" | Max 4" | Max 4" | Max 4" |
| Knitting system | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation (4 combined knitting/transfer systems) | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation | Independent knitting systems with split function for optimum system allocation (4 systems) |
| Transfer | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions |
| Sinker system | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down spring loaded sinkers: enables manufacturers to knit ultra coarse garment with a hand-made look (Mowbray, 2004). | Moveable holding-down sinkers |
| Yarn Carriers | 16 | 16 | 16 | 16 | 16 |
| Take down device | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb |
| Needle selection | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system |
| Production | Multi-gauge, Intarsia fabric | Multi-gauge, Flexible gauge | Fine gauge knitting, Multi-gauge | Coarse gauge knitting, | Coarser gauge knitting, Fully-Fashion, Multi-gauge, Intarsia fabric |

*Table 3. The Stoll knit and wear® machine system*



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### 7.3. Comparison of Complete Garment Knitting Systems between Shima Seiki & Stoll

Table 4 compares seamless garment knitting systems between two companies, Shima Seiki and Stoll. The characteristics of the machines are generally comparable except in a few features. The main difference between two offerings is that Shima Seiki machines employ three different types of needles for complete garment knitting such as latch needles, compound needles and slide needles, whereas Stoll machines employ only latch needles. Table 4 shows the machines of two companies have quiet similar characteristics.

**A comparison of complete garment knitting systems between Shima Seiki and Stoll**
(Sources from www.shimaseiki.co.jp and www.stoll.de, 2004)

| | Shima Seiki WholeGarment® Machines | Stoll Knit-and-Wear® Machines |
|---|---|---|
| Knitting Width | 50" – 80" (126 – 203 cm ) | 72" – 84" (183 – 213 cm) |
| Gauge | 5 - 18 gauge | 5 -18 gauge |
| Knitting Speed | Max 1.3m/sec | Max 1.2m/sec |
| Racking | Max 3" total | Max 4" total |
| Knitting System | 3 – 4 systems | 3 – 4 systems |
| Transfer | Simultaneous transfer | Simultaneous transfer |
| Sinker System | Spring-type movable full sinker system | Spring-type moveable holding-down sinker system |
| Yarn Carriers | Up to 16 | Up to 16 |
| Take-down Device | Main/sub take down rollers | Main/upper take down rollers |
| Needle Selection | Electric selection system | Electric selection system |
| Needle | Latch needles, Compound needles, Slide needles | Latch needles |
| CAD system | Integrated knit production system allowing planning, design, evaluation and production | Complete design, patterning, and programming system |

*Table 4. Comparisons of complete garment knitting systems between Shima Seiki and Stoll*


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## 8. CONCLUSIONS

Seamless garment knitting on V-bed machines creates one entire complete garment by using several different carriers eliminating the need for additional cut and sewn operations. The garment can be created in tubular forms: one wider tube for the body portion and two narrower tubes for the sleeve portions. Two leading companies, Shima Seiki and Stoll, manufacture seamless or complete garment V-bed knitting machines. Both companies develop various complete garment machines according to the machine gauge, types of needles, sinker systems, take down systems, and application of knit structures.

For seamless garment knitting, the machines have the capability not only to create shaped knitting, but also to make various knit design structures in the complete garment by utilizing alternate needle selection. Alternate needle selection, however, creates fabrics more open and less elastic than conventional fully-fashioned garments. Nevertheless, complete garment knitting provides major benefits for the market as well as for technical production. (See Table 5) Manufacturers do not have to rely on the cutting and sewing process. As a result, it is believed to offer savings in terms of production times and cost, and it minimizes yarn consumption. In addition, seamless garment knitting provides more consistent and homogeneous product quality, which gives lightness and comfort in the garments. It also offers knit designers more creative knit possibilities.

Three-dimensional seamless knitting with its diverse capabilities can be applied to numerous products such as fashion, upholstery, automotives, aerospace, medical textiles, et cetera. Seamless knitting is forecasted to continue growing and could be one of the largest next generation knitting technologies.

| Potential benefits of seamless knitting |
|---|
| 1. Minimizing or eliminating labor intensive cutting and sewing process |
| 2. Savings in production times and cost |
| 3. Minimal yarn consumption |
| 4. Higher productivity |
| 5. Multi-gauge knitting |
| 6. Lightness and softness |
| 7. No bulky and irritating stitches/seams |
| 8. More constant product quality |
| 9. Better trimmability for finished edge lines |
| 10. Better look, better fit and more comfortable |
| 11. More creative possibilities for knitwear designers |
| 12. Quick-response production for size and pattern changes |
| 13. Just-in-time production |
| 14. Mass customization |

*Table 5. Potential proposal for seamless garment knitting*



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## Glossary

Barre' : Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric.

Bearded needle: the needles having an extended terminal hook or beard that can be flexed to close the hook.

Binding-off: The process that sequentially moves the stitches to the next loop from the edge. This technique is usually utilized to finish edge lines.

Brushes: The aim of brushes is to open the latches at the first course when the machine starts to knit and to avoid closing of the latches.

Cable stitch: Cable stitch is a stitch formed by small groups of plain wales plaited with one another in ropelike fashion.

Carriage: Carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam.

Cam: The device which converts the rotary machine drive into suitable reciprocating action for the needles.

Circular knitting machine: Needles are set radically or parallel in one or more circular beds. Used without further qualification, the term generally refers to a weft-knitting machine of this type.

Comb: Comb on V-bed knitting machine is used to set up a yarn required to knit. The comb hooks the set-up yarn, and moves up



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and down, pulling down the set-up yarns connected with a garment.

Compound needle: The hook and hook closing portions are separately controlled. The compound needle gives higher operational stability at higher speed compared to latch needle.

Flat knitting machine: Flat knitting machine employs straight needle beds carrying independently operated, usually latch needles.

Flechage: Course shaping in knitting. A term increasingly used to define two and three-dimensional shaping of knitted fabric by increasing and/or decreasing the length of succeeding knitted courses to a pre-planned series. Beret knitting is also a term used to describe this process. The term is derived from the French for wedge. (http://www.resil.com/dictionary/f.htm)

Fully-fashioned knitting: Fully-fashioned knitting is shaped wholly or in part by widening or narrowing by loop transference to increase or decrease of the number of wales.

Gauge (cut): Gauge indicates the number of needles per inch.

Holding down: Holding down is one of functions of sinkers. It prevents previous loops from riding with needles. Thus, it gives tighter structures with improved appearance.

Intarsia fabric: An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (textures), so that both sides of the fabric are equal.

Interlock: a double-faced rib-based structure consisting of two 1X1 rib joined by interlocking sinker loops.

Interlock gating: The opposed alignment of one set of needles with the other on a knitting machine.

Knitting: The process of forming a fabric by the intermeshing of loops of yarn.

Knocking over: Knocking over is one of functions of sinkers. It supports the old loop as the new loop is drawn though it.

Latch needle: It has a latch or swinging fingers that closes into the hook of needle as it pulls the yarn through a loop to form a new loop.

Linking: Linking is a process of joining side seams or edges of a piece of fabrics together with a row of knitting on a linking machine.

Loop transference: Loop transference is the process that moves stitches from the needles on which they were made to other needles for the purpose of shaping or design.

Mass customization: It is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology.

Miss stitch: A knitting cycle where a needle or needles do not take a yarn and produce a float loop either intentionally or as the result of knitting fault.

Multiple-gauge knitting: Multiple-gauge knitting is a number of different gauges can be knitted in a single course.

Productivity: Machine productivity is expressed in pattern rows per minutes.

Racking: Racking is the lateral movement of a needle bed or point bar across a predetermined distance on a flat knitting machine.

Rib gating: The alternate alignment of one set of needles with the other on a machine equipped with two sets of needles arranged to knit rib fabrics.



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Sinker: Sinker helps loop formation, holding-down, and knocking-over on a machine.

Slide needle: A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove.

Take down rollers: Take down rollers are required in order that the previous loop which is located in the hook enclosure is prevented from the riding up with ascending needle.

Tubular knitting: Tubular knitting is created on both needle beds but front and back bed knitting are done alternately.

Warp knitting: Warp knitting is composed of loops formed in a vertical direction.

Weft knitting: Weft knitting is composed of loops formed in a horizontal direction.

Welt: Welt in knitting is a secure edge of a fabric. The welts are usually at the starting end of the fabric.

Yarn carrier (feeder): The yarn coming from a single yarn feeder is feeding the needle in a sequential order and by doing so connects the adjacent loops into a course.

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*Volume 4, Issue 3, Spring 2005*

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## *Refereed Articles*

**Size-specific Analysis of Body Scan Data to Improve Apparel Fit**

**Suzanne Loker, Susan Ashdown, and Katherine Schoenfelder**
**Cornell University, Department of Textiles and Apparel**
**326 MVR, Cornell University, Ithaca, NY 14853**

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Complete Article

**ABSTRACT**

This paper describes how size-specific analyses of body scan data of an apparel company's target market can provide information that can be used to adjust ready-to-wear sizing to improve apparel fit. We describe a variety of size-based statistical and visual analysis methods that can be applied to target market body scan data. These analyses begin to describe and address the variety of body shapes and measurements that exist within a sizing system and identify potential design adjustments that could be made in order to increase the percent of acceptable fit within each size category for a target market.

KEYWORDS: apparel, body scan, fit, sizing system

**THREE DIMENSIONAL SEAMLESS GARMENT KNITTING ON V-BED FLAT KNITTING MACHINES**

**Wonseok Choi, Ph. D. Student**
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Preview First Page

Complete Article

**ABSTRACT**

Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial

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application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.

The purpose of this research is to review the principles of seamless knitting on V-bed machines and to compare the machines from two major flat-knitting machine suppliers, Shima Seiki and Stoll. This paper will also discuss characteristics and applications of complete garment knitting in various products. This research was accomplished through interviews and a review of the literature. It has implications for academicians and industrial personnel who require information in three dimensional knitting technology and related machinery.

KEYWORDS: Knitting, tubular, seamless, complete garment

**Behavior of Prepared-For-Print Fabrics in Digital Printing**

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Preview First Page

Complete Article

**ABSTRACT**

Engineered print design for sewn products can reduce material waste and facilitate customized design of textile products. But, digital printing systems must produce output reliably and consistently for integration into a production process. This study examined changes in dimension and grain alignment of digitally printed and post-treated prepared-for-print (PFP) cotton fabric. Following post-treatment, substantial shrinkage and some skewing of the printed design was found. Furthermore, dimensional change results from one fabric were not predictive of results for a second fabric. These performance concerns impact end product quality and adaptability to the production environment. Future work should focus on delineating an optimum set of pretreatment conditions for PFP fabrics that will result in proper grain orientation and minimal, predictable shrinkage.

KEYWORDS: Digital textile printing, Print Design, Engineered Print, Ink jet printing, Prepared-for-print Fabric, Printing Quality

**TAKING ADVANTAGE OF THE DESIGN POTENTIAL OF DIGITAL PRINTING TECHNOLOGY FOR APPAREL**

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Complete Article

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**ABSTRACT**

The integration of digital technologies into apparel forms allows designers to explore and visualize new creative possibilities. How the technology is used and how design concepts are perceived in the industry are areas of crucial importance to the technology's longevity. Our goal, as collaborative artists, focuses on integrating technology into the creative process to create both art and industry-oriented apparel. The applications of digital textile and apparel design have implications for many areas of the industry, but we have focused on three: art-to-wear, custom design, and mass customizable products. The body of research and artwork that we have developed suggests that a systematic approach to integrating new technologies into the textile and apparel design process can be developed, recorded and employed in future design explorations to inspire the most rapid technology integration with the greatest potential for new product conceptualization.

KEYWORDS: Digital textile printing, apparel design, design process, art-to-wear

**Expanding Garment Functionality through Embedded Electronic Technology**

**Lucy E. Dunne[1], Susan P. Ashdown[2], Barry Smyth1**

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**ABSTRACT**

Electronic technology offers exciting new possibilities for functional clothing design. Technology allows a garment's functionality to become dynamically adaptable, changing in response to environmental or situational changes. However, there are many challenges to integrating electronic technology into a textile-based garment structure. This paper outlines some of the possibilities and challenges to apparel designers in this new field, and highlights the importance of the apparel design perspective in the successful design of wearable technology.

KEYWORDS: Wearable technology, smart clothing, wearable computing, functional clothing, apparel design

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**FIT ANALYSIS OF LIQUID COOLED VEST PROTOTYPES USING 3D BODY SCANNING TECHNOLOGY**

**JinHe Nam, Ph.D. Student/Graduate Research Associate**
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**Semra Peksoz and Dr. Cheryl Farr**
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Complete Article

**Dr. Susan Ashdown**
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**ABSTRACT**

First responders are frequently exposed to hazardous materials and hostile environments that necessitate wearing specially devised personal protective equipment (PPE). Personal cooling garments play an important role in reducing thermal stress associated with wearing insulative and impermeable PPE. As conduction is the primary cooling mechanism for liquid cooled garments (LCGs), there is need for intimate contact between the skin and garment. The fit of two liquid cooled vests was compared and analyzed through use of a3D body scanner. Visual images from thirteen volunteer subjects, primarily first responders and life safety specialists, were used to evaluate the fit of both cooling vest prototypes. Perceptual data from the subjects provided user feedback on the prototype vests. The results indicated that both prototypes received high scores in the expert fit ratings although prototype II received higher ratings in many body areas. Ratings from the subjects' perceived fit ballot also indicated that prototype II was rated higher although both vests received high marks.

KEYWORDS: 3D body scanning, anthropometric data, cooling garment, LCGs, cooling vest, liquid cooled vest, fit analysis

**Understanding Aesthetic Preference:**
**Approaches Toward Improved Product Development**

Preview First Page

Complete Article

**Janet Hethorn**
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**ABSTRACT**

Every garment has a visual presence and every garment provides physical qualities in relationship with the body. In the design process, both functional and aesthetic attributes contribute to the overall success of the complete apparel system for the consumer. New developments in technology and materials have generated interesting applications toward this goal through functional design research. Research on aesthetic preference – consumer visual response and desire- is also taking advantage of these opportunities. This paper highlights the possibilities and the roadblocks present in exploring aesthetic issues, in combination with other factors in the design process. Several examples are provided of design research on aesthetic preference and new possibilities are suggested that take advantage of emerging technology directions.

KEYWORDS: aesthetic preference, visual style, appearance, design process

**BIOMECHANICAL ANALYSIS OF A PROTOTYPE SPORTS BRA**

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Complete Article

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**ABSTRACT**

A Latin Square Experimental Design was used to compare a prototype sports bra previously developed for large-busted women, with two other sports bras through a controlled laboratory wear study. Vertical breast displacement data were gathered by videotaping the first three running strides of six large busted active females recruited from local fitness centers. Multiple regression results found that the garment treatment significantly related to the breast displacement experienced by subjects during each test session [F (2,213) = 16.393; p< .0001]. Approximately 13% of the variability in breast displacement was predicted by garment, indicated by the Squared Multiple Correlation Coefficient. ANOVA results found significant subject, garment, and subject-by-garment effects. Subjects wearing garments A and B had a lower level of vertical breast displacement of .031" as compared to subjects wearing garment C with .045" of displacement.

KEYWORDS: biomechanical research, sports bras, brassieres, vertical breast displacement, breast discomfort, female exercise, and human motion.

**Fabric Drape Measurement: A Modified Method Using Digital Image Processing**

Preview First Page

Complete Article

**Narahari Kenkare and Traci May- Plumlee**
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**North Carolina State University,**
**Raleigh, N.C. 27695**

**ABSTRACT**

The textile and clothing industry has traditionally used Cusick Drapemeter for the assessment of fabric drape. In this paper, a modified method of measuring fabric drape using the Cusick Drapemeter was demonstrated. The modified method involves digitally capturing image and processing it in simple steps using image processing software. The study was conducted using a range of woven fabric samples. The fabrics were conventionally evaluated using the Cusick Drapemeter (British Standard Institute: BS5058, 1974). Digital images of the draped fabrics were captured and processed as well using the modified method. Drape coefficient was selected to use as the comparative parameter to evaluate the results from conventional and digital method. The average drape coefficient of each fabric sample obtained through the conventional cut-and-weigh technique was compared statistically with that obtained through the modified digital technique. The study demonstrates that results of the modified digital method for evaluating drape were similar to that of conventional method of drape evaluation.

KEYWORDS: Fabric Drape, Cusick Drapemeter, Testing Instruments, Textile Measurement

**The Critical Success Factors of Sourcing Production for Small and Medium-sized Clothing Firms in Hong Kong**

Preview First Page

Complete Article

**Fung-yi Tam, Ka-leung Moon, Sau-fun Ng, Chi-leung Hui**
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**ABSTRACT**

The main purpose of this paper is to identify the critical success factors (CSFs) of sourcing production, and to study the impacts of production sourcing strategies, buyer supplier relationships and firm-related characteristics on the level of satisfaction with sourcing performance. Using a multiple case methodology

to study ten firms and a two-phase data collection approach, in-depth interviews and mail questionnaires, we found that the industrial sector is the only firm-related characteristic that has an influence on sourcing performance satisfaction. Also, the firms that have adopted insourcing were more satisfied with their sourcing performance than those that adopted outsourcing. Based on the level of satisfaction with a firm's sourcing performance, we identified three main CSFs for production sourcing: (1) to build relationships with production provider personnel at all levels, (2) to develop a comprehensive communication plan with production providers; and (3) to choose the production providers carefully.

KEYWORDS: Small and medium-sized enterprises (SMEs); production sourcing strategy; critical success factors (CSFs); performance satisfaction; buyer-supplier relationship

## Scholarly Works

**An Analysis of Apparel Industry Fit Sessions**

**Elizabeth Bye and Karen LaBat**
**University of Minnesota, F240 McNeal Hall**
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Preview First Page

Complete Article

**ABSTRACT**

The fit session is the main point of evaluation for a garment during the product development process. This paper presents an analysis of the perceptions and practices of apparel industry professionals regarding best practices and areas for improvement for fit sessions. Participants from a large manufacturer of athletic apparel, including designers, merchandisers, product development managers, and pattern makers a responded to a survey. Their responses suggest that fit sessions encompass product development decisions that extend beyond the fit of the garment. The evaluation of the design is of equal importance. Recommendations are made to address the organization and communication of industry fit sessions with suggestions for using new technology to improve garment fit.

KEYWORDS: fit, fit session, sizing, apparel

**Branding to Compete: Applications to Textiles and Apparel**

**Shanna M. Bruer, Ph.D. Student**
**Nancy Cassill, Professor**
**Michelle Jones, Assistant Professor**
**NCSU**

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Complete Article

**ABSTRACT**

Purpose: The objective of this paper is to briefly review competitive strategies that are relevant to the U.S. textile and apparel industry, focusing specifically on differentiation and branding methods. The various approaches and strategies are then applied through specific examples and illustrations.

Methodology: A comprehensive review of secondary data sources, both research and trade combined with primary data sources (via industry interviews) are reviewed. Results are presented as the differentiation typology proposed by Barney (2002).

Findings: Numerous competitive strategies can aid textile and apparel firms in preserving and/or improving their current market position. A specific strategy used, branding, aids in the differentiation of product throughout both the textile and apparel industry.

Practical Implications: The compilation of literature on differentiation and branding will be useful in further research and studies that focus on textiles and apparel or those that are concerned with product differentiation. Direct applications to both textile and apparel firms are made and a potential structures by which they may develop brands is introduced.

Value of Paper: The paper will aid both academia and industry in the development of textile and apparel brands through the introduction of literature on the topic, as well as recommendations on brand strategy and creation.

KEYWORDS: Competitive strategies, Differentiation, Branding, Private label, Textile and apparel industry

**Clothing Branding Strategies: Influence of Brand Personality on Advertising Response**

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Complete Article

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**Minoo Farhangmehr**
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**ABSTRACT**

This paper examines the influence of brand personality on advertising response in fashion clothing branding context. Print ad stimuli of 30 fashion clothing brands with different nationalities and different expected personalities were evaluated by young students (16-25 years old) in terms of Brand Personality Scale of Aaker (1997). The self-congruence implications are discussed. From the brand builder perspective, some benchmarks brands were identified. The results should help the understanding of antecedents and consequences of brand personality processing.

KEYWORDS: Brand personality, fashion clothing branding, advertising, self-congruence, youth market.

**Sustainable Development: Building a Case for Hemp**

Preview First Page

Complete Article

**Tun Lin, M.A., Graduate Student**
**University of Cambridge**

**Catherine Chan-Halbrendt, Ph.D., Professor of the Department of Natural Resources and Environmental Management, The University of Hawaii**
**College of Tropical Agriculture and Human Resources**

**Pauline Sullivan (contact person), Ph.D., Associate Professor**

**Florida State University, College of Human Sciences**
**Department of Textiles and Consumer Sciences**
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**ABSTRACT**

Objectives of this paper are to discuss hemp within the context of sustainable development and examine the economic impact of establishing a hemp sector in rural U.S. locations. This study focuses on the textile industry and examines the interlinking industry impacts from hemp production, fiber processing, and apparel manufacturing. First this paper discusses hemp cultivation in terms of sustainable development, secondly we identify its performance attributes, thirdly we talk about the market for hemp products, fourthly we describe the manufacturing and processing of hemp, and then we describe our input-output model, its analysis of a hemp sector, and research findings. Establishing one hemp apparel manufacturing firm and processing plant appears to be comparable to establishing one cotton apparel manufacturing firm and processing plant in terms of total industry output and employment based on the assumptions of the study.

KEYWORDS: Hemp sector, textile industry, economic impact, sustainable development

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# THREE DIMENSIONAL SEAMLESS GARMENT KNITTING ON V-BED FLAT KNITTING MACHINES

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## ABSTRACT

*Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.*

*The purpose of this research is to review the principles of seamless knitting on V-bed machines and to compare the machines from two major flat-knitting machine suppliers, Shima Seiki and Stoll. This paper will also discuss characteristics and applications of complete garment knitting in various products. This research was accomplished through interviews and a review of the literature. It has implications for academicians and industrial personnel who require information in three dimensional knitting technology and related machinery.*

*Keywords: Knitting, tubular, seamless, complete garment*

## 1. INTRODUCTION

Seamless knitting technology creates one entire complete garment with minimal or no cutting and sewing process. This innovative technology eliminates post labor work, which saves production time and cost. In addition, the technology offers knitwear consumers more comfort and better fit by eliminating seams. Thus, seamless technology provides benefits to manufacturers as well as end users. Seamless knitting technology has entered the mainstream in the knitwear market.

Through this research, principles of seamless knitting techniques are discussed, and two major suppliers for V-bed machines, Shima Seiki and Stoll, and machine characteristics will be introduced. In addition, advantages and disadvantages of this type of production are revealed. In order to understand the seamless knitting technology, it is important to review the fundamentals of the knitting process. By a review of the evolution of the knitting process, an explanation of knitting methods, and the description of knitting machines' characteristics, the distinctiveness of seamless knitting will be better understood.



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## ABSTRACT

*Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.*

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This research was achieved through a review of the literature and additional primary data was collected through interviews, company visits, etc.

### 1.1. Knitting Fundamentals

To fully examine the developments in seamless knitting, a basic foundation of knitting construction and characteristics should be discussed. Knitting is defined as "the process of forming a fabric by the intermeshing of loops of yarn" [22] and knitting accounts for more than 30% of total fabric production [24]. The end use of knitted fabrics, created either in tubular or flat form, can be apparel and other products including sweaters, underwear, hosiery, socks and stockings.

Knitting is classified into two fields, weft knitting and warp knitting. In weft knitting, loops are formed in a horizontal direction whereas in warp knitting, loops are formed in a vertical direction [1] (Figure 1.1a and 1.1b). Weft knitting is more resilient, more open and has additional design possibilities as compared to warp knitting. Conversely, warp knitting has less resilience, more cover, lighter weight and higher productivity. Weft knitting can be divided into circular knitting and flat knitting according to type of fabric, type of needle, and form of needle bed. In the circular knitting machine, needles are set radically or parallel in one or more circular beds [3]. On the other hand, a flat knitting machine employs straight needle beds carrying independently operated needles, which are usually of the latch type [3].

Compared to flat knitting machines, circular weft knitting machines provide higher productivity. Thus, circular knitting machines have more rapid production speeds than weft knit flat bed machines. However, flat knitting machines have greater versatility in loop structure combinations and patterning because their machine cams can be changed after every course (even after every stitch), and they are able to knit one or both beds easily [52]. It should also be noted that electronic circular machines have the same capability.

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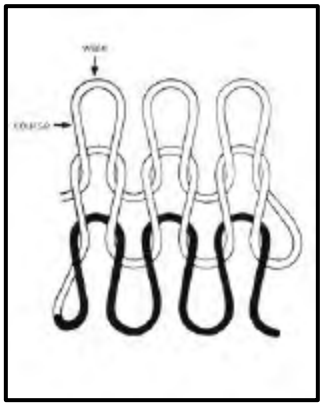



*Figure1.1a. Weft knitting*

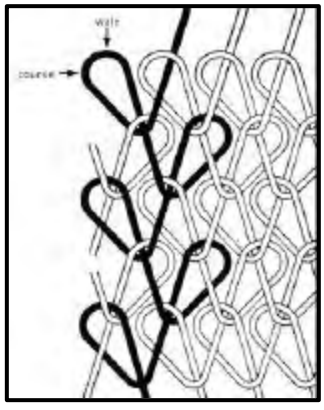



*Figure 1.1b. Warp knitting* (Black, 2002



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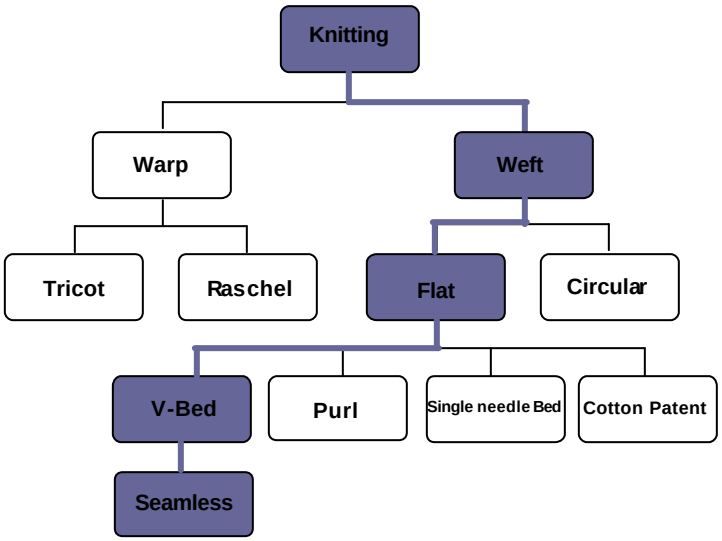



*Figure 1.1c. Knitting Classification Diagram*

Spencer defines cams as "the devices which convert the rotary machine drive into suitable reciprocating action for the needles" [42]. Figure 1.1d shows the knitting action of latch needles for the cam track on a V-bed knitting machine. According to the position of needle butts moving up and down through the cam system, the loop can be formed sequentially [34].

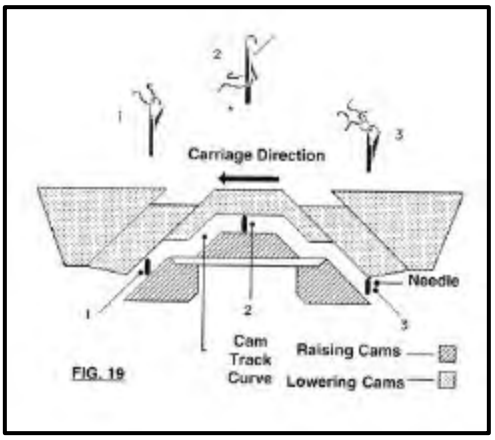



*Figure 1.1d. Knitting action of latch needle though cam track*
(Raz, 1991)

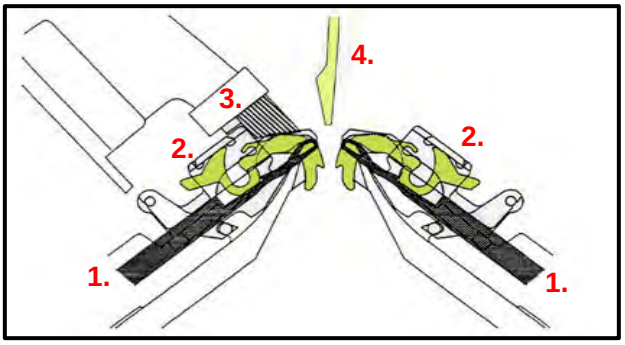
Figures 1.1e and 1.1f illustrate the basic knitting machine parts on a flat bed machine including a carriage, latch needles, sinkers, brushes, yarn carriers and take down rollers. A carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam [34].

The latch needle, the most widely used needle in weft knitting, is mainly composed of a needle hook, a latch, and a needle stem (Figure 1.1g). The major advantage of the latch needle is that it self acts or controls the loop so that individual movement and control of the needle permits loop selection to be accomplished [42]. The sinker is another primary element in knitting. Main purposes of the sinkers are loop formation, holding down, and knocking-over [42]. However, the role of sinkers on a V-bed knitting machine with latch needles is chiefly a holding-down function. Therefore, holding down sinkers are capable of tighter fabric structures with an improved appearance. The purpose of the brushes is to open the latches at the first course when the machine starts to knit and to avoid any closing of the latches [21]. The yarn carrier or yarn feeder is pulled along the needle bed by the carriage and introduces and feeds yarns required for knitting. The yarn carrier is assembled on a dovetail-profiled rail [34]. Take down rollers are needed to prevent the previous loop, which is located in the hook enclosure, from riding up with the needle ascension. This is very crucial for loop formation because without take down tension the previous loop will not slide under the latches and new loops will not be formed without the operation of the take down rollers [34].

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1. Latch needles
2. Sinkers
3. Brushes
4. Yarn Carrier (Feeder)

*Figure 1.1e. Knitting machine system on flat V-bed machine* (Shima Seiki Manual [37])

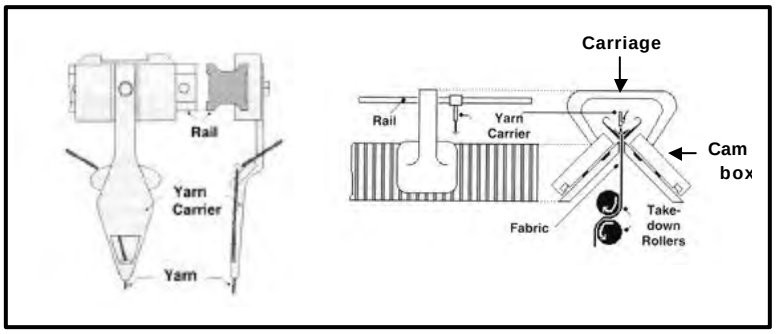



*Figure 1.1f. Yarn Carriers, Carriage and Take-down Rollers* (Raz, 1991)

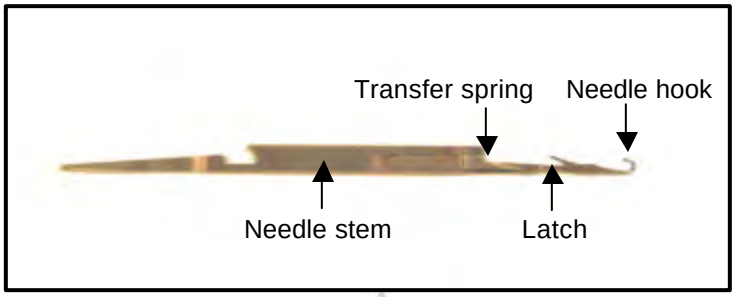



*Figure 1.1g. Latch needle on Shima Seiki Machine*

Flat bed machines have four different classes; (i) *V-bed flat machines* which have two inverted V-formed needle beds; (ii) *Purl machines* which have double ended needles; (iii) machines that have *a single bed* of needles which include most domestic models and a few hand manipulated intarsia machines [40]; and (iv) *Cotton patent machines* which are single-bed machines with bearded needles arranged vertically [1]. Bearded needles are the needles having an extended terminal hook or beard that can be flexed to close the hook [22].

## 1.2. Historical Events Contributing to the Development of Seamless Knitting

In the evolution of seamless knitting it is important to review the developments in knitting that directly affect three-dimensional knitting techniques. Kadolph and Langford [12] explain that historical remnants of knit fabrics have been dated from A.D. 250 in the Palestine area. Knitting was accomplished by a hand process until 1589, when William Lee in England invented a flat-bed weft-knitting frame to create hosiery [12]. The first operational V-bed flat knitting machine using latch needles was invented in 1863 by



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Issac W. Lamb [34]. William Cotton of Loughborough took out a patent in 1864 for his rotary-driven machine that used a flat bed to produce fully-fashioned garments [16]. According to Hunter [9], in the 1800's, the flat knitting machine was fitted with sinkers, which controlled loops in order to knit single jersey tubular articles such as gloves, socks and berets. In 1940, the manufacture of shaped knitted skirts was patented in the USA. This permitted darting on knitted skirts using a technique called "flechage" (See glossary). The flechage technique not only improved drape and fit, but cut production cost. In 1955, the Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaping of components. In the 1960's, the Shima Seiki company further explored the tubular-type knitting principle commercially to produce gloves. Also, in the mid1960's, engineers at Courtaulds in the UK established British patents on the idea of producing garments by joining tube knitting. However, the method was too advanced to be commercialized at that time. By 1995, Shima Seiki fully developed shaped seamless knitting [9]. Recently, by employing more advanced computerized systems, simpler programming was possible, and the computerized systems enabled the production of more complicated and sophisticated knitted structures and products. Table 1 introduces the historical events of seamless knitting.

| Year | Historical Events Contributing to Development of Seamless Knitting |
|---|---|
| 1589 | William Lee in England invented the first flat-bed frame to create hosiery. |
| 1863 | Issac W. Lamb invented the first operational V-bed flat knitting machine including the latch needles. |
| 1864 | William Cotton of Loughborough patented his rotary-driven machine that used a flat bed to produce fully-fashioned garments |
| 1800's | The flat knitting machine was fitted with sinkers, which controlled stitches in order to knit single jersey tubular articles such as gloves, socks and berets. |
| 1940 | The manufacture of shaped knitted skirts using a "flechage" technique was patented in the USA. |
| 1955 | The Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaped sections. |
| 1960's | Shima Seiki company further explored the tubular-type knitting principle to produce gloves commercially. |
| 1960's | Courtaulds established British patents on the idea of producing garments by joining tube knitting. |
| 1995 | Shima Seiki introduced seamless entire garment knitting at ITMA. |

*Table 1. Historical Events Contributing to Development of Seamless Knitting*

Seamless entire garment knitting was introduced in 1995, at ITMA, the International Textile Machinery Association [24]. Seamless knitting, or complete knitting, which produces one entire complete garment without a sewing or linking process, provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages. In Section 2, numerous advantages of seamless garment knitting are discussed.


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## 2. ADVANTAGES OF SEAMLESS GARMENT KNITTING

In general, V-bed knitting process has more flexible needle selection capability and more design possibilities compared to warp knitting process [2]. Through computerized flat bed knitting, more variety of knit patterns and structures can be created and designs can be instantly and efficiently changed through a computer-aided design system. Furthermore, seamless garment knitting makes it possible not only to create several types of tubular formed knitting but also to build diverse design structures on the tubular knitted garments simultaneously.

Complete garment knitting offers a variety of benefits in technical aspects as well as in the market demands. For benefits to the market, quick-response production and just-in-time production are possible. The required number of products can be quickly knitted in less time to meet the needs of the market. It also enables mass customization for many markets. Onal states "Mass customization is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology" [29]. In certain markets, seamless knitting could be considered for mass customization by rapid design changes according to customers' requirements through computerized knitting systems. Seamless knitting systems may be utilized for sampling prototype and for niche market limited production items.

For the focus of this paper, the benefits of seamless technology are mainly discussed. First, there is no longer the traditional labor-intensive cutting and sewing process because of eliminating seam production. Hence, the tubular-typed seamless knitting results in potential savings in terms of production time and cost. For instance, according to Melliand International, in the case of a complete woman's knit sweater, a time saving of about 35% can be achieved with seamless knitting [20]. Additionally, yarn consumption can be minimized by complete garment knitting as well as by effectively analyzing yarn feed through the computerized system on the machine [7]. The DSCS (Digital Stitch Control System) on Shima Seiki machine predetermines how much yarn is required for the each stitch. Loop size can be controlled accordingly and there is much less stress on the yarn at the sinker. According to Mowbray, this device not only permits a variety of types of yarns to be used but also offers maximum production efficiency because higher speeds can be achieved [26]. The range of gauges for complete garment machines varies from 5 gauge to 18 gauge. Seamless garment knitting technology adds flexibility through gauge conversion and multi-gauge knitting [20]. The capability of multi-gauge application allows the conversion of gauges in the same machine. As a result, it saves time and cost for investing in different machines for every gauge.

In garments, three-dimensional knitting is purported to give lightness and softness in knitwear because there is no linking and sewing production [39]. In addition, there are no bulky and annoying stitches at the underarm points, shoulders and neck lines [39]. For finished edges, the garment can have better trimmed edge lines through a machine binding-off process instead of a sewing or linking operation.

In decreasing the number of production processes such as the cutting or sewing steps, the risk of defects and damages can also be minimized. A single entire piece production method is claimed to provide more consistent product quality [20]. Consequently, seamless knitwear is promoted to look better, fit better and is believed to be much more comfortable than a traditional fully-fashioned piece of knitwear. Seamless knitting also allows knit designers to create design structures and patterns across the entire garment. Designers can easily program and style both more sophisticated design structures and shaped patterns through the computerized design system.


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Finally, in the global environment, according to Shima, seamless garment knitting puts less stress on the environment by minimizing waste disposal and reducing the need to grow as much as cotton, wool and other natural raw materials [26].

## 3. TECHNICAL ISSUES

Although seamless garment knitting technology provides a variety of advantages for the knitting industry, it still has several technical issues to be considered. The main problem in complete garment knitting has been fabric take-down [10]. To keep equal tension of each loop (i.e., stitch), diverse sinker systems and take-down tension systems have been utilized. Finally, the novel sinker systems such as a spring-type moveable sinker system and a computerized take-down tension system, appropriate to complete garment knitting, have been developed to solve the problem. Even though the systems have brought higher stability for knitting, there is the opinion of users that it still is not easy to control an exact take-down tension for the complete garment.

Complete garment knitting also has a problem caused by the alternate needle selection. The alternate needle selection knitting makes fabrics more open and less elastic than conventional fully-fashioned garments [27]. This problem occurs in the welt or the cuff areas. A welt in knitting means "a secure edge of a fabric. The welts are usually at the starting end of the fabric" [22]. To solve the looser fabric problem, it is critical to select appropriate yarns for the machine gauge; and in this context, elastic, flexible and durable yarns are recommended such as wool. For instance, a Yorkshire spinning company in the UK uses the elastic Spirol® lamb-wool on the cuffs and the collars, which can be knitted tighter like a fully-fashioned product [27]. In the current global knitting industry, natural fibers, such as wool, cashmere and angora, and manufactured fiber such as acrylic are mainly used to create seamless garments for outerwear [11]. Viscose and polyamide with Lycra® or other elastomerics are also utilized for complete garment knitting [11]. Cotton is also a popular fiber used in seamless apparel.

Another issue for complete garment knitting is that if the garment has a defect during knitting such as a hole or a barre' problem, the entire garment is useless and must be discarded. Pratt explains "Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric" [32]. Compared to fully-fashioned knitting, there would be more waste when the complete knitted garment has any defect. In cut and sewn production pattern pieces could be placed for cutting on a flat piece of fabric to avoid any defects.

## 4. APPLICATIONS OF SEAMLESS KNITTING

Seamless garment knitting on the V-bed machine has primarily been used for apparel. However, in recent years, this new three-dimensional knitting technique has been extended in other areas such as fashion, upholstery, industrial, automotive, and medical textiles.

### 4.1. Apparel (Figure 4.1)

A diverse range of seam-free products can be created such as hand gloves, hats, socks, and sweaters according to the machine gauge and types of machine. Additionally, patterns for knitted trousers and skirts are available on the complete knitting machines. As far as design structures, most knit structures knitted on fully-fashioned machines can be created on the seamless garment machines such as cable stitches and even intarsia structures.
(See glossary for structures.) [33]

### 4.2. Upholstery (Figure 4.2)

Several upholstery companies are utilizing three-dimensional seamless seat upholstery production. The Teknit Company offers three-dimensional knit upholstery for the office chair market. Teknit creates shaped three-dimensional polyester seat covers that compete against woven fabric, which


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requires a cutting and sewing process [43]. According to Teknit, lead times are substantially lower than conventional woven fabric and the office chairs covered with seamless knitted fabric are their fastest selling line. The company also has the capability of promoting rapid design changes by using sophisticated CAD systems [46]. Additionally, seamless shaped knitting with its inherent stretch characteristics follows the contours of the seat, providing better seat trimming [46]. It enhances appearance and enables users to feel more comfortable by eliminating ridges caused by a sewing or a linking process.

### 4.3. Automotives

Courtaulds and General Motors Corporation developed the three-dimensional knitting technique to produce seat covers in 1985 [40]. Marjorie Sorge proposed that automotive seat covers made by seamless knitting also provide great potential for the automotive market in that the three dimensional knitting process cuts lead time by eliminating cut-and-sew operations, brings down warranty costs and adds quality [40]. Lear Corporation which owns patents on three-dimensional knitting technologies claimed the ability to design new seats using a predictive computer model which reduced the time needed for seat design by 25% [31]. Seamless knitting for automotive also provides a potential for designing a more ergonomic seat through the ability to alter the knitted tube size.

### 4.4. Medical textiles

Recently, specialty textiles created by three-dimensional flat bed knitting machines have also been applied to medical textiles. Tubular typed knitted structures such as bandages, orthopedic supports, and medical compression stockings have been developed. In the future, it is expected that more advanced and sophisticated medical textiles created by seamless knitting technology would be produced. The incorporation of high performance fibers and additional sensors or electronics could provide further opportunities for seamless products in healthcare applications.

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*Figure 4.1. Seam free garment created on Shima Seiki WholeGarment® Machine* (Shima Seiki, 2003)



*Figure 4.2. Claud 9™ Chair created by NeutralPosture®* (*NeutralPosture, 2004*)



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Each of these market applications has specific performance requirements and specialized aesthetics. In order to use this technology to fulfill these market needs, the principles of knitting and knitwear production, and the evolution of seamless knitting need to be reviewed.

## 5. EVOLUTION OF THE KNITTING PROCESS FROM CUT AND SEWN PRODUCTION TO SEAMLESS GARMENT KNITTING

As described in Table 1, the knitting industry has gradually developed since William Lee of Calverton successfully converted the actions of hand knitting with two needles into a mechanical process. Lee's work was the first attempt at mechanizing hosiery knitting in 1589 [16]. Since the invention of the frame-knitting machine, knitting technology has progressed from hand flat machines to complete garment-knitting machines. Section 5.1, 5.2, and 5.3 will explain the evolution of the knitwear process from cut-and-sew production to seamless knitting.

### 5.1. Cut and Sew Production

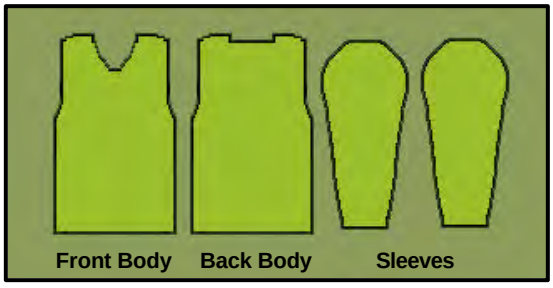



*Figure 5.1. Cut and sew production*
(Shaded area: Cutting Waste)

Cut and sew production is created by the use of one entire panel of fabric. Figure 5.1 shows the cutting layout for the front and rear body portions and also the sleeve portions required to create a sweater. Through the cutting and sewing process, the finished garment is created. However, this garment production process requires several post-knitting processes including cutting and sewing. Additionally, in this process, separately knitted trimmings and pockets need stitching. The Shima Seiki Company explains that with cut and sew production, up to 40% of the original fabric can be waste [39].

### 5.2. Fully-Fashioning

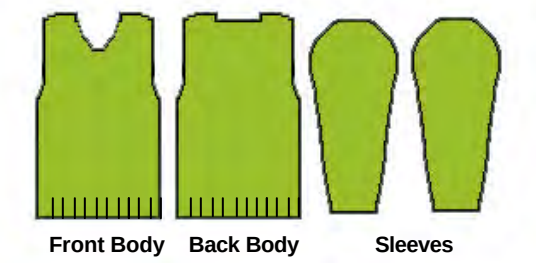
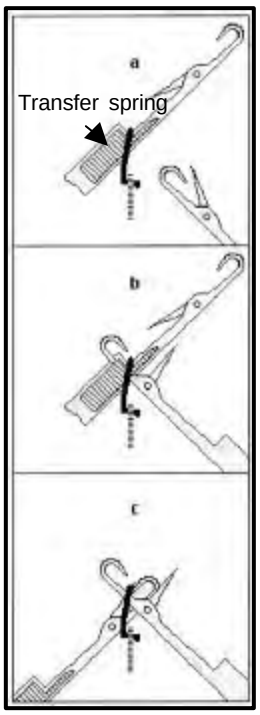



*Figure 5.2. Fully-fashioning production*

Fully-fashioned knitting means "shaped wholly or in part by widening or narrowing of piece of fabric by loop transference in order to increase or decrease of the number of wales" [3]. Thus, as the number of loops are increased or decreased, the fabric can get shaped areas as seen in Figure 5.2. To achieve fully-fashioned knitting, loop transference is necessary. The loop transference is the process that moves stitches (i.e., loops) from the needles on which they were made to other needles [49]. Figure 5.2a illustrates the mechanism of loop transference on a V-bed flat knitting machine.

In addition, the following stitch notation (Figure 5.2.1) describes how widening or narrowing occurs by loop transference on fully-fashioned machines. The fully-fashioning process allows the separate creation of shaped front and back body parts and sleeve parts by increasing or decreasing the number of loops (Figure 5.2); this eliminates the cutting operation. However, because all parts of the garment are knitted separately, the fully-fashioned knitting still requires a post sewing or linking process. Linking is defined as a process of joining side seams or edges of fabric pieces together with a row of knitting on a linking machine [19].


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a. The delivering needle is raised by a cam in the carriage. The loop is stretched over the transfer spring.

b. The receiving needle is raised slightly from its needle bed. The receiving needle enters the transfer spring of delivering needle and penetrates the loop that will be transferred.

c. The delivering needle retreats leaving the loop on the receiving needle. The transfer spring opens to permits the receiving needle to move back from its closure. Finally, loop transference is completed.

*Figure 5.2a. the mechanism of loop transference on V-bed flat knitting machine* (Raz, 1991)

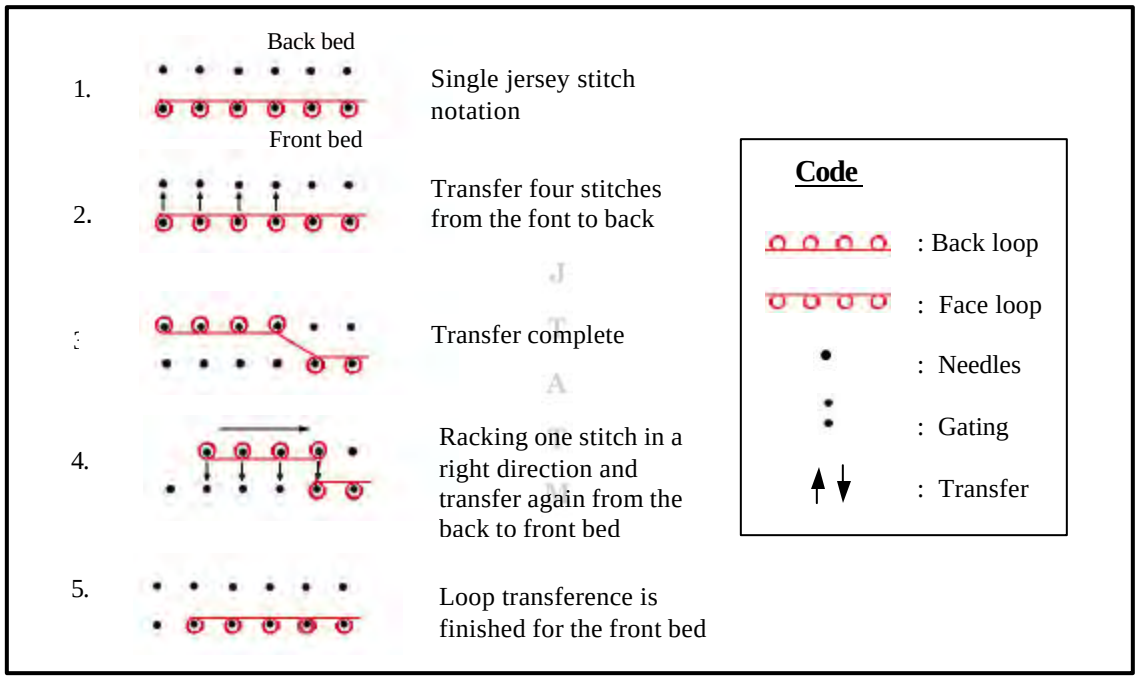



*Figure 5.2.1. Narrowing process by loop transference on flat V-bed machine*


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### 5.3. Seamless garment knitting



*Figure 5.3. Complete garment production by a seamless flat knitting machine*

"Seamless" garment knitting creates a complete garment by several different carriers (feeders) with minimal or no cutting and sewing processes (Figure 5.3). Thus, seamless knitting has the capability for production time and cost saving by removing post-knit processes such as the linking or sewing and cutting operation [39].

It also minimizes yarn consumption by reducing the cutting waste and can achieve higher productivity. Machine productivity in knitting is expressed in pattern rows per minute [41]. Complete garment knitting can be achieved either on a circular knitting machine or a flat (V-bed) knitting machine. However, seamless circular knitting machines are different from seamless flat knitting machines in that circular machines such as the Santoni create only a single tubular type of garment. Seamless flat knitting machines such as the Shima can create more than one knitted tube at the same time, and the tubes are joined together on the machine (Figure 5.3a). The complete garments knitted on circular machines may also need minimal cutting as seen in Figure 5.3a. In addition, the complete garments created by circular knitting machines still require minimal seam joining on one body tube and two sleeve tubes as well as the finished edges. Santoni has recently introduced the SM4 TL2 machine, which shapes the knitted tube and will eliminate the cutting process [35]. Consequently, seamless knitting on circular machines is not true seamless knitting.

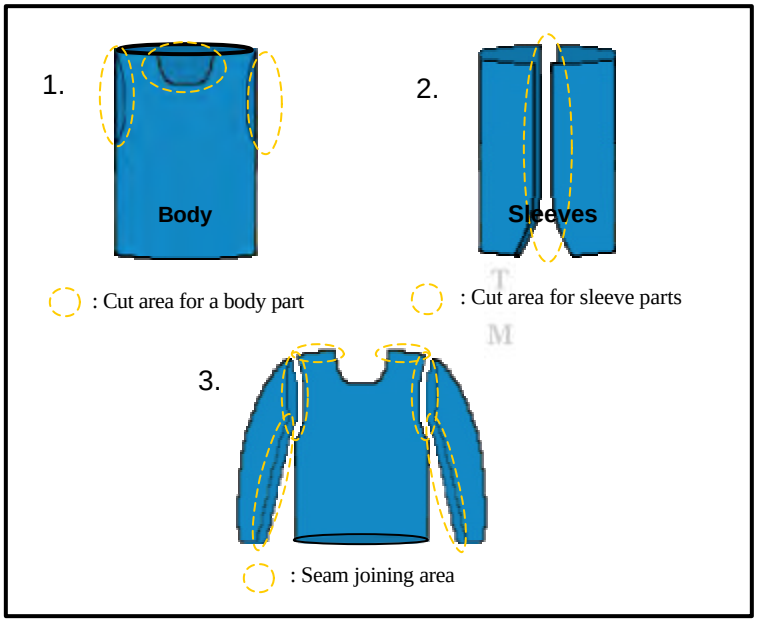



Figure 5.3a. *Complete garment production by a seamless circular knitting machine*



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In recent years, several companies have developed seamless or complete garment machines such as Santoni, Sangiacomo, and Orizio Santoni, part of the Lonati Group, is the biggest supplier of the circular knitting machinery. Lonati has recently acquired Sangiacomo, and its expanded seamless circular knitting technology is in the forefront of the industry. Santoni, whose customers include Nike, Adidas, Sara Lee et cetera [30], offers 14 different models of circular knitting machines, from 7 to 32 gauge. The machines produce swimwear, sportswear, outerwear, underwear et cetera. [35].

However, in the strict sense of the word, seamless flat V-bed knitting actually creates complete garments, which do not require any kind of cutting or sewing process. For Section 6, the knitting method of multi-tubular knitting techniques created on a V-bed knitting machine will be discussed.

## 6. V-BED MACHINE KNITTING OF SEAMLESS GARMENTS

As mentioned earlier, seamless garments on a flat V-bed machine can be created in three separate tubular forms by knitting one wider tube for the body part and two narrower tubes for the sleeve parts. Tubular knitting is created on both needle beds but front and back bed knitting are done alternately [23]. The continuously alternate knitting of all needles on front and back needle beds creates a single plain tube. Tubular type knitting is not a new technique. Since the 1800's, single jersey tubes have been produced on flat machines [8]. However, seamless garment knitting can be seen as a more advanced technique in that it can connect the three tubes together to create a sweater [6] and has the capability to increase and decrease the dimensions of the tubes [44]. Moreover, various structures such as plain, rib, and purl can be created within the seamless garment at the same time.

On the flat machine, the three tubes are knitted on a pair of front and back needle beds. The flat machine knits and transfers loops between the front needle bed and the back needle bed with different yarn carriers for one body tube (Feeder 2) and two sleeve tubes (Feeders 1 and 3) (Figure 6.1). The three-tube knitting continues to the underarm point. At the underarm point, the two carriers knitting sleeve parts (Feeders 1 and 3) are taken out of the knitting zone. The remaining carrier (Feeder 2) that knitted the main body part knits together the three tubes into one tube [10] (Figure 6.2). The tubes are joined at the underarm points, shoulders and neck points. In this manner, seamless garment knitting is accomplished. However, in order to make loop transference for performing shaping or design structures, loops should be formed by selecting alternate needles [17] (Figure 6.3).

Figure 6.4 reveals how loop transference occurs on complete garment knitting by using empty needles. By loop transference using the alternate needles, single jersey tubes as well as rib type tubes can be knitted on the complete garment machine. Figure 6.5 depicts how the 2X2 rib structure can be created on the complete garment V-bed knitting machine. However, due to the alternate needle selection on seamless machines, the garment tends to be more open and less elastic than a traditional fully-fashioned garment [27]. This requires the use of more elastic yarns on the seamless knitting machine compared to the other regular V-bed machines such as fully-fashioned machines.

In addition, the number of tubes knitted on the machine depends on the desired type of knitted product. The complete garment machine does not have to create three tubes all the time. For instance, to create a sweater, it requires three tubular typed forms. On the other hand, a seat cover may require only one type of tube for the complete cover, but could also provide an integrated attachment tube.


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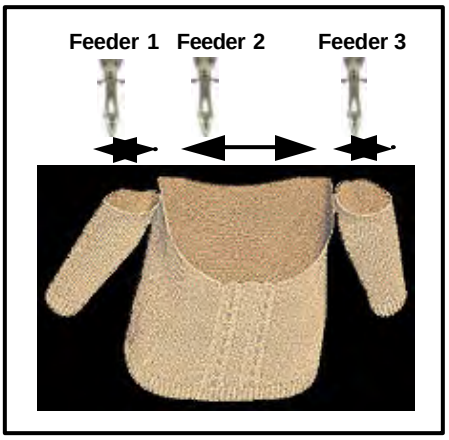



*Figure 6.1. Three-dimensional complete garment knitting until underarm point* (Shima Seiki)

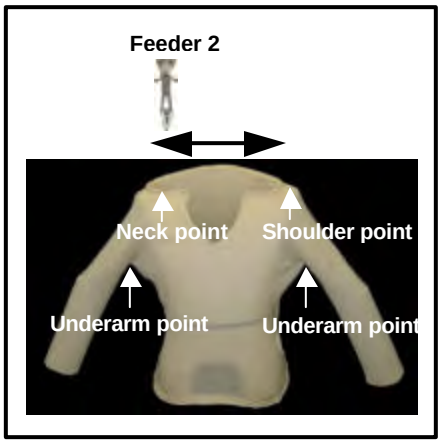



*Figure 6.2. Three-dimensional complete garment knitting after underarm point*

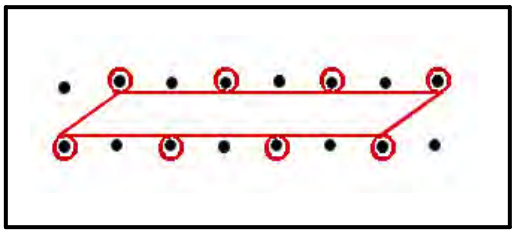


*Figure 6.3. Alternate stitch notation on complete garment knitting*

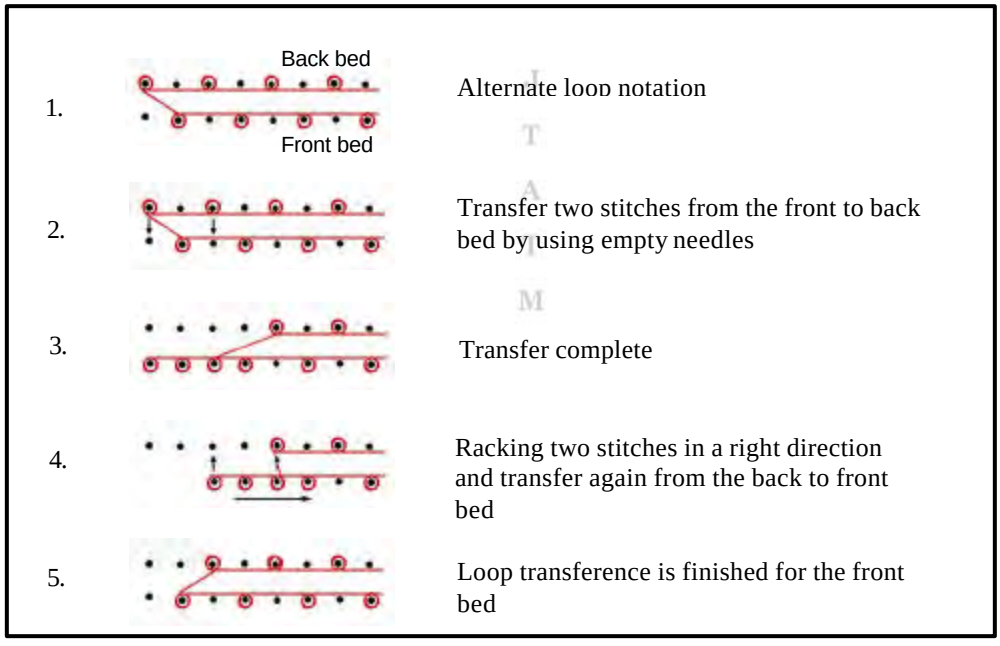
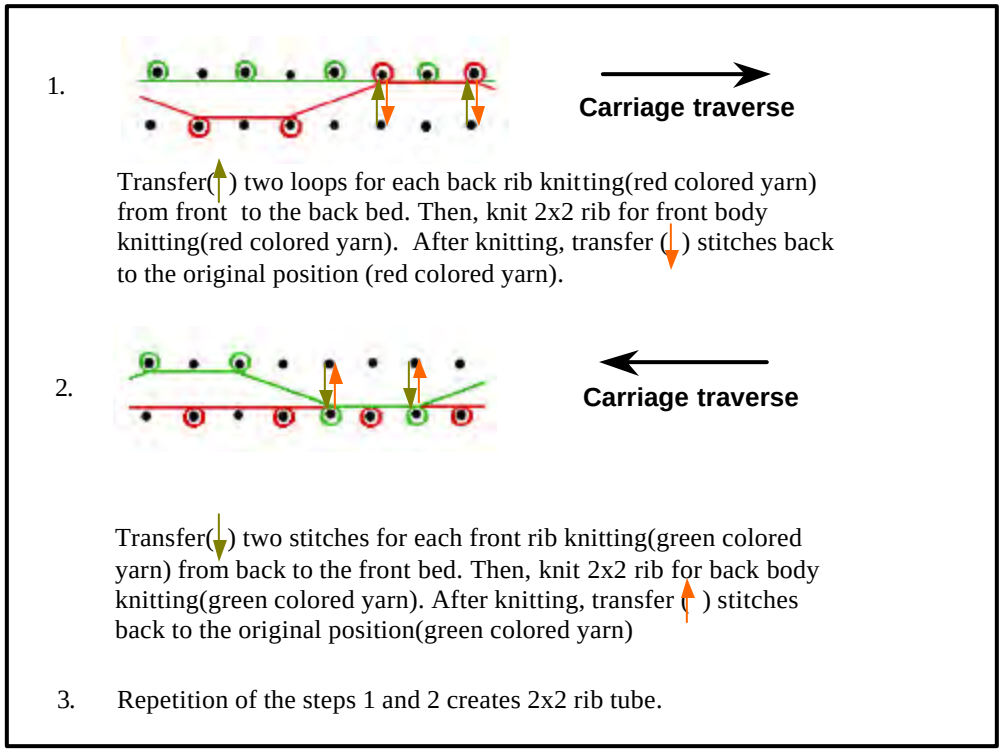



*Figure 6.4. Loop transference on complete garment knitting*



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** The upper figures show 2x2 rib tubular type knitting. Green colored yarn and red colored yarn represent the same yarn. In order that loop notation is seen easily, two different colors are*

*Figure 6.5. Tubular knitting of 2x2 rib on complete garment machine*

## 7. SEAMLESS MACHINES

For seamless flatbed knitting machines, two suppliers, Shima Seiki and Stoll, are the leaders in machine manufacturing. They offer solutions for the knitting of complete garments on computerized V-bed knitting machines. In Section 7, the two companies, Shima Seiki and Stoll, and their seamless knitting machine systems will be introduced and compared.

### 7.1. Shima Seiki

The Shima Seiki company invented the WholeGarment® machine and introduced the commercial complete garment knitting (SWG-V machine) in 1995 at ITMA (International Textile Machinery Association) [24]. Since the beginning of WholeGarment® machine production, about 3500 WholeGarment® machines have been manufactured and sold worldwide [11]. The seamless garment machines of Shima Seiki have different range of gauges from 5 to 18 gauge (needles per inch) and knitting widths ranging from 50 inches to 80 inches. Shima Seiki produces five versions of the innovative WHOLEGARMENT® machine that can produce a one-piece three-dimensional complete garment with no stitching, linking or sewing processes. Figure 7.1 illustrates the SWG-V WholeGarment® knitting machine system that shows various machine features such as a machine tuning screen, a computer controller, top tension devices, yarn carriage, et cetera.


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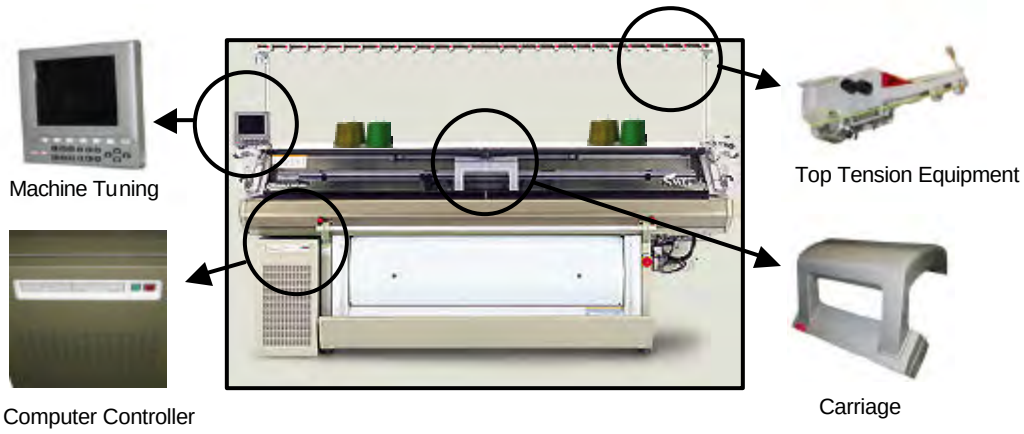



*Figure 7.1. SWG-V® machine*

### 7.1.1. Shima Seiki CAD system and machines

Figure 7.1.1 shows the Shima Seiki® knitting machine system. In general, knit patterns can be created on the CAD (Computer-Aided Design) system and all data can be saved to a diskette. The saved data can then be transferred to the Shima Seiki knitting machine and the machine can be operated. The machine-tuning screen allows operator interface with the settings of the machine. Finally, one complete three-dimensional garment can be knitted on the machine.

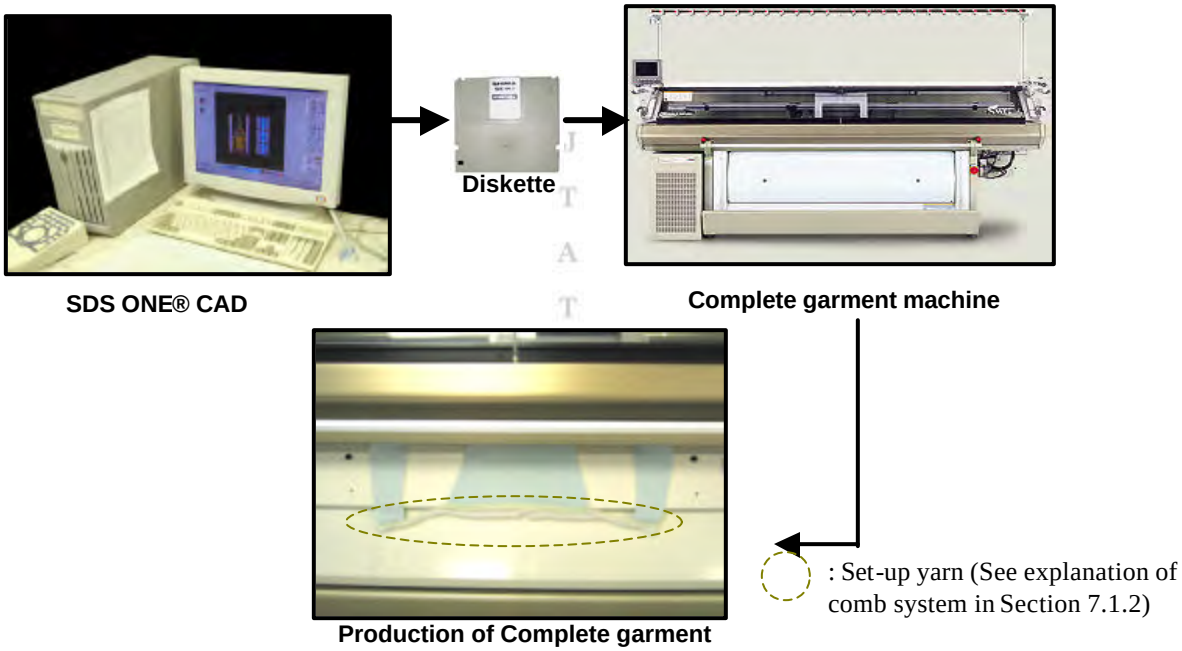


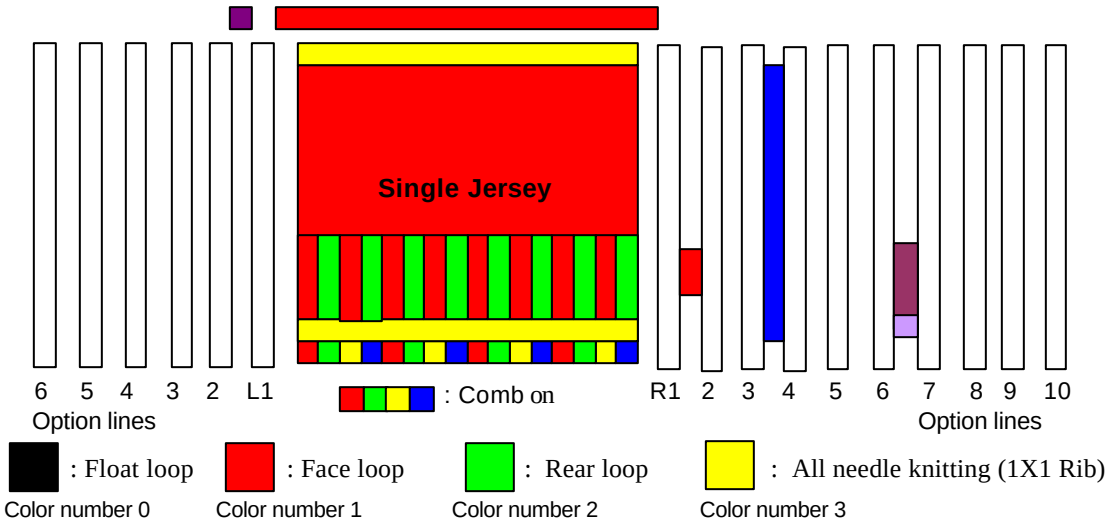

*Figure 7.1.1. Shima Seiki Knitting machine system*



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### 7.1.2. Shima Seiki CAD system

The Shima SDS ONE® CAD system is a totally integrated knit production system that allows all phases including planning, design, evaluation and production [44]. Specifically, the loop simulation program permits quick estimation of knit structures without any kind of actual sample making [8]. The program provides an opportunity to see knit problems and to try out diverse knit structures on the computer system before beginning the actual knitting. In the Shima CAD system, each different type of knitting loop is represented by different colored squares (Figure 7.1.2a). For example, as seen in the following figure 7.1.2a, color number 1(red) indicates a jersey (face loop) and color number 2 (green) indicates a reverse jersey (rear loop). Thus, the following red colored figure shows how a single jersey structure can be displayed on fully-fashioned CAD system of Shima Seiki machine.




* A Comb on a V-bed knitting machine is used to set up the yarn required to knit. The comb hooks the set-up yarn, and moves up and down, pulling down the set-up yarns connected with a knitted garment.
* Option line is used to control the data for a knit structure on the CAD system. For example, the right side of option line number 1 is utilized to decide repetition of a pattern area. Each option line represents specific functions of the machine knitting.

*Figure 7.1.2a. Shima Seiki CAD system for fully-fashioned*

The CAD patterning of the seamless garment knitting is more complicated than that of the fully-fashioned knitting due to alternate needle selection. The bottom figure (Figure 7.1.2b) depicts a single course notation of the tubular-formed knitting. In Figure 7.1.2b, the first row indicates front bed knitting (color number 1) and the second row indicates back bed knitting (color number 2). Accordingly, continuous knitting in a lateral direction between the front and back needle beds forms a tubular-typed fabric. In Figure 7.1.2c, it shows how loop transference for complete garment knitting can occur and how it can be displayed on the CAD system. The empty needles thus can be used for the loop transference. For the loop transference on complete garment knitting, at least two loops are transferred in a right or a left direction due to alternate needle selection such as Figure 7.1.2c. Note that only even number of loops can be transferred for seamless knitting on V-bed knitting machines.


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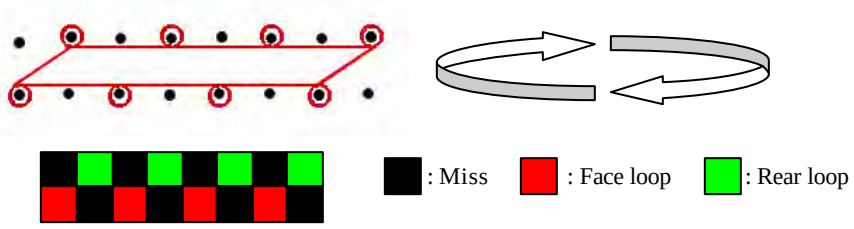



*Figure 7.1.2b. Stitch notation for seamless knitting and CAD design on Shima Seiki CAD system*




*Figure 7.1.2c. Loop transference on front bed for seamless garment knitting*

By utilizing the principle of the alternate stitch notation, two-dimensional design can be created on the CAD system as seen in Figure 7.1.2d. This represents a three-dimensional tubular typed garment. Figure 7.1.2d displays a whole garment designed on the Shima Seiki CAD system.

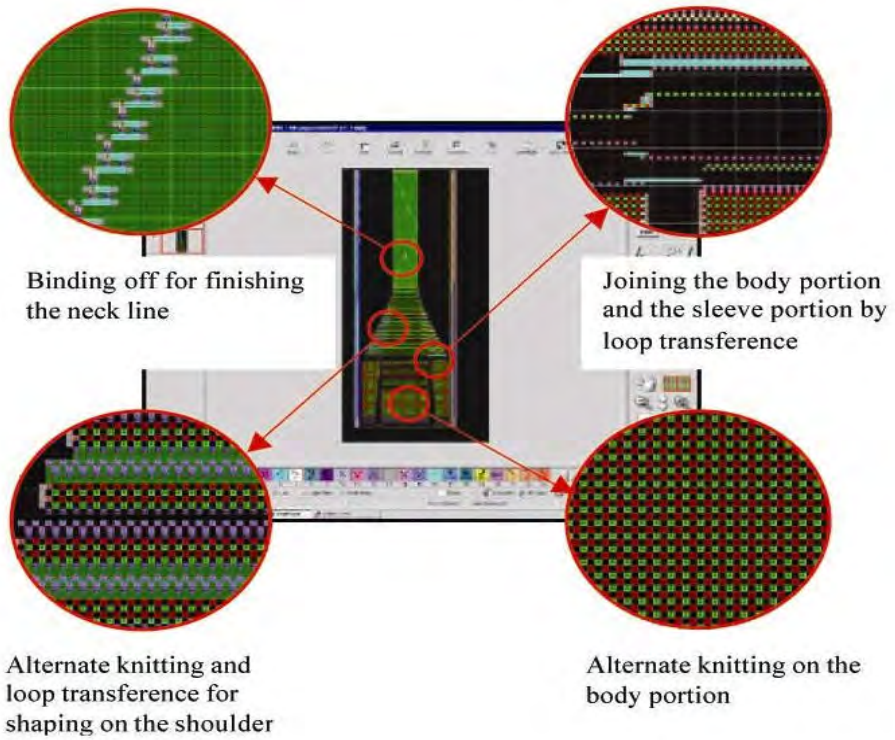



*Figure 7.1.2d. Design for complete garment on Shima Seiki CAD system*

Binding-off: The process that sequentially moves the stitches to the next loop from the edge [38]. This technique is generally utilized to finish edge lines.



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The interface between the knitwear designers and the knit technicians is critical to the success of new sample development. The designer's concept sketch must be realized through the capabilities of the machine governed by the technical expertise of the technician. Shima Seiki addresses this interpretative process through its enhanced Shima Seiki SDS ONE® CAD system. "Knit designs created in the paint program are simultaneously converted to knit programming data, so that designers and technicians can keep in close communication with each other over the same job" [39]. The combination of knit structures and yarn selections available in the design system will allow virtual simulation of potential garments without actual knitting.

Recently, Shima Seiki created a large pattern structure database of knitted parts including collars, plackets, cuffs et cetera. Knit and garment designs can be easily changed at will (Figure 7.1.2.e and 7.1.2f) [39]

### 7.1.3. Types of Shima Seiki Seamless knitting machines

Shima Seiki offers a line of machines capable of seamless knitting. These five different machines have special attributes, which can be selected according to application or end use. Gauge and needle type are the primary distinguishing factors.

#### 7.1.3.1. SWG-V®

The Shima Seiki's SWG-V® machine, which comes in 5 gauge and 7 gauge, is the first commercial application of Wholegarment® technology (See Figure 7.1) [39]. The SWG-V® machine uses a latch needle where the latch closes into the hook of needle as it pulls the yarn through a loop to form a new loop [33] (Figure 7.1.3.1a). The latch needles used in flat bed machines require an additional attachment, a transfer spring, in order to transfer a loop as can be seen in Figure 7.1.3.1a. However, due to the transfer spring, the needles cannot be located in the center of the needle groove, which results in a slightly asymmetrical loop formation. This will be discussed on Sections 7.1.3.4 and 7.1.3.5.

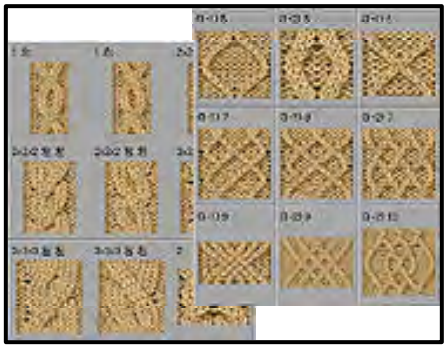


*Figure 7.1.2e. Structure pattern database*



*Figure 7.1.2f Virtual sampling* (Shima Seiki)


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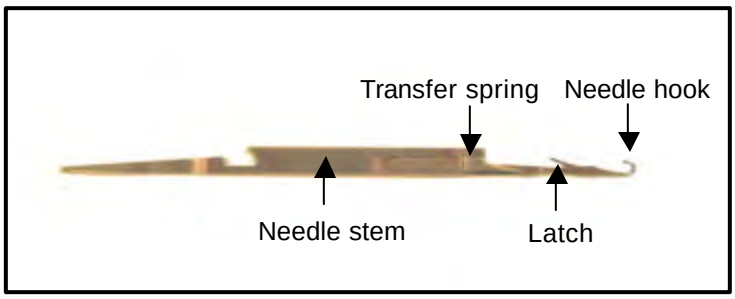



*Figure 7.1.3.1a.*
*Latch needle on SWG-V® machine*

Shima Seki introduced a version of the SWG-V® machine, with its enhanced technical capabilities such as the yarn carrier kickback device and increased memory capacity [39]. The New SWG-V® machine also has a special twin gauge needle configuration (Figure 7.1.3.1b) that includes a pair of needles working together in each needle slot. Complete garment knitting with loop transference requires two sets of needles, for the front and back of the garment, unlike a traditional single jersey tube that has only one set of needles [10]. Therefore, this twin needle configuration allows the needles to more effectively create widening or narrowing as well as diverse knit structures for complete garment knitting.



*Figure 7.1.3.1b. twin gauge needles*
(Shima Seiki)

### 7.1.3.2. SWG-X®

The SWG-X® machine is used to produce fine gauge knitwear, which has either 12 gauge or 15 gauge. Fine gauge knitting is produced by the slide needle and pull-down device, which independently controls takedown tension for front and back body portions. Specifically, the SWG-X® is configured for complete garment knitting with four separate needle beds and an additional loop presser bed [39]. This is the reason why the SWG-X® machine is the only machine that can knit complete garments without alternate needle technique. As can be seen in Figure 7.1.3.2, front body knitting can be achieved on needle beds 1 and 2, whereas back body knitting can be done between beds 3 and 4.

Actually, a machine that includes four needle beds and four cam plates is much more expensive to produce than a V-bed machine with two needle beds [10]. The reason Shima Seiki chose the more expensive four-bed route for fine gauge is in that if the machine was to take the half-gauge route for the fine gauge, the gauge would be just too fine for flat knitting technology [10]. The half gauge route on two needle beds for 12 or 15 gauge knitting is too fine to endure rigorous racking or transferring for complete garment knitting. The needle hook is also too small to accept the yarn required for 12 or 15 gauge knitting.



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This multi-needle bed configuration permits complete garment production with sufficient stitch density. Moreover, stitch transference can be more easily accomplished to create tubular ribs. In addition, various knit structures can be knitted at the same time with required stitch densities (Figure 7.1.3.2).

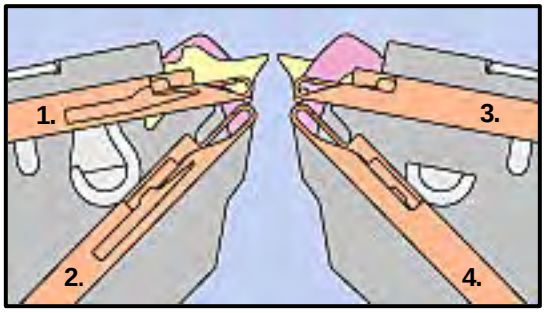



*Figure 7.1.3.2. Cross section Diagram of the SWG-X® four-needle bed configuration* (Shima Seiki)

### 7.1.3.3. SES-S.WG®

As with the SWG-V® machine, the SES-S.WG® has the capability to knit complete garments with latch needles. However, unlike the SWG-V's twin-needle configuration, the SES-S.WG® uses the standard latch needles and spring-type sinkers at the same pitch. This enables the machine to knit fine-gauge shaping as well as integral knitting, and it also makes possible multiple-gauge knitting. In multiple-gauge knitting, a number of different gauges can be knitted in a single course. Multiple-gauge knitting is different from fixed gauge knitting in that an assortment of gauge sizes may be knitted in a single garment [39] (Figure 7.1.3.3). The multiple gauges contain a combination of techniques, such as half-gauging, intarsia technique, using different numbers of yarn ends, and blocks of different gauges of needles each working with its corresponding count of yarn and yarn carriers [44]. Shima Seiki explains that this capacity responds to the change of seasons and trends without investing in a machine for every gauge. As a result, it saves time by eliminating the task of gauge conversion from one machine to another machine. Product variety can be greatly enhanced by achieving more interesting and sophisticated design patterns [39].

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*Figure 7.1.3.3. multiple-gauge knitting sample with 12G and 7G mixed side by side* (Shima Seiki)



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### 7.1.3.4. SES-C.WG®

The SES-C.WG® is a flexible machine in that it can achieve quality knitting in a range of production styles. The SES-C.WG® machine has the capability to perform shaping and integral knitting similar to the other SES-series. In addition, this machine can knit coarser gauge complete knitwear. By using compound needles and a take down system featuring a pull-down device, the SES-C.WG® can produce a high-quality coarse gauge seamless garment. The compound needle, in which the hook and hook closing portions are separately controlled [22], is generally used in warp knitting machines [13] (Figure 7.1.3.4a). However, Shima Seiki applied the concept of compound needles to the flat bed machine.

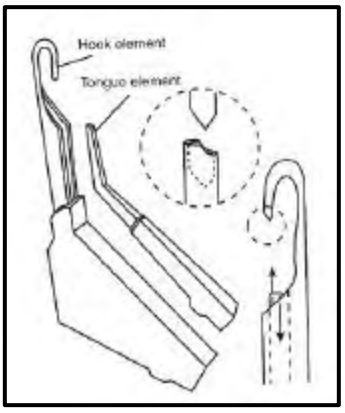



*Figure 7.1.3.4a. Compound needle* (Kadolph and Langford, 1998)

Compared to traditional latch needles, the compound needle is more complex and expensive to manufacture [44]. However, the compound needle gives higher operational stability, which is required for larger needle sizes. According to Shima Seiki, the compound needle offers significant reduction in needle stroke to allow for similar reductions in needle bed and carriage size [39]. Thus, the short stroke knitting helps reduce space in the carriage and permits smaller and lighter carriage [6]. According to John Ward [50], a technician at Shima Seiki USA Inc., the compound needle eliminates the necessity for a brush on the carriage, because the needle has a slider that opens and closes the hook of the needle unlike a latch needle. The slider moves up and down by the movement of the cam system, which is timed to work closely with the movement of the needle. This increases the stability of knitting, and there are no brushes to be worn out.

Another feature of the compound needle is that it does not have to be raised as high because there is no latch that must be cleared which increases knitting stability at higher speeds. However, one drawback of both the latch and the compound needle is that both needles have to be off center in the trick wall to allow for the transfer spring. This puts the needle hook closer to the knock-over bit on one side, resulting in a slightly imbalanced stitch. To solve the problem of imbalance, the Shima Seiki developed the slide needle [50]. The slide needle will be discussed in Section 7.1.3.5.

### 7.1.3.5. First®

This machine executes all types of production from fully fashioning and three-dimensional shaping to seamless production. All this capability is accomplished through the development of the slide needle instead of the latch needles, which uses a unique two-piece, slide mechanism [39] (Figure 7.1.3.5a).



*Fig 7.1.3.5a. Slide needle* (Shima Seiki)

Shim Seiki points out "A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove. The slide needle thereby achieves perfectly symmetrical loop formation for knitting the highest possible



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quality fabrics (Figure 7.1.3.5b and 7.1.3.5c)" [39]. Accordingly, by using the slide needle, the machine provides better quality and stable knitting as well as higher productivity. However, in order to transfer loops by slide needles, the First® machine needs an additional transfer bed that can only move stitches [51]. The machine also requires an extra cam system to control the slider on the slide needle [51]. In consequence, the additional equipments make the machine with slide needles more expensive than a machine with latch needles.

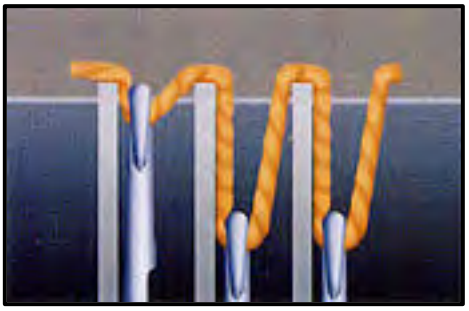


*Fig 7.1.3.5b. Conventional latch needles offset slots* (Shima Seiki)



*Fig 7.1.3.5c. Slide needles centered in slots*

Another distinctive feature of the First® machine is its takedown system. "Precision pull down of the garment is independently controlled by tiny pins mounted on front and rear panels which feature adjustable working width through individually controlled 1.5 inch wide sections. This precise control of takedown tension permits 3-dimensional shaping of complete garment items" [10].

The following Table 2 shows the five-versions of Shima Seiki WholeGarment® knitting system. All sources are cited from the Shima Seiki company website, www.shimaseiki.co.jp.

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**Shima Seiki WholeGarment® Systems**
(Sources from www.shimaseiki.co.jp, 2004)

| | First® | New SWG-V® | SWG-X® | New SES-S.WG® | New SES-C.WG® |
|---|---|---|---|---|---|
| Knitting Width | 126-181cm 50-72” | Max 183cm 72” | Max 172cm 68” | 183cm 72” | 203cm 80” |
| Gauge | 12 - 18 gauge | 5, 7 gauge | 12, 15 gauge | 8, 10, 12, 14, 16 gauge | 5 gauge(capable of producing 3G fabric) |
| Knitting Speed | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.1m/sec |
| Racking | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) |
| Knitting system | 3 or 4 system | Triple Knitran® system. Single carriage | 3 system (1 knitting system + 2 transfer system) | Triple Knitran® system. Single carriage | Ultra-compact 2-system (1 knitting system + 1 transfer system) |
| Transfer | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch |
| Sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system | Fixed sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system |
| Yarn Carriers | 12-16 | 13 | 12 | 13 | 16 |
| Take down device | Main/sub rollers, Changeable 31 levels | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear |
| Needle selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Full-jacquard solenoid selection |
| Needle | Slide needle | Latch needle | Slide needle | Latch needle (Standard layout of needles) | Compound Needle |
| Production | Everything from full-fashioning, rib shaping to 3-dimensional shaping, as well as seamless | | High quality fine gauge knitwear | Fine-gauge shaping and integral knitting, even multi-gauge knitting | Coarse gauge knitting |

*Table 2. The Shima Seiki WholeGarment® machine Systems*


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## 7.2. Stoll



*Figure 7.2. STOLL Knit and Wear® Machine* (Stoll)

The other major machinery producer for seamless knitting considered in this research is Stoll. The Stoll system is examined in comparison with the Shima Seiki based on research at Cotton Inc. with Emmett Hylton, Knitting Manager [5]. This section considers the CAD system, the knitting equipment and the seamless systems available. Seamless garment knitting systems from Stoll and Shima are similar, and a comparison of the complete garment knitting systems offered by Shima Seiki and Stoll are considered in this section. Stoll has manufactured flat knitting machines for more than 130 years and has today more than 1,100 employees worldwide [45]. The Stoll machine also markets complete garment knitting machines called "Knit and Wear®". The range of gauge for Stoll Knit and Wear® machine is from E2.5 to E9.2 gauge and the knitting width is from 72 inches to 84 inches. The Stoll Company also has a multiple gauge system, which permits different gauge areas to be knitted in one single course [45].

### 7.2.1. Stoll CAD system

According to Spencer [44], the Stoll SIRIX® (M1) CAD system is a complete design, patterning, and programming system, and it utilizes two windows to graphically develop knitting programs for the Stoll machines. In the Stoll CAD system, all knit structures are displayed by real modules. Figure 7.2.1 shows how 2X2 rib and single jersey can be displayed on the Stoll M1 CAD system.

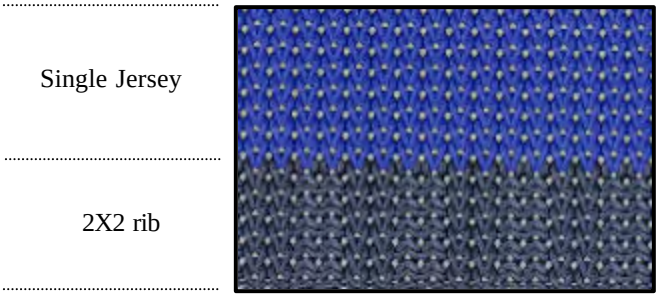



Figure 7.2.1. *2X2 Rib and single jersey displayed on the Stoll M1 CAD system*

As in the Shima CAD system, Stoll's M1 CAD system offers two different windows for designers and technicians who need different information for the same design (Figure 7.2.2). The technical window shows the developing design in the form of running yarn notations and technical data, while the design window presents design as a knitted structure [44]. Both windows can be easily displayed and automatically converted. Therefore, it is expected to minimize miscommunication between designers and technicians in knitting industry. By understanding the knit structures, it is possible to improve collaborative efforts and resulting samples.

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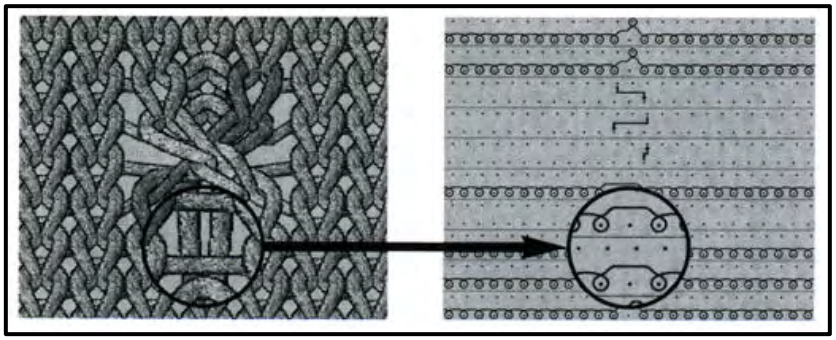


*Figure 7.2.2. Linked windows options of fabric design view and technical view*
(Spencer, 2001)

### 7.2.2. Types of Stoll seamless knitting machines

#### 7.2.2.1. CMS 330 and CMS 340 TC Knit and Wear® machines

CMS 330 TC and 340 TC knit and wear® machines have a 72-inch (183 cm) knitting width. The CMS 330 TC knit and wear® machines cover three systems and a gauge range from E6.2 to E7.2. E6.2 provides a range from E6 to E12 and E7.2 gives a range from E7 to E14. On the other hand, the CMS 340 TC knit and wear® machine has four systems that combine the knitting and the transfer system, and a gauge range from E2, 5.2 to E9.2. Technically, the CMS 330 TC machine is capable of producing fully fashioned, multiple gauge as well as intarsia fabrics. An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (or textures), so that both sides of the fabric are equal [48]. Its three systems yield a high level of production. The CMS 340 TC machine has the capability of multiple-gauge knitting such as Shima Seiki New SES-S.WG [45].

#### 7.2.2.2. CMS 330 TC-T Knit and Wear®

This machine offers a 72-inch (183 cm) knitting width and the range of the gauge is between E6.2 and E7.2. By using its three systems and two additional needle beds with transfer elements and independent racking front and rear, fine gauge knitting is possible in gauges E12 and E14 with all needles [45]. This machine is also capable of multiple-gauge knitting in order to create an interesting knit structure between finely knit areas knitted with all needles and coarser areas knitted only with every second needle [45].

#### 7.2.2.3. CMS 330 TC-C Knit and Wear®

CMS 330 TC-C knit and wear® machine has a three-system capability and a working width of 84 inches (213 cm). This width can easily produce coarse gauge knitwear in extra-large sizes. The gauge E2,5.2, in conjunction with knitting and transferring systems designed especially for this application and a new type of holding-down technology, allows the production of seamless garment knitting [45].

#### 7.2.2.4. CMS 340 TC-M Knit and Wear®

This machine is equipped with a new extra wide working width of 84 inches (213 cm) for producing triple XL sized seamless sweaters [13]. The four system model features a gauge range from E2, 5.2 to E7.2 (up to 14 cut) and the machine also offers gauge conversion capability. It also can be used efficiently for fully-fashioned, multiple-gauge and intarsia fabrics. Thus, it joins the advantages of the comb machines with those of multi piece knitting. Consequently, profitability can be enhanced and even multi-piece fully-fashioned knitting can be achieved [45]. For instance, two front pieces, two back pieces, and four sleeve pieces can be sequentially knitted in the necessary sizes. In two-piece knitting,


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the left fabric can be knitted by the two left knitting systems, and the right fabric can be knitted by the two right knitting systems (Figure 7.2.2.4). This figure also shows the two separate yarn carriages. Two-piece knitting significantly increases productivity compared to one-piece seamless knitting [45]. "This machine knits complete garment panels as multi-layer applications and also as racked and structured patterns in multi layer knits and an absolute novelty in the sector – two gauges in one fabric" [36]. In addition, this machine is capable of producing ultra-coarse gauge garments with the fabric appearance of 2-gauge with a hand-knitted look [13].

With new take-down technology, this machine offers a new shoulder solution, the so-called "French shoulder". This style of shoulder features the connection between the front and back body portions of the garment not in the middle of the shoulder but at the top of the back. This new knitting sequence demonstrates that the shoulder part of the garment can be produced with greater quality with a wide range of possible variations in terms of visual appearance and elasticity [45]. Table 3 shows the five-versions of the Stoll Knit-and-Wear® knitting system. All sources are cited from the Stoll website, www.stoll.de.

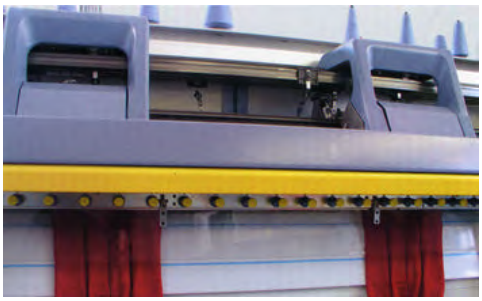


*Figure 7.2.2.4. Two piece fully fashioning* (Stoll)

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**Type of Knit–and–Wear® machines**
(Sources from www.stoll.de, 2004)

| | CMS 330 TC Knit and Wear | CMS 340 TC Knit and Wear | CMS 330 TC-T Knit and Wear | CMS 330 TC-C Knit and Wear | CMS 340 TC-M Knit and Wear |
|---|---|---|---|---|---|
| Knitting Width | 183 cm 72” | 183 cm 72” | 183 cm 72” | 213 cm 84” | 213 cm 84” |
| Gauge | E2,5.2- E7.2 | E2,5.2- E9.2 | E6.2-E7.2 | E2,5.2- E2,5.2 | E2,5.2- E7.2 |
| Knitting Speed | Max 1.2m/sec | Max 1.2m/sec | Max 1.2m/sec | Max 1m/sec | Max 1.2m/sec |
| Racking | Max 4” | Max 4” | Max 4” | Max 4” | Max 4” |
| Knitting system | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation (4 combined knitting/transfer systems) | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation | Independent knitting systems with split function for optimum system allocation (4 systems) |
| Transfer | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions |
| Sinker system | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down spring loaded sinkers: enables manufacturers to knit ultra coarse garment with a hand-made look (Mowbray, 2004). | Moveable holding-down sinkers |
| Yarn Carriers | 16 | 16 | 16 | 16 | 16 |
| Take down device | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb |
| Needle selection | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system |
| Production | Multi-gauge, Intarsia fabric | Multi-gauge, Flexible gauge | Fine gauge knitting, Multi-gauge | Coarse gauge knitting, | Coarser gauge knitting, Fully-Fashion, Multi-gauge, Intarsia fabric |

*Table 3. The Stoll knit and wear® machine system*


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### 7.3. Comparison of Complete Garment Knitting Systems between Shima Seiki & Stoll

Table 4 compares seamless garment knitting systems between two companies, Shima Seiki and Stoll. The characteristics of the machines are generally comparable except in a few features. The main difference between two offerings is that Shima Seiki machines employ three different types of needles for complete garment knitting such as latch needles, compound needles and slide needles, whereas Stoll machines employ only latch needles. Table 4 shows the machines of two companies have quiet similar characteristics.

**A comparison of complete garment knitting systems between Shima Seiki and Stoll**
(Sources from www.shimaseiki.co.jp and www.stoll.de, 2004)

| | Shima Seiki WholeGarment® Machines | Stoll Knit-and-Wear® Machines |
|---|---|---|
| Knitting Width | 50" – 80" (126 – 203 cm ) | 72" – 84" (183 – 213 cm) |
| Gauge | 5 - 18 gauge | 5 -18 gauge |
| Knitting Speed | Max 1.3m/sec | Max 1.2m/sec |
| Racking | Max 3" total | Max 4" total |
| Knitting System | 3 – 4 systems | 3 – 4 systems |
| Transfer | Simultaneous transfer | Simultaneous transfer |
| Sinker System | Spring-type movable full sinker system | Spring-type moveable holding-down sinker system |
| Yarn Carriers | Up to 16 | Up to 16 |
| Take-down Device | Main/sub take down rollers | Main/upper take down rollers |
| Needle Selection | Electric selection system | Electric selection system |
| Needle | Latch needles, Compound needles, Slide needles | Latch needles |
| CAD system | Integrated knit production system allowing planning, design, evaluation and production | Complete design, patterning, and programming system |

*Table 4. Comparisons of complete garment knitting systems between Shima Seiki and Stoll*


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## 8. CONCLUSIONS

Seamless garment knitting on V-bed machines creates one entire complete garment by using several different carriers eliminating the need for additional cut and sewn operations. The garment can be created in tubular forms: one wider tube for the body portion and two narrower tubes for the sleeve portions. Two leading companies, Shima Seiki and Stoll, manufacture seamless or complete garment V-bed knitting machines. Both companies develop various complete garment machines according to the machine gauge, types of needles, sinker systems, take down systems, and application of knit structures.

For seamless garment knitting, the machines have the capability not only to create shaped knitting, but also to make various knit design structures in the complete garment by utilizing alternate needle selection. Alternate needle selection, however, creates fabrics more open and less elastic than conventional fully-fashioned garments. Nevertheless, complete garment knitting provides major benefits for the market as well as for technical production. (See Table 5) Manufacturers do not have to rely on the cutting and sewing process. As a result, it is believed to offer savings in terms of production times and cost, and it minimizes yarn consumption. In addition, seamless garment knitting provides more consistent and homogeneous product quality, which gives lightness and comfort in the garments. It also offers knit designers more creative knit possibilities.

Three-dimensional seamless knitting with its diverse capabilities can be applied to numerous products such as fashion, upholstery, automotives, aerospace, medical textiles, et cetera. Seamless knitting is forecasted to continue growing and could be one of the largest next generation knitting technologies.

| **Potential benefits of seamless knitting** |
|---|
| 1. Minimizing or eliminating labor intensive cutting and sewing process |
| 2. Savings in production times and cost |
| 3. Minimal yarn consumption |
| 4. Higher productivity |
| 5. Multi-gauge knitting |
| 6. Lightness and softness |
| 7. No bulky and irritating stitches/seams |
| 8. More constant product quality |
| 9. Better trimmability for finished edge lines |
| 10. Better look, better fit and more comfortable |
| 11. More creative possibilities for knitwear designers |
| 12. Quick-response production for size and pattern changes |
| 13. Just-in-time production |
| 14. Mass customization |

*Table 5. Potential proposal for seamless garment knitting*



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## Glossary

Barre' : Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric.

Bearded needle: the needles having an extended terminal hook or beard that can be flexed to close the hook.

Binding-off: The process that sequentially moves the stitches to the next loop from the edge. This technique is usually utilized to finish edge lines.

Brushes: The aim of brushes is to open the latches at the first course when the machine starts to knit and to avoid closing of the latches.

Cable stitch: Cable stitch is a stitch formed by small groups of plain wales plaited with one another in ropelike fashion.

Carriage: Carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam.

Cam: The device which converts the rotary machine drive into suitable reciprocating action for the needles.

Circular knitting machine: Needles are set radically or parallel in one or more circular beds. Used without further qualification, the term generally refers to a weft-knitting machine of this type.

Comb: Comb on V-bed knitting machine is used to set up a yarn required to knit. The comb hooks the set-up yarn, and moves up


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Skechers v Nike

and down, pulling down the set-up yarns connected with a garment.

Compound needle: The hook and hook closing portions are separately controlled. The compound needle gives higher operational stability at higher speed compared to latch needle.

Flat knitting machine: Flat knitting machine employs straight needle beds carrying independently operated, usually latch needles.

Flechage: Course shaping in knitting. A term increasingly used to define two and three-dimensional shaping of knitted fabric by increasing and/or decreasing the length of succeeding knitted courses to a pre-planned series. Beret knitting is also a term used to describe this process. The term is derived from the French for wedge. (http://www.resil.com/dictionary/f.htm)

Fully-fashioned knitting: Fully-fashioned knitting is shaped wholly or in part by widening or narrowing by loop transference to increase or decrease of the number of wales.

Gauge (cut): Gauge indicates the number of needles per inch.

Holding down: Holding down is one of functions of sinkers. It prevents previous loops from riding with needles. Thus, it gives tighter structures with improved appearance.

Intarsia fabric: An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (textures), so that both sides of the fabric are equal.

Interlock: a double-faced rib-based structure consisting of two 1X1 rib joined by interlocking sinker loops.

Interlock gating: The opposed alignment of one set of needles with the other on a knitting machine.

Knitting: The process of forming a fabric by the intermeshing of loops of yarn.

Knocking over: Knocking over is one of functions of sinkers. It supports the old loop as the new loop is drawn though it.

Latch needle: It has a latch or swinging fingers that closes into the hook of needle as it pulls the yarn through a loop to form a new loop.

Linking: Linking is a process of joining side seams or edges of a piece of fabrics together with a row of knitting on a linking machine.

Loop transference: Loop transference is the process that moves stitches from the needles on which they were made to other needles for the purpose of shaping or design.

Mass customization: It is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology.

Miss stitch: A knitting cycle where a needle or needles do not take a yarn and produce a float loop either intentionally or as the result of knitting fault.

Multiple-gauge knitting: Multiple-gauge knitting is a number of different gauges can be knitted in a single course.

Productivity: Machine productivity is expressed in pattern rows per minutes.

Racking: Racking is the lateral movement of a needle bed or point bar across a predetermined distance on a flat knitting machine.

Rib gating: The alternate alignment of one set of needles with the other on a machine equipped with two sets of needles arranged to knit rib fabrics.


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Sinker: Sinker helps loop formation, holding-down, and knocking-over on a machine.

Slide needle: A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove.

Take down rollers: Take down rollers are required in order that the previous loop which is located in the hook enclosure is prevented from the riding up with ascending needle.

Tubular knitting: Tubular knitting is created on both needle beds but front and back bed knitting are done alternately.

Warp knitting: Warp knitting is composed of loops formed in a vertical direction.

Weft knitting: Weft knitting is composed of loops formed in a horizontal direction.

Welt: Welt in knitting is a secure edge of a fabric. The welts are usually at the starting end of the fabric.

Yarn carrier (feeder): The yarn coming from a single yarn feeder is feeding the needle in a sequential order and by doing so connects the adjacent loops into a course.

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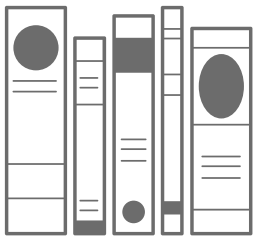

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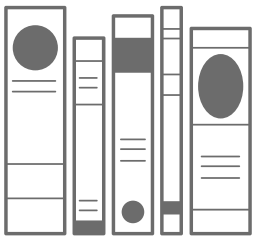
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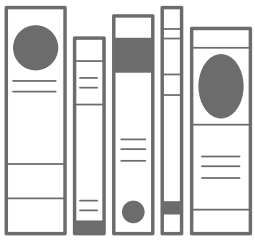
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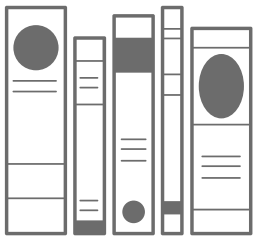


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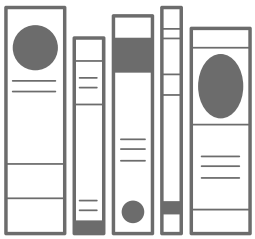


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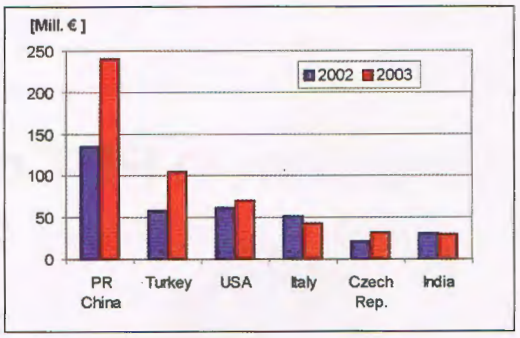

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In the first quarter of 2003 German textile machinery exports increased by 19 % with main markets in China, Turkey, USA, and Italy (see page 182 of this issue).

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# 3D-products for fashion and technical textile applications from flat knitting machines

**M. Legner, H. Stoll GmbH & Co., Reutlingen/Germany**

Against the trend, most of the other textile machinery sectors have experienced, the demand for modern flat knitting machines has grown steadily over the past years and kept an astonishing, relatively high level of machines being sold per year. There are both economic and technical factors to be found in order to explain this phenomenon:

Economic reasons:

- high demand for knit goods supported by knit-friendly fashion trends
- immense demand for modern machines in Far East to replace large numbers of hand knitting machines
- concentration of knitwear production, primarily in Far East, such as China, Korea and India as well as in Turkey and some Eastern European and Arabian countries with the effect to build up new and modern production units
- global supply of the world markets out of the aforementioned regions, however, also increasing domestic demands in the delivery countries due to a growing prosperity of the home population
- fast response of the traditional, trend setting knit wear production countries towards the use of new techniques to incorporate new design ideas and production concepts.

Technical factors:

- increased versatility of modern machines regarding the diversity of patterning designs
- enhanced flexibility of the machine technology towards gauge conversion and multi- or flexible gauge applications
- facilitated programming and styling of knitted articles by means of modern CAD/CAM systems, supported by mostly automated programming tools
- steadily improved technology to produce integral knit garments to revolutionize the way of garment manufacturing and to strip down the production process.

However, even if the success of the flat knitting technology has been proven as steady, there are more and more indications, that it might just be a question of time, that the era of this technology will be terminated not only due to a market saturation, which will occur somewhere along the way, but also due to new knitting technologies, which do not base on the flat knitting principle.

Lecture held at the World Congress Knitting for the 21st Century in Manchester/UK, October 7/8, 2002

Some people say that there is a growing demand among the manufacturers of knit wear products following the pressure of the powerful purchasing organizations to produce knitted textiles, respectively garments in a faster and finally cheaper way. This demand goes hand in hand with an expectation that there will be a technology available, which produces at a generally good quality level and which requires less experienced personnel to program and handle the machines.

The arguments to be found in favor for this thesis are the continued demand for cotton machines, as well as the enlarged and specifically explored use of circular knitting machines for the production of seamless knit garments, where first attempts to produce coarser gauge outerwear articles have been started as well.

In addition, there are tendencies to produce exceptionally designed fully fashion and seamless garments on tricot warp knitting machines.

These new technologies might represent possible alternatives for the manufacturing for coarser knitted articles in the future in order to achieve the aforementioned expectations, particularly as far as mass production is concerned.

Producers of flat knitting machines follow these development trends closely and are able to respond to it by showing new sides of the flat knitting technology. The way the vast patterning and design possibilities, in conjunction with the capabilities of producing 3D products, are applied to generate new designs and concepts for the general fashion industry as well as for alternative application areas is looked at more closely here.

## Scope and versatility of 3D applications for knitted fabrics

In comparison to other builders of textile machinery producing fabrics, the flat knitting machine manufacturer is caught in something of a conflict situation. On the one hand, knitting metered goods using flat knitting machines is a relatively slow process. On the other hand these machines offer a scope for design options which cannot be matched in terms of implementation simplicity as regards their styling and design versatility. Thereby fabric characteristics can easily be influenced as well.

A flat knitting machine comprises two or more needle beds, which are run over by a carriage bearing knitting systems. With every stroke of the carriage, stitches are generated or other knitting functions performed. Each stitch is created by a needle, which is selected by electronic means following a program laying down the knitting sequence of a pattern.

To knit, for example, a spherical shell the needle on the left begins with only a few stitches, increasing the number of stitches towards the center needles and then decreasing their number again by the time needles, positioned further to the right, are reached. When this process is continued regularly with once activating the needle operation and once disabling its function, a spherical shell is produced, presuming, that every needle knits precisely the number of stitches corresponding to its section of the periphery, considering the fact, that every stitch theoretically represents an object of a constant parametrical size.

Consequently such a spherical shell is not made by a particular 3D forming device, but is generated by a 3D knitting program.

Spherical shaped objects are not the only 3D realizations possible with flat knitting machines. Within the framework of three-dimensional styling options, the following possibilities can be implemented by using all techniques of fabric forming of flat knitting machines. All these possibilities can normally be produced and even jointly applied on the same machine:

- *Voluminous knit structures*

The double bed set up is used to create two-faced knit structures which have a higher volume compared to single-face fabrics. This can lead to a considerable fabric thickness of approx. 1 cm, when applied on a machine of gauge E 3. Depending on the knitted construction, the fabric thickness can be further increased and strengthened by tuck stitch insertions.

By means of needle selection, voluminous stitch allocations can be optionally positioned in a regular knit fabric for optical design affects or cushioning purposes.

- *Spacer structures*

With this type of knitted fabric, two or more single-faced fabric sides positioned opposite to each other are joined together by stitch or tuck links. The generated volume as well as the fabric characteristics depend on the construction and the selection of the pile material by causing stuffing or springing effects.



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- *Web or Interface structures*

Here, the three-dimensional formation of the fabric is created by a knitted bridge or crosslink connection of two or more fabric layers positioned opposite each other.

By knitting the fabric layers with every second needle (1x1 needle selection), the remaining empty needles can be used for formation of the connecting webs. In this process, the length of the webs and thus also the height of the overall fabric can be optionally selected and also varied in terms of the appearance of the surface evenness. The orientation of the connecting webs can also be modified by influencing the rhythm of the stitch formation of the individual layers. The cavities created by this process could be subsequently filled, for example, by inserting reinforcing materials, pipes, cables or others.

- *Tubular structures*

With the aid of the double needle beds, tubular structures of optional diameters can be produced on flat knitting machines. Besides the production of tubes as such, tubular extensions and attachments can be implemented in a knit fabric in various manners. Knitted tubes can be placed along the selvedge or in any location of the fabric face.

- *Spherical 3D structures*

In contrast to volumetrically engineered 3D fabric forms as described, the so-called wedge technique permits the shaping of a knitted fabric in a three-dimensional, spatial way. The technique of implementing spherical curved fabrics as described before can also be applied in segments of other, more complex knit applications, such as in the heel area of stockings or contoured seat covers. During the knitting process, individual needles or groups of needles are allotted fewer stitches than others. The stitch allocation per needle can be performed along geometric fabric lines or homogeneously distributed over the surface of the knit object. This knitting method, known as the wedging technique, forms less fabric in certain sectors and more in others. This causes the fabric to take on a three-dimensional shape. This technique can be additionally supported by different stitch sizes in individual sections. Different materials and narrowing or widening processes can also be applied. Warp and weft threads can be integrated, as can floats and tuck stitches. Equally, functions such as stitch splitting and transfer can additionally extend the repertoire.

The variable use of the wedge technique opens up new possibilities for fabric styling and product customization. The immense potential of 2D and 3D shaping, which is inherent to the styling techniques of modern flat knitting machines however needs to be seen in the option to freely combine all the above mentioned techniques in - if required - one knitted product. This permits an enormous degree of design variability, which can be utilized in the development of new ways of producing and designing knit garments as well as in generating new fields of application for knit products.

**Use of 3D knitting applications in fashion**

- *From yarded goods - cut to size - to fully fashioned fabrics*

In former years, the standard method of production was to knit a length of fabric, cut out the required panels and make them up into a finished article.

Using modern electronic control systems, it is now possible to simply program a flat knitting machine in a way, that the individual needles perform precise operations to conduct intended functions. This capability has led to the success of "fully fashion" manufacturing of knitted articles. By widening and narrowing the fabric, parts are fashioned on the machine. Panels, fashioned in this way for the body and sleeve components are sewn together to create the end product. The benefits - besides enhanced optical appearance - are material savings and exact, reproducible garment sizes.

In the fashion sector, when producing conventional outerwear garments, 3D applications have been restricted largely to structural design features. These refer to familiar relief-type effects produced by interchanging plain and purl stitches, missed stitch applications and pattern formations such as cable and Aran designs.

Knit-in pockets can also be viewed at as 3D applications. Additionally, varied accumulation of stitches in the form of "wave motifs" can be termed as 3D fabric appearance.

- *From fully fashion to ready-to-wear articles*

With the introduction of the knit and wear technology by H. Stoll GmbH & Co., Reutlingen/Germany and the way to produce complete garments on flat knitting machines, an actual 3D manufacturing process is commonly applied on flat knitting machines.

This technology is based on a technique, where - when producing a pullover - three fashioned tubular parts are joined to form a finished, ready-to-wear article through knitting, transfer and linking processes.

The way, ready-to-wear garments can be designed, hardly finds any restrictions any longer, since besides structural effects, simple jacquard and Intarsia patterns, typical knitwear formations for the shoulder, neck and collar area can be applied. Thus shoulder formations such as inserted sleeves, Raglan and Saddle shoulders can be standardly incorporated in new, very fashionable variations.

The same applies to the styling of necklines and collars, which also allow common designs, however open up the creativity for new, ready made solutions as well.

The underlying knitting principle applied in the production of knit and wear articles is that of knitting with halved gauge, in which knitting takes place only on every second needle. As a result of the 1x1 needle selection, free needles remain in both needle beds which can be used for any optional transfer processes required for structural effects or narrowing operations.

Within an increasing acceptance of so-called "seamless garments", today, machines have been majorly asked for in a gauge range from E3 to E12 as concerns the appearance of the finished outerwear garments. As regards the needle bed configuration these machines are capable of producing finer gauges but are fitted with needles with a larger needle hook to allow a coarser textile look, when the knitting process is performed by every second needle.

Depending on the required knit fabric design and by the possible use of machines with additional needle or transfer beds, such as the Stoll CMS 330 TC-4 and TC-R, complete outerwear garments are also produced in finer gauges.

Looking at technical restrictions of seamless circular knitting machines to implement the perfect shape, this complete garment technology of flat knitting machines might open up their use for new or former fashion areas, which have not been of particular interest to most of the flat knitting machine manufacturers in the past.

Alongside the advantages offered by this production technology to integrate knitting and making-up in one process, this knitting technique also allows new approaches in the design and styling of fashion articles and other applications. The restrictions posed by the making-up process, which also apply to regular fully fashion production, are no longer binding when using the knit and wear technique. This manufacturing process permits new paths to be explored in the production of different fits which were not possible or are only possible by using



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highly complex conventional manufacturing methods. Thus contemporary fashion trends like tight fits can ideally be supported accentuating particular body curves and lines.

- *Benefits of the knit and wear manufacturing*

Even if - depending on the actual design - the summarized knitting time for the individual components of a sweater might be less than the manufacturing of a complete sweater, the overall production time, needed to sew and finish the product, generally takes much longer. Compared to the manufacturing period required to produce, for example, a complete woman's fully fashion sweater, time savings of about 35% can be reached. This is not very surprising, considering, that steps like cutting, if still required, checking and pressing of the individual parts become obsolete. Finally linking and sewing operations do not apply either.

Depending on the production organization further stages like a build up of garment components, handling and shipping of the individual parts to the making-up locations and all relevant organizational and control efforts around these stages are not required either.

The production of complete garments is the optimal process regarding yarn consumption, since there virtually is no waste generated due to the missing cutting and sewing operations. All yarn is supposed to run into the sweater. The particular knitting process also allows the continuous use of yarn cones and facilitates and optimizes the actual yarn processing. The volume of the yarn orders can be adapted and does not need to foresee a comprehensive excess charge.

An economic evaluation of the aforementioned points indicates that due to shortened lead time the cash flow is positively activated due to an overall reduction in idle times. The streamlined process resulting in the knitting being the major production part reduces the number of personnel being involved in the manufacturing and the production control.

Further positive cost reductions are achieved by the optimized yarn consumption, minimized storage and logistic costs as well as by less expenditure for waste disposal. The decreased number of production and handling steps reduces the risk of defects and damages. As a consequence of the single piece production method, the product quality can be seen as more constant and homogenous. This helps avoiding the damage and loss caused by defective parts.

Besides its general economic advantages the Stoll - knit and wear manufacturing method makes the whole knitwear production more compact and faster. The knitwear producer controls a more reliable and simpler production process, which will allow him to accept orders more flexibly. Thus he can respond to short termed orders more easily than with any traditional production operation.

- *Supplements to the Stoll - knit and wear technology*

1. Multi - layer fabric applications
(Stoll - applications)

Both in the traditional and in the seamless production method the use of every second or even higher numbered needle permits the production of multiplied textile structures. This ability can be used either to create certain design effects or to implement specific pattern or functional applications. This way, it is possible to enhance knit fabric designs and to manufacture simple integrated pockets and structural designs on seamless garments. The same technology can be applied at conventionally fabricated knitwear to generate interesting multi - layer fabric appearances and to integrate finished collar oversteps, button tapes and complex pockets with structure effects and flaps by knitting independent fabric layers which are linked along specific lines.

2. Multi - gauge applications
(Stoll - multi gauges)

The possibility to freely apply the needle selection on modern flat knitting machines according to the knitting pattern and operation demand allows to select adjacent needles subsequently or to select needles deliberately following a particular sequence, i.e. every second, third needle etc.

On machines, similarly equipped like the Stoll CMS knit and wear machines, this feature is particularly used to combine fabric structures of different fineness. The larger hook of the fine gauge needles permits to use coarser yarn qualities and follows the idea applied for the complete garment manufacturing by working with every second needle and as such producing fabric structures of coarser appearance.

The yarn feed technique bases on the Intarsia principle, which allows the creation and free combination of various fields of different fabric fineness.

Thus particular pattern and Intarsia designs are possible, enhancing the quality of the knit fabric appearance in a way of imitating elaborately made up knits and enriching the scope of patterning possibilities.

The technique can also be applied during the making of complete garments opening up another field of design options for three dimensionally styled knit products.

**Future and alternative 3D-knitting applications**

- *Underwear and foundation garments*

In earlier times, stockings, leggings and underwear garments were traditionally produced on flat knitting machines, mostly run by hand. Nowadays by exploiting the experience gained from the Stoll - knit and wear technology and the availability of machines of fine gauges, i.e. E 18 and E 20 or with additional needle beds these garment sectors might gain in importance again for the flat knitting technology due to the new concept of ready-to-wear production combined with the above described patterning options.

In the clothing sector, the fine gauged machine range can open markets for articles worn next to the skin.

Even, if we take the impressive achievements in the development and implementation of seamless garments of the circular knitting technology into account, there is still interest in improving the actual shaping performance and the capability to get complete garments off the machine without further making up works.

If we contemplate, for example, the complex making-up involved in the production of leg wear articles, the elimination of the following work stages by an integral knitted process is possible:

- sewing together the two leg halves and adding an elastic waistband
- cutting out and sewing in the gusset insert
- closing the ends of the toes
- producing a uniform fabric quality, without seams.

There are possibilities to generate various waistband solutions added to a completely finished hose with integrally knitted in gusset section and toes regularly linked on the machine.

Thanks to a tension-controlled yarn feeding and adjustable stitch densities, the processing of elastic yarns represents no problem and permits the manufacture of a homogenous stitch quality.

The field of application ranges from a coarse-knit pantyhose and leggings in staple fiber qualities and - if required - with structured patterning in the customary gauge segment up to fine products in gauge E 18 or E 20 in an elastic multifilament quality.

In a similar way to the above described production optimization the use of the knit and wear technique might also be evaluated for other areas in the sports- and home wear or lingerie sector, partic-

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ularly, when highly labor intense work stages are involved.
Narrowing and widening processes permit the styling of contours and shapes of knitted tops and brassiere types of garments. The wedge technique can support the 3D shaping of cups. Further knit applications and structures might be applied to integrate technical details to enhance the performance and quality of the knit product.

- *Functional and medical garments*

The field of knitted compression textiles with weft or tuck inlaid pressure generating elastic yarns, covers a wide spectrum, starting with the manufacture of various forms of sport and support braces for orthopedic problems, through to custom-made compression garments for treating disorders of vein and lymph vessels as well as of wounds after burns and plastic surgery.
Flat knitted stockings are preferably used wherever high compression values are called for and the strength of the material structure needs to exert a certain supporting effect. The perfect and adaptable fit of the fully-fashioned knitted garments still raises the quality and effectiveness of these articles above most of its competitive products.
The possibility of reliably securing an elastic weft or tuck thread into a tubularly knitted formation allows the flat knitting method to combine the above-described capability of producing articles as ready to wear with the characteristics of a classical compression article. The scope for fashioning is not restricted and even allows producing complex and customized seamless gloves. The products demonstrate a good compressive effect and can be manufactured within an economically viable period on the machine. The aesthetic appearance of the products has improved by elimination of the seams, and this has been very positively received by affected patients.
If this production method is able to assert itself in today's largely automated knitwear manufacture of custom - made compression articles, we may assume that other compression products as aforementioned will be produced in the same way.

- *Knitted upholstery fabrics*

Emerging from particular specifications of car and furniture manufacturers knitted upholstery fabric variations have been developed which profit from the fashioning and shaping flexibility offered by the flat knitting technology.
Depending on the actual shape implementation and the required fastening solution, upholstering can actually take place without the need for any particular preparation and making-up process.
Particularly for automotive use possible product implementations range from the use of fully fashion knitted inserts and front panels integrated into the complete seat covers by sewing through to three-dimensionally shaped fabrics which follow the progression of the seat contours and thus cover the whole cushion surface.
Following the selected design other upholstered areas of the car interior, i.e. arm- and headrests, side panels or dashboard sections can be covered in the same manner.
A double jersey fabric version permits a wide scope and combination of jacquard and structural pattern variations. Simpler pattern forms such as plain fabrics, decorated by stripes, Intarsia and structured patterns can also be implemented by three dimensionally knitted single jersey fabrics, possibly resulting in knitted to fit slip cover bags. The enhanced elasticity of knitted fabric ensures extremely good draping and covering properties.
Besides the mostly described fashion or fashion related 3D knit applications, the production of knitted-to-use upholstery fabrics opens up a total new scope of possibilities challenging not only the textile world but also the design departments of the relevant seating industries.



**Fig. 1 Knnitted spacer structure in coarse gauge, made of glass fiber yarn**



**Fig. 2 Knitted web or interface structure of a glass fiber/p-aramid blend**



**Fig. 3**
**Spherical shaped, knitted helmet reinforcement inlay, made of glass fiber/p-aramid blend**

- *Knitted spacer fabrics*

The potential offered by three-dimensionally knitted fabrics in form of spacer textiles is still at an early stage of its development. In principle, the possibilities offered here are being met with high interest and compared to other existing production possibilities. Major benefits offered by knitted "spacer" fabrics are beside their perfect symmetrical structure the fully fashioning capability of the fabric, which permits the fabric selvedges to be neatly finished off as well as the arbitrary integration and placement of such structures in any knitted fabric.
The scope of use for these types of knitted textiles ranges:

- as upholstery elements for seats and orthopedic applications
- as dense fabrics used for protective applications
- as open-knit fabrics with large material surfaces for use in the catalytic converters
- as spacers in light-weight constructions.

The materials used can vary and are applied in each case depending on requirements. Both special high-bulk yarns, monofilaments and metal wires can be used as pile material generating either dense and compact or flexible fabric characteristics.

## Outlook

The design and application fields presented within the scope of this paper are not complete and can just indicate the potential for uses of this knitting technology. It should not be forgotten, that all the knitting possibilities mentioned here can also be combined with each other using a wide variety of either common or exceptional materials in all known construction variants. Textiles used in automotive engineering and other means of transport, in the technical and industrial field, in medicine technology, in the underwear and clothing industry, in upholstery and also in protective applications can all be three-dimensionally knitted.

knit and wear = registered trademark

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# IKME preview

## Stoll: flat knitting machines

H. Stoll GmbH & Co. KG, Reutlingen/Germany will present a cross section throughout its entire flat knitting machine program. Visitors will have an opportunity to see for themselves a wide range of machine types from all Stoll machine classes in operation in many different applications. Some interesting new products rounding off the Stoll machine program will also be on show.

One of the focal aspects of the presented machine program and its applications will be concentrating on Stoll-knit and wear. Pattern possibilities and ready-to wear article production with Stoll-knit and wear will be demonstrated with a wide range of ready-to-wear articles, from ultra coarse to extremely fine gauges.

In addition, several pattern workstations M1 will be on show with new interfaces, additional functions and modules. This will feature the latest methods for pattern development, together with applications for the acquisition of operating and machine data, all rounded off by new services for the customer when it comes to Fashion&Technology.

In addition, a new Stoll-pattern collection is being developed with current knitting trends. The very latest trend yarns will be used to present new knitting techniques and applications in all customary gauges. ❐

### Groz-Beckert: needles

In Milan, Groz-Beckert KG, Albstadt/Germany presents the product group knitting machine needles. The company informs about its new developments.

## Universal Stricksysteme: flat knitting machines

Universal Stricksysteme Vertriebs GmbH, Westhausen/Germany will show the following new and developed flat knitting machines:

- Flat knitting machine for the production of trendy "ready-to-wear" articles, type MC-844 RTW E10, with four identical systems (2x2), 80 inches, two compact carriages.
- Flat knitting machine at a reasonable price, type MC-328 E14, covering large part of the production nowadays required, with two identical systems (2 x 1, 2 x 43 inches, as well as 1 x 2, 1 x 90 inches), two compact carriages.
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- High performance flat knitting machine for Fully-Fashion, type MC-835XL E8, in particular suitable for large sizes, with three identical systems and one compact carriage
- Flat knitting machine type MC-825CXL E3 for all kinds of precious coarse gauge fabrics, with two identical systems and one compact carriage.
- Flat knitting machine for highest productivity, type MC-844 XL E5, to knit shaped fabrics, very flexible and suitable for outsize articles, with four identical systems and two compact carriages, design work station MA-8000.

### Memminger-IRO: yarn feeders

Already market-proven products, a range of product modifications as well as product improvements and innovations will be shown by Memminger-IRO GmbH, Dornstetten/Germany.

- SFE: Storage feeder for all knitted structures requiring irregular yarn demand. The following improvements can be attained. Production increase thanks to a considerable reduction of yarn breakage and a simultaneous acceleration of the machine speed. Yarn of poor quality can be made processable by installing the paraffin wax device (e.g. dry yarn, which has been stored over a longer period of time). Less knitting pieces of second quality and less wastage. Improved length consistency of the fabrics.
- EFS-620: Yarn tension controlling feeder for the infeed of bare and covered elastanes in flat knitting machines. The production of knitted garments with bare elastanes on flat knitting machines offers the following advantages: Very good shape recovery effect; less garment wear , e.g. at the sleeves. More aesthetic garment due to improved fitting. Lower stock keeping costs as bare elastanes can be processed into any color, whereas covered elastanes must be stored in all colors.
- MSF-AI: With the MSF-AI combination feeder, air-interlaced yarns can be directly produced on the machine and fed to the machine in a targeted manner.
- Rojtricot: Storage feeder with yarn separation and fixed winder body.
- MLT-Wesco: Electronic measuring device for the measurement of yarn tension, yarn length and yarn speed.

With this product program the Memminger-IRO GmbH company once more proves its corporate objective of enabling its customers the realization of reliable production solutions on an extremely high level of economical and quality-relevant aspects.

## Saxonia International: guide needles and sinkers

Under the headline of Saxonia International the worldwide operating companies Saxonia Umformtechnik GmbH, Göppingen, Saxonia Hitmetal Asia Ltd., Arrow/SI Inc., and the Bayerische Nadelleistenfabrik Leistner GmbH, Schwabach, present themselves at a common.

As worldwide leading suppliers of guide needles, sinkers and subassemblies for warp knitting machinery, flat knitting machinery, circular knitting machinery with large diameter, sock and hosiery machinery, Jacquard machinery and the general textile machine engineering Saxonia International will present the latest developments and products in the well-known OEM quality. The company Leistner produces a great variety of pin plates for stenter frames and comb bars. Among other things further improvements of wear-resistant surfaces will be on show, which have been designed for most different applications in the textile machine engineering with regard to the warp knitting and knitting field. Moreover, a further development in the rounding and hardening of looping elements as well as the production of complete subassemblies out of fine blanked elements will be presented.

On the basis of Saxonia's experience as a long-standing development supplier and the utilization of know-how resources from Saxonia International quick and uncomplicated customer-orientated and innovative solutions are offered, which fully match the requirements of our customers. For the After Sales market Saxonia offers a great range of spare parts, which mostly can be delivered ex stock.



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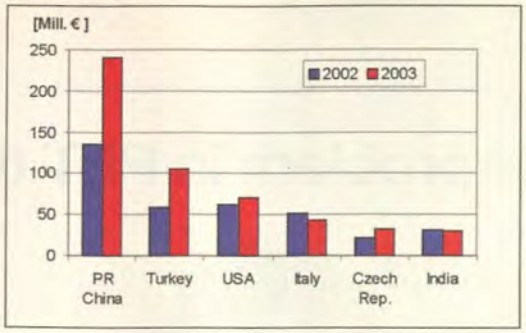
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In the first quarter of 2003 German textile machinery exports increased by 19 % with main markets in China, Turkey, USA, and Italy (see page 182 of this issue).

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# IKME preview

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# 3D-products for fashion and technical textile applications from flat knitting machines

M. Legner, H. Stoll GmbH & Co., Reutlingen/Germany

Against the trend, most of the other textile machinery sectors have experienced, the demand for modern flat knitting machines has grown steadily over the past years and kept an astonishing, relatively high level of machines being sold per year. There are both economic and technical factors to be found in order to explain this phenomenon:

Economic reasons:

- high demand for knit goods supported by knit-friendly fashion trends
- immense demand for modern machines in Far East to replace large numbers of hand knitting machines
- concentration of knitwear production, primarily in Far East, such as China, Korea and India as well as in Turkey and some Eastern European and Arabian countries with the effect to build up new and modern production units
- global supply of the world markets out of the aforementioned regions, however, also increasing domestic demands in the delivery countries due to a growing prosperity of the home population
- fast response of the traditional, trend setting knit wear production countries towards the use of new techniques to incorporate new design ideas and production concepts.

Technical factors:

- increased versatility of modern machines regarding the diversity of patterning designs
- enhanced flexibility of the machine technology towards gauge conversion and multi- or flexible gauge applications
- facilitated programming and styling of knitted articles by means of modern CAD/CAM systems, supported by mostly automated programming tools
- steadily improved technology to produce integral knit garments to revolutionize the way of garment manufacturing and to strip down the production process.

However, even if the success of the flat knitting technology has been proven as steady, there are more and more indications, that it might just be a question of time, that the era of this technology will be terminated not only due to a market saturation, which will occur somewhere along the way, but also due to new knitting technologies, which do not base on the flat knitting principle.

Lecture held at the World Congress Knitting for the 21st Century in Manchester/UK, October 7/8, 2002

Some people say that there is a growing demand among the manufacturers of knit wear products following the pressure of the powerful purchasing organizations to produce knitted textiles, respectively garments in a faster and finally cheaper way. This demand goes hand in hand with an expectation that there will be a technology available, which produces at a generally good quality level and which requires less experienced personnel to program and handle the machines.

The arguments to be found in favor for this thesis are the continued demand for cotton machines, as well as the enlarged and specifically explored use of circular knitting machines for the production of seamless knit garments, where first attempts to produce coarser gauge outerwear articles have been started as well.

In addition, there are tendencies to produce exceptionally designed fully fashion and seamless garments on tricot warp knitting machines.

These new technologies might represent possible alternatives for the manufacturing for coarser knitted articles in the future in order to achieve the aforementioned expectations, particularly as far as mass production is concerned.

Producers of flat knitting machines follow these development trends closely and are able to respond to it by showing new sides of the flat knitting technology. The way the vast patterning and design possibilities, in conjunction with the capabilities of producing 3D products, are applied to generate new designs and concepts for the general fashion industry as well as for alternative application areas is looked at more closely here.

## Scope and versatility of 3D applications for knitted fabrics

In comparison to other builders of textile machinery producing fabrics, the flat knitting machine manufacturer is caught in something of a conflict situation. On the one hand, knitting metered goods using flat knitting machines is a relatively slow process. On the other hand these machines offer a scope for design options which cannot be matched in terms of implementation simplicity as regards their styling and design versatility. Thereby fabric characteristics can easily be influenced as well.

A flat knitting machine comprises two or more needle beds, which are run over by a carriage bearing knitting systems. With every stroke of the carriage, stitches are generated or other knitting functions performed. Each stitch is created by a needle, which is selected by electronic means following a program laying down the knitting sequence of a pattern.

To knit, for example, a spherical shell, the needle on the left begins with only a few stitches, increasing the number of stitches towards the center needles and then decreasing their number again by the time needles, positioned further to the right, are reached. When this process is continued regularly with once activating the needle operation and once disabling its function, a spherical shell is produced, presuming, that every needle knits precisely the number of stitches corresponding to its section of the periphery, considering the fact, that every stitch theoretically represents an object of a constant parametrical size.

Consequently such a spherical shell is not made by a particular 3D forming device, but is generated by a 3D knitting program.

Spherical shaped objects are not the only 3D realizations possible with flat knitting machines. Within the framework of three-dimensional styling options, the following possibilities can be implemented by using all techniques of fabric forming of flat knitting machines. All these possibilities can normally be produced and even jointly applied on the same machine:

- *Voluminous knit structures*

The double bed set up is used to create two-faced knit structures which have a higher volume compared to single-face fabrics. This can lead to a considerable fabric thickness of approx. 1 cm, when applied on a machine of gauge E 3. Depending on the knitted construction, the fabric thickness can be further increased and strengthened by tuck stitch insertions.

By means of needle selection, voluminous stitch allocations can be optionally positioned in a regular knit fabric for optical design affects or cushioning purposes.

- *Spacer structures*

With this type of knitted fabric, two or more single-faced fabric sides positioned opposite to each other are joined together by stitch or tuck links. The generated volume as well as the fabric characteristics depend on the construction and the selection of the pile material by causing stuffing or springing effects.



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- *Web or Interface structures*

Here, the three-dimensional formation of the fabric is created by a knitted bridge or crosslink connection of two or more fabric layers positioned opposite each other.

By knitting the fabric layers with every second needle (1x1 needle selection), the remaining empty needles can be used for formation of the connecting webs. In this process, the length of the webs and thus also the height of the overall fabric can be optionally selected and also varied in terms of the appearance of the surface evenness. The orientation of the connecting webs can also be modified by influencing the rhythm of the stitch formation of the individual layers. The cavities created by this process could be subsequently filled, for example, by inserting reinforcing materials, pipes, cables or others.

- *Tubular structures*

With the aid of the double needle beds, tubular structures of optional diameters can be produced on flat knitting machines. Besides the production of tubes as such, tubular extensions and attachments can be implemented in a knit fabric in various manners. Knitted tubes can be placed along the selvedge or in any location of the fabric face.

- *Spherical 3D structures*

In contrast to volumetrically engineered 3D fabric forms as described, the so-called wedge technique permits the shaping of a knitted fabric in a three-dimensional, spatial way. The technique of implementing spherical curved fabrics as described before can also be applied in segments of other, more complex knit applications, such as in the heel area of stockings or contoured seat covers. During the knitting process, individual needles or groups of needles are allotted fewer stitches than others. The stitch allocation per needle can be performed along geometric fabric lines or homogeneously distributed over the surface of the knit object. This knitting method, known as the wedging technique, forms less fabric in certain sectors and more in others. This causes the fabric to take on a three-dimensional shape. This technique can be additionally supported by different stitch sizes in individual sections. Different materials and narrowing or widening processes can also be applied. Warp and weft threads can be integrated, as can floats and tuck stitches. Equally, functions such as stitch splitting and transfer can additionally extend the repertoire.

The variable use of the wedge technique opens up new possibilities for fabric styling and product customization. The immense potential of 2D and 3D shaping, which is inherent to the styling techniques of modern flat knitting machines however needs to be seen in the option to freely combine all the above mentioned techniques in - if required - one knitted product. This permits an enormous degree of design variability, which can be utilized in the development of new ways of producing and designing knit garments as well as in generating new fields of application for knit products.

**Use of 3D knitting applications in fashion**

- *From yarded goods - cut to size - to fully fashioned fabrics*

In former years, the standard method of production was to knit a length of fabric, cut out the required panels and make them up into a finished article.

Using modern electronic control systems, it is now possible to simply program a flat knitting machine in a way, that the individual needles perform precise operations to conduct intended functions. This capability has led to the success of "fully fashion" manufacturing of knitted articles. By widening and narrowing the fabric, parts are fashioned on the machine. Panels, fashioned in this way for the body and sleeve components are sewn together to create the end product. The benefits - besides enhanced optical appearance - are material savings and exact, reproducible garment sizes.

In the fashion sector, when producing conventional outerwear garments, 3D applications have been restricted largely to structural design features. These refer to familiar relief-type effects produced by interchanging plain and purl stitches, missed stitch applications and pattern formations such as cable and Aran designs.

Knit-in pockets can also be viewed at as 3D applications. Additionally, varied accumulation of stitches in the form of "wave motifs" can be termed as 3D fabric appearance.

- *From fully fashion to ready-to-wear articles*

With the introduction of the knit and wear technology by H. Stoll GmbH & Co., Reutlingen/Germany and the way to produce complete garments on flat knitting machines, an actual 3D manufacturing process is commonly applied on flat knitting machines.

This technology is based on a technique, where - when producing a pullover - three fashioned tubular parts are joined to form a finished, ready-to-wear article through knitting, transfer and linking processes.

The way, ready-to-wear garments can be designed, hardly finds any restrictions any longer, since besides structural effects, simple jacquard and Intarsia patterns, typical knitwear formations for the shoulder, neck and collar area can be applied. Thus shoulder formations such as inserted sleeves, Raglan and Saddle shoulders can be standardly incorporated in new, very fashionable variations.

The same applies to the styling of necklines and collars, which also allow common designs, however open up the creativity for new, ready made solutions as well.

The underlying knitting principle applied in the production of knit and wear articles is that of knitting with halved gauge, in which knitting takes place only on every second needle. As a result of the 1x1 needle selection, free needles remain in both needle beds which can be used for any optional transfer processes required for structural effects or narrowing operations.

Within an increasing acceptance of so-called "seamless garments", today, machines have been majorly asked for in a gauge range from E3 to E12 as concerns the appearance of the finished outerwear garments. As regards the needle bed configuration these machines are capable of producing finer gauges but are fitted with needles with a larger needle hook to allow a coarser textile look, when the knitting process is performed by every second needle.

Depending on the required knit fabric design and by the possible use of machines with additional needle or transfer beds, such as the Stoll CMS 330 TC-4 and TC-R, complete outerwear garments are also produced in finer gauges.

Looking at technical restrictions of seamless circular knitting machines to implement the perfect shape, this complete garment technology of flat knitting machines might open up their use for new or former fashion areas, which have not been of particular interest to most of the flat knitting machine manufacturers in the past.

Alongside the advantages offered by this production technology to integrate knitting and making-up in one process, this knitting technique also allows new approaches in the design and styling of fashion articles and other applications. The restrictions posed by the making-up process, which also apply to regular fully fashion production, are no longer binding when using the knit and wear technique. This manufacturing process permits new paths to be explored in the production of different fits which were not possible or are only possible by using



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highly complex conventional manufacturing methods. Thus contemporary fashion trends like tight fits can ideally be supported accentuating particular body curves and lines.

- *Benefits of the knit and wear manufacturing*

Even if - depending on the actual design - the summarized knitting time for the individual components of a sweater might be less than the manufacturing of a complete sweater, the overall production time, needed to sew and finish the product, generally takes much longer. Compared to the manufacturing period required to produce, for example, a complete woman's fully fashion sweater, time savings of about 35% can be reached. This is not very surprising, considering, that steps like cutting, if still required, checking and pressing of the individual parts become obsolete. Finally linking and sewing operations do not apply either.

Depending on the production organization further stages like a build up of garment components, handling and shipping of the individual parts to the making-up locations and all relevant organizational and control efforts around these stages are not required either.

The production of complete garments is the optimal process regarding yarn consumption, since there virtually is no waste generated due to the missing cutting and sewing operations. All yarn is supposed to run into the sweater. The particular knitting process also allows the continuous use of yarn cones and facilitates and optimizes the actual yarn processing. The volume of the yarn orders can be adapted and does not need to foresee a comprehensive excess charge.

An economic evaluation of the aforementioned points indicates that due to shortened lead time the cash flow is positively activated due to an overall reduction in idle times. The streamlined process resulting in the knitting being the major production part reduces the number of personnel being involved in the manufacturing and the production control.

Further positive cost reductions are achieved by the optimized yarn consumption, minimized storage and logistic costs as well as by less expenditure for waste disposal. The decreased number of production and handling steps reduces the risk of defects and damages. As a consequence of the single piece production method, the product quality can be seen as more constant and homogenous. This helps avoiding the damage and loss caused by defective parts.

Besides its general economic advantages the Stoll - knit and wear manufacturing method makes the whole knitwear production more compact and faster. The knitwear producer controls a more reliable and simpler production process, which will allow him to accept orders more flexibly. Thus he can respond to short termed orders more easily than with any traditional production operation.

- *Supplements to the Stoll - knit and wear technology*

1. Multi - layer fabric applications
(Stoll - applications)

Both in the traditional and in the seamless production method the use of every second or even higher numbered needle permits the production of multiplied textile structures. This ability can be used either to create certain design effects or to implement specific pattern or functional applications. This way, it is possible to enhance knit fabric designs and to manufacture simple integrated pockets and structural designs on seamless garments. The same technology can be applied at conventionally fabricated knitwear to generate interesting multi - layer fabric appearances and to integrate finished collar oversteps, button tapes and complex pockets with structure effects and flaps by knitting independent fabric layers which are linked along specific lines.

2. Multi - gauge applications
(Stoll - multi gauges)

The possibility to freely apply the needle selection on modern flat knitting machines according to the knitting pattern and operation demand allows to select adjacent needles subsequently or to select needles deliberately following a particular sequence, i.e. every second, third needle etc.

On machines, similarly equipped like the Stoll CMS knit and wear machines, this feature is particularly used to combine fabric structures of different fineness. The larger hook of the fine gauge needles permits to use coarser yarn qualities and follows the idea applied for the complete garment manufacturing by working with every second needle and as such producing fabric structures of coarser appearance.

The yarn feed technique bases on the Intarsia principle, which allows the creation and free combination of various fields of different fabric fineness.

Thus particular pattern and Intarsia designs are possible, enhancing the quality of the knit fabric appearance in a way of imitating elaborately made up knits and enriching the scope of patterning possibilities.

The technique can also be applied during the making of complete garments opening up another field of design options for three dimensionally styled knit products.

**Future and alternative 3D-knitting applications**

- *Underwear and foundation garments*

In earlier times, stockings, leggings and underwear garments were traditionally produced on flat knitting machines, mostly run by hand. Nowadays by exploiting the experience gained from the Stoll - knit and wear technology and the availability of machines of fine gauges, i.e. E 18 and E 20 or with additional needle beds these garment sectors might gain in importance again for the flat knitting technology due to the new concept of ready-to-wear production combined with the above described patterning options.

In the clothing sector, the fine gauged machine range can open markets for articles worn next to the skin.

Even, if we take the impressive achievements in the development and implementation of seamless garments of the circular knitting technology into account, there is still interest in improving the actual shaping performance and the capability to get complete garments off the machine without further making up works.

If we contemplate, for example, the complex making-up involved in the production of leg wear articles, the elimination of the following work stages by an integral knitted process is possible:

- sewing together the two leg halves and adding an elastic waistband
- cutting out and sewing in the gusset insert
- closing the ends of the toes
- producing a uniform fabric quality, without seams.

There are possibilities to generate various waistband solutions added to a completely finished hose with integrally knitted in gusset section and toes regularly linked on the machine.

Thanks to a tension-controlled yarn feeding and adjustable stitch densities, the processing of elastic yarns represents no problem and permits the manufacture of a homogenous stitch quality.

The field of application ranges from a coarse-knit pantyhose and leggings in staple fiber qualities and - if required - with structured patterning in the customary gauge segment up to fine products in gauge E 18 or E 20 in an elastic multifilament quality.

In a similar way to the above described production optimization the use of the knit and wear technique might also be evaluated for other areas in the sports- and home wear or lingerie sector, partic-



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ularly, when highly labor intense work stages are involved.
Narrowing and widening processes permit the styling of contours and shapes of knitted tops and brassiere types of garments. The wedge technique can support the 3D shaping of cups. Further knit applications and structures might be applied to integrate technical details to enhance the performance and quality of the knit product.

- *Functional and medical garments*

The field of knitted compression textiles with weft or tuck inlaid pressure generating elastic yarns, covers a wide spectrum, starting with the manufacture of various forms of sport and support braces for orthopedic problems, through to custom-made compression garments for treating disorders of vein and lymph vessels as well as of wounds after burns and plastic surgery.
Flat knitted stockings are preferably used wherever high compression values are called for and the strength of the material structure needs to exert a certain supporting effect. The perfect and adaptable fit of the fully-fashioned knitted garments still raises the quality and effectiveness of these articles above most of its competitive products.
The possibility of reliably securing an elastic weft or tuck thread into a tubularly knitted formation allows the flat knitting method to combine the above-described capability of producing articles as ready to wear with the characteristics of a classical compression article. The scope for fashioning is not restricted and even allows producing complex and customized seamless gloves. The products demonstrate a good compressive effect and can be manufactured within an economically viable period on the machine. The aesthetic appearance of the products has improved by elimination of the seams, and this has been very positively received by affected patients.
If this production method is able to assert itself in today's largely automated knitwear manufacture of custom - made compression articles, we may assume that other compression products as aforementioned will be produced in the same way.

- *Knitted upholstery fabrics*

Emerging from particular specifications of car and furniture manufacturers knitted upholstery fabric variations have been developed which profit from the fashioning and shaping flexibility offered by the flat knitting technology.
Depending on the actual shape implementation and the required fastening solution, upholstering can actually take



**Fig. 1 Knnitted spacer structure in coarse gauge, made of glass fiber yarn**



**Fig. 2 Knitted web or interface structure of a glass fiber/p-aramid blend**



**Fig. 3**
**Spherical shaped, knitted helmet reinforcement inlay, made of glass fiber/p-aramid blend**

place without the need for any particular preparation and making-up process.
Particularly for automotive use possible product implementations range from the use of fully fashion knitted inserts and front panels integrated into the complete seat covers by sewing through to three-dimensionally shaped fabrics which follow the progression of the seat contours and thus cover the whole cushion surface.
Following the selected design other upholstered areas of the car interior, i.e. arm- and headrests, side panels or dashboard sections can be covered in the same manner.
A double jersey fabric version permits a wide scope and combination of jacquard and structural pattern variations. Simpler pattern forms such as plain fabrics, decorated by stripes, Intarsia and structured patterns can also be implemented by three dimensionally knitted single jersey fabrics, possibly resulting in knitted to fit slip cover bags. The enhanced elasticity of knitted fabric ensures extremely good draping and covering properties.
Besides the mostly described fashion or fashion related 3D knit applications, the production of knitted-to-use upholstery fabrics opens up a total new scope of possibilities challenging not only the textile world but also the design departments of the relevant seating industries.

- *Knitted spacer fabrics*

The potential offered by three-dimensionally knitted fabrics in form of spacer textiles is still at an early stage of its development. In principle, the possibilities offered here are being met with high interest and compared to other existing production possibilities. Major benefits offered by knitted "spacer" fabrics are beside their perfect symmetrical structure the fully fashioning capability of the fabric, which permits the fabric selvedges to be neatly finished off as well as the arbitrary integration and placement of such structures in any knitted fabric.
The scope of use for these types of knitted textiles ranges:

- as upholstery elements for seats and orthopedic applications
- as dense fabrics used for protective applications
- as open-knit fabrics with large material surfaces for use in the catalytic converters
- as spacers in light-weight constructions.

The materials used can vary and are applied in each case depending on requirements. Both special high-bulk yarns, monofilaments and metal wires can be used as pile material generating either dense and compact or flexible fabric characteristics.

## Outlook

The design and application fields presented within the scope of this paper are not complete and can just indicate the potential for uses of this knitting technology. It should not be forgotten, that all the knitting possibilities mentioned here can also be combined with each other using a wide variety of either common or exceptional materials in all known construction variants. Textiles used in automotive engineering and other means of transport, in the technical and industrial field, in medicine technology, in the underwear and clothing industry, in upholstery and also in protective applications can all be three-dimensionally knitted.

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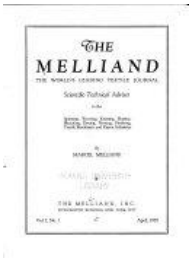
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Legner, M.,& Stoll, H. (2003, September). 3D-products for fashion and technical textile applications from flat knitting machines, Melliand International, vol. 9, issue 3 (September 2003), pp. 238-241.

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| 002 | https://web.archive.org/web/20051109095833/http://www.tx.ncsu.edu/jtatm/volume4issue3/articles/Choi/Choi_full_145_05.pdf |

8. I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

DATE: 06/17/2024

Nathaniel Frank-White
Nathaniel E Frank-White

**Please see attached All Purpose Jurat form for additional Notary Events**



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NOTARY PUBLIC
COUNTY OF CHEATHAM

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## *Fall 2002 Books*

### KNITWEAR IN FASHION

Sandy Black




Lacy dresses, glittering evening wear, body-contoured sweaters, luxury cashmere pieces, seamless lingerie. . . . From Julien Macdonald's cobweb confections and Lainey Keogh's filigree works of art, through Prada's sophisticated classics with a twist and Missoni's rainbow stripes, to Martin Margiela's avant-garde deconstructions and Issey Miyake's revolutionary clothing concept A-POC, the best of today's fashion designers are using radical ideas in knitwear design. Since the 1970s, developments in modern technology, a revival of traditional craft skills, and a new appreciation of couture workmanship have ensured knitwear's place at the forefront of fashion.

The enthusiasm for knitting is spreading to other creative fields. Fashion designers such as Jean-Paul Gaultier and Bodymap have collaborated in the creation of costumes for theater and dance. Accessory designers such as Jo Gordon and Hikaru Noguchi use knitting for their colorful and imaginative bags, scarves, gloves, and hats. Artists, including Maria Blaisse and Freddie Robins, inspired by experimental yarns and fabric processes, are creating knitted installations for museums and galleries. Product designers capitalize on the unique visual and light-filtering qualities of knitted fabrics to create remarkable furnishings, sculpture, lighting, and jewelry. Whether hand-knitted or industrially produced, whimsical or theatrical, ingenious or just plain beautiful, these pieces are all stunning examples of the new vogue in knitting.

Lavishly illustrated with color photographs, *Knitwear in Fashion* shows off the best in international knitwork. An extensive reference section covers the technology of knitting, developments in design, and new fibers, and includes a glossary of technical terms and biographies of designers. This book is essential for anybody concerned with textiles, fashion, or contemporary design.

Sandy Black is a Lecturer at the London College of Fashion.

ISBN 0-500-51084-9 · 8 $^{1}/_{4}$" x 11 $^{5}/_{8}$" · 300 illustrations, 285 in color · 192 pages · FASHION / DESIGN

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## *Refereed Articles*

**Size-specific Analysis of Body Scan Data to Improve Apparel Fit**

**Suzanne Loker, Susan Ashdown, and Katherine Schoenfelder**
**Cornell University, Department of Textiles and Apparel**
**326 MVR, Cornell University, Ithaca, NY 14853**

Preview First Page

Complete Article

**ABSTRACT**

This paper describes how size-specific analyses of body scan data of an apparel company's target market can provide information that can be used to adjust ready-to-wear sizing to improve apparel fit. We describe a variety of size-based statistical and visual analysis methods that can be applied to target market body scan data. These analyses begin to describe and address the variety of body shapes and measurements that exist within a sizing system and identify potential design adjustments that could be made in order to increase the percent of acceptable fit within each size category for a target market.

KEYWORDS: apparel, body scan, fit, sizing system

**THREE DIMENSIONAL SEAMLESS GARMENT KNITTING ON V-BED FLAT KNITTING MACHINES**

**Wonseok Choi, Ph. D. Student**
**Nancy B. Powell, Associate Professor**
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Preview First Page

Complete Article

**ABSTRACT**

Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.

The purpose of this research is to review the principles of seamless knitting on V-bed machines and to compare the machines from two major flat-knitting machine suppliers, Shima Seiki and Stoll. This paper will also discuss characteristics and applications of complete garment knitting in various products. This research was accomplished through interviews and a review of the literature. It has implications for academicians and industrial personnel who require information in three dimensional knitting technology and related machinery.

KEYWORDS: Knitting, tubular, seamless, complete garment

**Behavior of Prepared-For-Print Fabrics in Digital Printing**

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Complete Article

**ABSTRACT**

Engineered print design for sewn products can reduce material waste and facilitate customized design of textile products. But, digital printing systems must produce output

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reliably and consistently for integration into a production process. This study examined changes in dimension and grain alignment of digitally printed and post-treated prepared-for-print (PFP) cotton fabric. Following post-treatment, substantial shrinkage and some skewing of the printed design was found. Furthermore, dimensional change results from one fabric were not predictive of results for a second fabric. These performance concerns impact end product quality and adaptability to the production environment. Future work should focus on delineating an optimum set of pretreatment conditions for PFP fabrics that will result in proper grain orientation and minimal, predictable shrinkage.

KEYWORDS: Digital textile printing, Print Design, Engineered Print, Ink jet printing, Prepared-for-print Fabric, Printing Quality

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**TAKING ADVANTAGE OF THE DESIGN POTENTIAL OF DIGITAL PRINTING TECHNOLOGY FOR APPAREL**

**J.R. Campbell, Associate Professor, Iowa State University**
**1073 Lebaron Hall**
**Ames, IA 50011**
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**Jean Parsons, Assistant Professor, Iowa State University**
**1071a Lebaron Hall**
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Complete Article

**ABSTRACT**

The integration of digital technologies into apparel forms allows designers to explore and visualize new creative possibilities. How the technology is used and how design concepts are perceived in the industry are areas of crucial importance to the technology's longevity. Our goal, as collaborative artists, focuses on integrating technology into the creative process to create both art and industry-oriented apparel. The applications of digital textile and apparel design have implications for many areas of the industry, but we have focused on three: art-to-wear, custom design, and mass customizable products. The body of research and artwork that we have developed suggests that a systematic approach to integrating new technologies into the textile and apparel design process can be developed, recorded and employed in future design explorations to inspire the most rapid technology integration with the greatest potential for new product conceptualization.

KEYWORDS: Digital textile printing, apparel design, design process, art-to-wear

---

**Expanding Garment Functionality through Embedded Electronic Technology**

**Lucy E. Dunne[1], Susan P. Ashdown[2], Barry Smyth1**

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**Department of Textiles and Apparel**
**Cornell University**

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Complete Article

**ABSTRACT**

Electronic technology offers exciting new possibilities for functional clothing design. Technology allows a garment's functionality to become dynamically adaptable, changing in response to environmental or situational changes. However, there are many challenges to integrating electronic technology into a textile-based garment structure. This paper outlines some of the possibilities and challenges to apparel designers in this new field, and highlights the importance of the apparel design perspective in the successful design of wearable technology.

KEYWORDS: Wearable technology, smart clothing, wearable computing, functional clothing, apparel design

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**FIT ANALYSIS OF LIQUID COOLED VEST PROTOTYPES USING 3D BODY SCANNING TECHNOLOGY**

**JinHe Nam, Ph.D. Student/Graduate Research Associate**
**College of Human Environmental Sciences Design,**
**Housing & Merchandising**
**Dr. Donna H. Branson, Dr. Huantian Cao, Dr. Byoungho Jin,**
**Semra Peksoz and Dr. Cheryl Farr**
**Oklahoma State University,**
**Stillwater, OK, 74078, U.S.**

**Dr. Susan Ashdown**
**Cornell University,**
**Ithaca, NY, 14853, U.S.**

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**ABSTRACT**

First responders are frequently exposed to hazardous materials and hostile environments that necessitate wearing specially devised personal protective equipment (PPE). Personal cooling garments play an important role in reducing thermal stress associated with wearing insulative and impermeable PPE. As conduction is the primary cooling mechanism for liquid cooled garments (LCGs), there is need for intimate contact between the skin and garment. The fit of two liquid cooled vests was compared and analyzed through use of a3D body scanner. Visual images from thirteen volunteer subjects,

primarily first responders and life safety specialists, were used to evaluate the fit of both cooling vest prototypes. Perceptual data from the subjects provided user feedback on the prototype vests. The results indicated that both prototypes received high scores in the expert fit ratings although prototype II received higher ratings in many body areas. Ratings from the subjects' perceived fit ballot also indicated that prototype II was rated higher although both vests received high marks.

KEYWORDS: 3D body scanning, anthropometric data, cooling garment, LCGs, cooling vest, liquid cooled vest, fit analysis

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Complete Article

**Understanding Aesthetic Preference:**
**Approaches Toward Improved Product Development**

**Janet Hethorn**
**University of Delaware**
**jhethorn@udel.edu**

**ABSTRACT**

Every garment has a visual presence and every garment provides physical qualities in relationship with the body. In the design process, both functional and aesthetic attributes contribute to the overall success of the complete apparel system for the consumer. New developments in technology and materials have generated interesting applications toward this goal through functional design research. Research on aesthetic preference – consumer visual response and desire- is also taking advantage of these opportunities. This paper highlights the possibilities and the roadblocks present in exploring aesthetic issues, in combination with other factors in the design process. Several examples are provided of design research on aesthetic preference and new possibilities are suggested that take advantage of emerging technology directions.

KEYWORDS: aesthetic preference, visual style, appearance, design process

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**BIOMECHANICAL ANALYSIS OF A PROTOTYPE SPORTS BRA**

**Cathy Starr, Oklahoma State University, College of Human Environmental Sciences, Design, Housing, & Merchandising, 431 HES, Stillwater, OK 74078, (405)-744-5035, bcstarr@provalue.net**
**Dr. Donna Branson, Oklahoma State University-CHES, DHM, 431 HES, Stillwater, OK**
**Dr. Randa Shehab, University of Oklahoma, College of Engineering, Norman, OK**
**Dr. Cheryl Farr, Oklahoma State University-CHES, DHM, 431 HES, Stillwater, OK**
**Dr. Shiretta Ownbey, Oklahoma State University-CHES, DHM, 431 HES, Stillwater, OK**
**Dr. Jane Swinney, Oklahoma State University – CHES, DHM, 431 HES, Stillwater, OK**

**ABSTRACT**

A Latin Square Experimental Design was used to compare a prototype sports bra previously developed for large-busted women, with two other sports bras through a controlled laboratory wear study. Vertical breast displacement data were gathered by videotaping the first three running strides of six large busted active females recruited from local fitness centers. Multiple regression results found that the garment treatment significantly related to the breast displacement experienced by subjects during each test session [$F(2,213) = 16.393$; $p < .0001$]. Approximately 13% of the variability in breast displacement was predicted by garment, indicated by the Squared Multiple Correlation Coefficient. ANOVA results found significant subject, garment, and subject-by-garment effects. Subjects wearing garments A and B had a lower level of vertical breast displacement of .031" as compared to subjects wearing garment C with .045" of displacement.

KEYWORDS: biomechanical research, sports bras, brassieres, vertical breast displacement, breast discomfort, female exercise, and human motion.

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Complete Article

**Fabric Drape Measurement: A Modified Method Using Digital Image Processing**

**Narahari Kenkare and Traci May- Plumlee**
**College of Textiles,**
**North Carolina State University,**
**Raleigh, N.C. 27695**

**ABSTRACT**

The textile and clothing industry has traditionally used Cusick Drapemeter for the assessment of fabric drape. In this paper, a modified method of measuring fabric drape using the Cusick Drapemeter was demonstrated. The modified method involves digitally capturing image and processing it in simple steps using image processing software. The study was conducted using a range of woven fabric samples. The fabrics were conventionally evaluated using the Cusick Drapemeter (British Standard Institute: BS5058, 1974). Digital images of the draped fabrics were captured and processed as well using the modified method. Drape coefficient was selected to use as the comparative parameter to evaluate the results from conventional and digital method. The average drape coefficient of each fabric sample obtained through the conventional cut-and-weigh technique was compared statistically with that obtained through the modified digital technique. The study demonstrates that results of the modified digital method for evaluating drape were similar to that of conventional method of drape evaluation.

KEYWORDS: Fabric Drape, Cusick Drapemeter, Testing Instruments, Textile Measurement

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**The Critical Success Factors of Sourcing Production for Small and Medium-sized Clothing Firms in Hong Kong**

Preview First Page

Complete Article

**Fung-yi Tam, Ka-leung Moon, Sau-fun Ng, Chi-leung Hui**
**Institute of Textiles and Clothing, the Hong Kong Polytechnic University,**
**Hung Hom Kowloon Hong Kong**

**ABSTRACT**

The main purpose of this paper is to identify the critical success factors (CSFs) of sourcing production, and to study the impacts of production sourcing strategies, buyer supplier relationships and firm-related characteristics on the level of satisfaction with sourcing performance. Using a multiple case methodology to study ten firms and a two-phase data collection approach, in-depth interviews and mail questionnaires, we found that the industrial sector is the only firm-related characteristic that has an influence on sourcing performance satisfaction. Also, the firms that have adopted insourcing were more satisfied with their sourcing performance than those that adopted outsourcing. Based on the level of satisfaction with a firm's sourcing performance, we identified three main CSFs for production sourcing: (1) to build relationships with production provider personnel at all levels, (2) to develop a comprehensive communication plan with production providers; and (3) to choose the production providers carefully.

KEYWORDS: Small and medium-sized enterprises (SMEs); production sourcing strategy; critical success factors (CSFs); performance satisfaction; buyer-supplier relationship

## *Scholarly Works*

**An Analysis of Apparel Industry Fit Sessions**

**Elizabeth Bye and Karen LaBat**
**University of Minnesota, F240 McNeal Hall**
**1985 Buford Ave, St. Paul, MN 55108**

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Complete Article

**ABSTRACT**

The fit session is the main point of evaluation for a garment during the product development process. This paper presents an analysis of the perceptions and practices of apparel industry professionals regarding best practices and areas for improvement for fit sessions. Participants from a large manufacturer of athletic apparel, including designers, merchandisers, product development managers, and pattern makers a responded to a survey. Their responses suggest that fit sessions encompass product development decisions that extend beyond the fit of the garment. The evaluation of the design is of equal importance. Recommendations are made to address the organization and communication of industry fit sessions with suggestions for using new technology to improve garment fit.

KEYWORDS: fit, fit session, sizing, apparel

**Branding to Compete: Applications to Textiles and Apparel**

**Shanna M. Bruer, Ph.D. Student**
**Nancy Cassill, Professor**
**Michelle Jones, Assistant Professor**
**NCSU**

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Complete Article

**ABSTRACT**

Purpose: The objective of this paper is to briefly review competitive strategies that are relevant to the U.S. textile and apparel industry, focusing specifically on differentiation and branding methods. The various approaches and strategies are then applied through specific examples and illustrations.

Methodology: A comprehensive review of secondary data sources, both research and trade combined with primary data sources (via industry interviews) are reviewed. Results are presented as the differentiation typology proposed by Barney (2002).

Findings: Numerous competitive strategies can aid textile and apparel firms in preserving and/or improving their current market position. A specific strategy used, branding, aids in the differentiation of product throughout both the textile and apparel industry.

Practical Implications: The compilation of literature on differentiation and branding will be useful in further research and studies that focus on textiles and apparel or those that are concerned with product differentiation. Direct applications to both textile and apparel firms are made and a potential structures by which they may develop brands is introduced.

Value of Paper: The paper will aid both academia and industry in the development of textile and apparel brands through the introduction of literature on the topic, as well as recommendations on brand strategy and creation.

KEYWORDS: Competitive strategies, Differentiation, Branding, Private label, Textile and apparel industry

**Clothing Branding Strategies: Influence of Brand Personality on Advertising Response**

**António Azevedo, Assistant Professor,**
**Fernando Pessoa University, Portugal**

**Minoo Farhangmehr**
**Universidade do Minho, Escola de Economia e Gestão,**

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Complete Article

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**ABSTRACT**

This paper examines the influence of brand personality on advertising response in fashion clothing branding context. Print ad stimuli of 30 fashion clothing brands with different nationalities and different expected personalities were evaluated by young students (16-25 years old) in terms of Brand Personality Scale of Aaker (1997). The self-congruence implications are discussed. From the brand builder perspective, some benchmarks brands were identified. The results should help the understanding of antecedents and consequences of brand personality processing.

KEYWORDS: Brand personality, fashion clothing branding, advertising, self-congruence, youth market.

**Sustainable Development: Building a Case for Hemp**

**Tun Lin, M.A., Graduate Student**
**University of Cambridge**

**Catherine Chan-Halbrendt, Ph.D., Professor of the Department of Natural Resources and Environmental Management, The University of Hawaii**
**College of Tropical Agriculture and Human Resources**

**Pauline Sullivan (contact person), Ph.D., Associate Professor**
**Florida State University, College of Human Sciences**
**Department of Textiles and Consumer Sciences**
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**E-mail: pmsullivan@mailer.fsu.edu**

**ABSTRACT**

Objectives of this paper are to discuss hemp within the context of sustainable development and examine the economic impact of establishing a hemp sector in rural U.S. locations. This study focuses on the textile industry and examines the interlinking industry impacts from hemp production, fiber processing, and apparel manufacturing. First this paper discusses hemp cultivation in terms of sustainable development, secondly we identify its performance attributes, thirdly we talk about the market for hemp products, fourthly we describe the manufacturing and processing of hemp, and then we describe our input-output model, its analysis of a hemp sector, and research findings. Establishing one hemp apparel manufacturing firm and processing plant appears to be comparable to establishing one cotton apparel manufacturing firm and processing plant in terms of total industry output and employment based on the assumptions of the study.

KEYWORDS: Hemp sector, textile industry, economic impact, sustainable development

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*Volume 4, Issue 3, Spring2005*

# THREE DIMENSIONAL SEAMLESS GARMENT KNITTING ON V-BED FLAT KNITTING MACHINES

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## ABSTRACT

*Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.*

*The purpose of this research is to review the principles of seamless knitting on V-bed machines and to compare the machines from two major flat-knitting machine suppliers, Shima Seiki and Stoll. This paper will also discuss characteristics and applications of complete garment knitting in various products. This research was accomplished through interviews and a review of the literature. It has implications for academicians and industrial personnel who require information in three dimensional knitting technology and related machinery.*

*Keywords: Knitting, tubular, seamless, complete garment*

## 1. INTRODUCTION

Seamless knitting technology creates one entire complete garment with minimal or no cutting and sewing process. This innovative technology eliminates post labor work, which saves production time and cost. In addition, the technology offers knitwear consumers more comfort and better fit by eliminating seams. Thus, seamless technology provides benefits to manufacturers as well as end users. Seamless knitting technology has entered the mainstream in the knitwear market.

Through this research, principles of seamless knitting techniques are discussed, and two major suppliers for V-bed machines, Shima Seiki and Stoll, and machine characteristics will be introduced. In addition, advantages and disadvantages of this type of production are revealed. In order to understand the seamless knitting technology, it is important to review the fundamentals of the knitting process. By a review of the evolution of the knitting process, an explanation of knitting methods, and the description of knitting machines' characteristics, the distinctiveness of seamless knitting will be better understood.



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*Volume 4, Issue 3, Spring2005*

# THREE DIMENSIONAL SEAMLESS GARMENT KNITTING ON V-BED FLAT KNITTING MACHINES

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## ABSTRACT

*Since the introduction of seamless garment knitting techniques on V-bed machines in 1995, this technology has been considered an innovative process and is currently growing in its commercial application around the world. By eliminating the cutting and sewing processes, complete garment knitting provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages.*

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## 1. INTRODUCTION

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This research was achieved through a review of the literature and additional primary data was collected through interviews, company visits, etc.

### 1.1. Knitting Fundamentals

To fully examine the developments in seamless knitting, a basic foundation of knitting construction and characteristics should be discussed. Knitting is defined as "the process of forming a fabric by the intermeshing of loops of yarn" [22] and knitting accounts for more than 30% of total fabric production [24]. The end use of knitted fabrics, created either in tubular or flat form, can be apparel and other products including sweaters, underwear, hosiery, socks and stockings.

Knitting is classified into two fields, weft knitting and warp knitting. In weft knitting, loops are formed in a horizontal direction whereas in warp knitting, loops are formed in a vertical direction [1] (Figure 1.1a and 1.1b). Weft knitting is more resilient, more open and has additional design possibilities as compared to warp knitting. Conversely, warp knitting has less resilience, more cover, lighter weight and higher productivity. Weft knitting can be divided into circular knitting and flat knitting according to type of fabric, type of needle, and form of needle bed. In the circular knitting machine, needles are set radically or parallel in one or more circular beds [3]. On the other hand, a flat knitting machine employs straight needle beds carrying independently operated needles, which are usually of the latch type [3].

Compared to flat knitting machines, circular weft knitting machines provide higher productivity. Thus, circular knitting machines have more rapid production speeds than weft knit flat bed machines. However, flat knitting machines have greater versatility in loop structure combinations and patterning because their machine cams can be changed after every course (even after every stitch), and they are able to knit one or both beds easily [52]. It should also be noted that electronic circular machines have the same capability.

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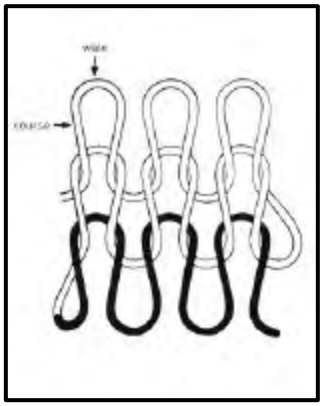



*Figure1.1a. Weft knitting*

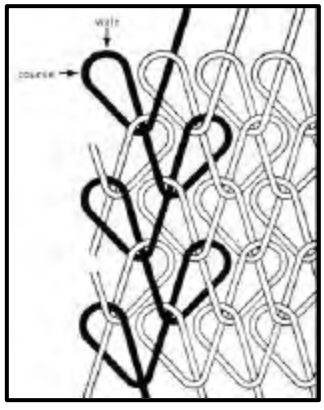



*Figure 1.1b. Warp knitting* (Black, 2002



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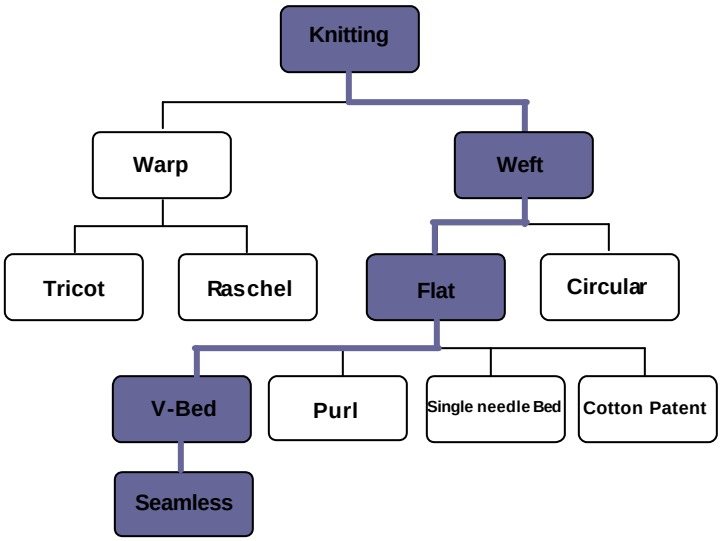



*Figure 1.1c. Knitting Classification Diagram*

Spencer defines cams as "the devices which convert the rotary machine drive into suitable reciprocating action for the needles" [42]. Figure 1.1d shows the knitting action of latch needles for the cam track on a V-bed knitting machine. According to the position of needle butts moving up and down through the cam system, the loop can be formed sequentially [34].

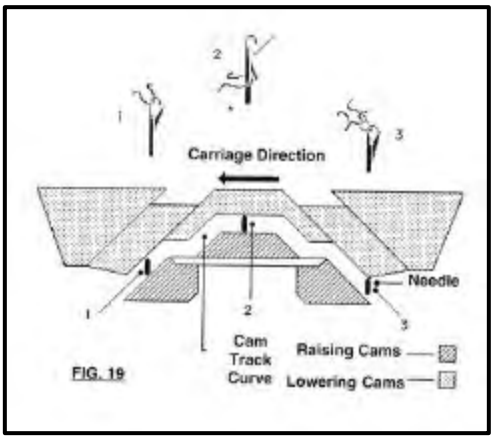



*Figure 1.1d. Knitting action of latch needle though cam track*
(Raz, 1991)

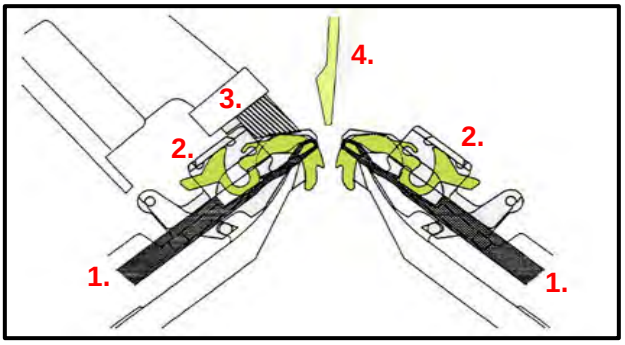
Figures 1.1e and 1.1f illustrate the basic knitting machine parts on a flat bed machine including a carriage, latch needles, sinkers, brushes, yarn carriers and take down rollers. A carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam [34].

The latch needle, the most widely used needle in weft knitting, is mainly composed of a needle hook, a latch, and a needle stem (Figure 1.1g). The major advantage of the latch needle is that it self acts or controls the loop so that individual movement and control of the needle permits loop selection to be accomplished [42]. The sinker is another primary element in knitting. Main purposes of the sinkers are loop formation, holding down, and knocking-over [42]. However, the role of sinkers on a V-bed knitting machine with latch needles is chiefly a holding-down function. Therefore, holding down sinkers are capable of tighter fabric structures with an improved appearance. The purpose of the brushes is to open the latches at the first course when the machine starts to knit and to avoid any closing of the latches [21]. The yarn carrier or yarn feeder is pulled along the needle bed by the carriage and introduces and feeds yarns required for knitting. The yarn carrier is assembled on a dovetail-profiled rail [34]. Take down rollers are needed to prevent the previous loop, which is located in the hook enclosure, from riding up with the needle ascension. This is very crucial for loop formation because without take down tension the previous loop will not slide under the latches and new loops will not be formed without the operation of the take down rollers [34].

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1. Latch needles
2. Sinkers
3. Brushes
4. Yarn Carrier (Feeder)

*Figure 1.1e. Knitting machine system on flat V-bed machine* (Shima Seiki Manual [37])

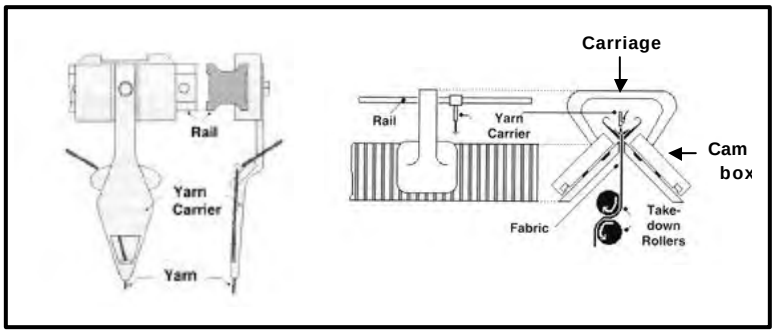



*Figure 1.1f. Yarn Carriers, Carriage and Take-down Rollers* (Raz, 1991)

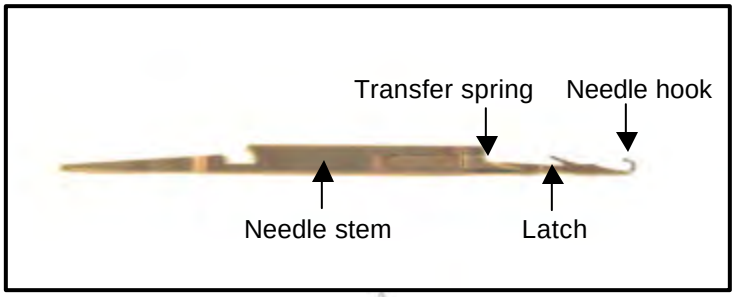



*Figure 1.1g. Latch needle on Shima Seiki Machine*

Flat bed machines have four different classes; (i) *V-bed flat machines* which have two inverted V-formed needle beds; (ii) *Purl machines* which have double ended needles; (iii) machines that have *a single bed* of needles which include most domestic models and a few hand manipulated intarsia machines [40]; and (iv) *Cotton patent machines* which are single-bed machines with bearded needles arranged vertically [1]. Bearded needles are the needles having an extended terminal hook or beard that can be flexed to close the hook [22].

## 1.2. Historical Events Contributing to the Development of Seamless Knitting

In the evolution of seamless knitting it is important to review the developments in knitting that directly affect three-dimensional knitting techniques. Kadolph and Langford [12] explain that historical remnants of knit fabrics have been dated from A.D. 250 in the Palestine area. Knitting was accomplished by a hand process until 1589, when William Lee in England invented a flat-bed weft-knitting frame to create hosiery [12]. The first operational V-bed flat knitting machine using latch needles was invented in 1863 by



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Issac W. Lamb [34]. William Cotton of Loughborough took out a patent in 1864 for his rotary-driven machine that used a flat bed to produce fully-fashioned garments [16]. According to Hunter [9], in the 1800's, the flat knitting machine was fitted with sinkers, which controlled loops in order to knit single jersey tubular articles such as gloves, socks and berets. In 1940, the manufacture of shaped knitted skirts was patented in the USA. This permitted darting on knitted skirts using a technique called "flechage" (See glossary). The flechage technique not only improved drape and fit, but cut production cost. In 1955, the Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaping of components. In the 1960's, the Shima Seiki company further explored the tubular-type knitting principle commercially to produce gloves. Also, in the mid1960's, engineers at Courtaulds in the UK established British patents on the idea of producing garments by joining tube knitting. However, the method was too advanced to be commercialized at that time. By 1995, Shima Seiki fully developed shaped seamless knitting [9]. Recently, by employing more advanced computerized systems, simpler programming was possible, and the computerized systems enabled the production of more complicated and sophisticated knitted structures and products. Table 1 introduces the historical events of seamless knitting.

| Year | Historical Events Contributing to Development of Seamless Knitting |
|---|---|
| 1589 | William Lee in England invented the first flat-bed frame to create hosiery. |
| 1863 | Issac W. Lamb invented the first operational V-bed flat knitting machine including the latch needles. |
| 1864 | William Cotton of Loughborough patented his rotary-driven machine that used a flat bed to produce fully-fashioned garments |
| 1800's | The flat knitting machine was fitted with sinkers, which controlled stitches in order to knit single jersey tubular articles such as gloves, socks and berets. |
| 1940 | The manufacture of shaped knitted skirts using a "flechage" technique was patented in the USA. |
| 1955 | The Hosiery Trade Journal reported on the automatic knitting of traditional berets through the shaped sections. |
| 1960's | Shima Seiki company further explored the tubular-type knitting principle to produce gloves commercially. |
| 1960's | Courtaulds established British patents on the idea of producing garments by joining tube knitting. |
| 1995 | Shima Seiki introduced seamless entire garment knitting at ITMA. |

*Table 1. Historical Events Contributing to Development of Seamless Knitting*

Seamless entire garment knitting was introduced in 1995, at ITMA, the International Textile Machinery Association [24]. Seamless knitting, or complete knitting, which produces one entire complete garment without a sewing or linking process, provides a variety of advantages in knitting production such as savings in cost and time, higher productivity, quick response production and other advantages. In Section 2, numerous advantages of seamless garment knitting are discussed.


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## 2. ADVANTAGES OF SEAMLESS GARMENT KNITTING

In general, V-bed knitting process has more flexible needle selection capability and more design possibilities compared to warp knitting process [2]. Through computerized flat bed knitting, more variety of knit patterns and structures can be created and designs can be instantly and efficiently changed through a computer-aided design system. Furthermore, seamless garment knitting makes it possible not only to create several types of tubular formed knitting but also to build diverse design structures on the tubular knitted garments simultaneously.

Complete garment knitting offers a variety of benefits in technical aspects as well as in the market demands. For benefits to the market, quick-response production and just-in-time production are possible. The required number of products can be quickly knitted in less time to meet the needs of the market. It also enables mass customization for many markets. Onal states "Mass customization is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology" [29]. In certain markets, seamless knitting could be considered for mass customization by rapid design changes according to customers' requirements through computerized knitting systems. Seamless knitting systems may be utilized for sampling prototype and for niche market limited production items.

For the focus of this paper, the benefits of seamless technology are mainly discussed. First, there is no longer the traditional labor-intensive cutting and sewing process because of eliminating seam production. Hence, the tubular-typed seamless knitting results in potential savings in terms of production time and cost. For instance, according to Melliand International, in the case of a complete woman's knit sweater, a time saving of about 35% can be achieved with seamless knitting [20]. Additionally, yarn consumption can be minimized by complete garment knitting as well as by effectively analyzing yarn feed through the computerized system on the machine [7]. The DSCS (Digital Stitch Control System) on Shima Seiki machine predetermines how much yarn is required for the each stitch. Loop size can be controlled accordingly and there is much less stress on the yarn at the sinker. According to Mowbray, this device not only permits a variety of types of yarns to be used but also offers maximum production efficiency because higher speeds can be achieved [26]. The range of gauges for complete garment machines varies from 5 gauge to 18 gauge. Seamless garment knitting technology adds flexibility through gauge conversion and multi-gauge knitting [20]. The capability of multi-gauge application allows the conversion of gauges in the same machine. As a result, it saves time and cost for investing in different machines for every gauge.

In garments, three-dimensional knitting is purported to give lightness and softness in knitwear because there is no linking and sewing production [39]. In addition, there are no bulky and annoying stitches at the underarm points, shoulders and neck lines [39]. For finished edges, the garment can have better trimmed edge lines through a machine binding-off process instead of a sewing or linking operation.

In decreasing the number of production processes such as the cutting or sewing steps, the risk of defects and damages can also be minimized. A single entire piece production method is claimed to provide more consistent product quality [20]. Consequently, seamless knitwear is promoted to look better, fit better and is believed to be much more comfortable than a traditional fully-fashioned piece of knitwear. Seamless knitting also allows knit designers to create design structures and patterns across the entire garment. Designers can easily program and style both more sophisticated design structures and shaped patterns through the computerized design system.



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Finally, in the global environment, according to Shima, seamless garment knitting puts less stress on the environment by minimizing waste disposal and reducing the need to grow as much as cotton, wool and other natural raw materials [26].

## 3. TECHNICAL ISSUES

Although seamless garment knitting technology provides a variety of advantages for the knitting industry, it still has several technical issues to be considered. The main problem in complete garment knitting has been fabric take-down [10]. To keep equal tension of each loop (i.e., stitch), diverse sinker systems and take-down tension systems have been utilized. Finally, the novel sinker systems such as a spring-type moveable sinker system and a computerized take-down tension system, appropriate to complete garment knitting, have been developed to solve the problem. Even though the systems have brought higher stability for knitting, there is the opinion of users that it still is not easy to control an exact take-down tension for the complete garment.

Complete garment knitting also has a problem caused by the alternate needle selection. The alternate needle selection knitting makes fabrics more open and less elastic than conventional fully-fashioned garments [27]. This problem occurs in the welt or the cuff areas. A welt in knitting means "a secure edge of a fabric. The welts are usually at the starting end of the fabric" [22]. To solve the looser fabric problem, it is critical to select appropriate yarns for the machine gauge; and in this context, elastic, flexible and durable yarns are recommended such as wool. For instance, a Yorkshire spinning company in the UK uses the elastic Spirol® lamb-wool on the cuffs and the collars, which can be knitted tighter like a fully-fashioned product [27]. In the current global knitting industry, natural fibers, such as wool, cashmere and angora, and manufactured fiber such as acrylic are mainly used to create seamless garments for outerwear [11]. Viscose and polyamide with Lycra® or other elastomerics are also utilized for complete garment knitting [11]. Cotton is also a popular fiber used in seamless apparel.

Another issue for complete garment knitting is that if the garment has a defect during knitting such as a hole or a barre' problem, the entire garment is useless and must be discarded. Pratt explains "Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric" [32]. Compared to fully-fashioned knitting, there would be more waste when the complete knitted garment has any defect. In cut and sewn production pattern pieces could be placed for cutting on a flat piece of fabric to avoid any defects.

## 4. APPLICATIONS OF SEAMLESS KNITTING

Seamless garment knitting on the V-bed machine has primarily been used for apparel. However, in recent years, this new three-dimensional knitting technique has been extended in other areas such as fashion, upholstery, industrial, automotive, and medical textiles.

### 4.1. Apparel (Figure 4.1)

A diverse range of seam-free products can be created such as hand gloves, hats, socks, and sweaters according to the machine gauge and types of machine. Additionally, patterns for knitted trousers and skirts are available on the complete knitting machines. As far as design structures, most knit structures knitted on fully-fashioned machines can be created on the seamless garment machines such as cable stitches and even intarsia structures.
(See glossary for structures.) [33]

### 4.2. Upholstery (Figure 4.2)

Several upholstery companies are utilizing three-dimensional seamless seat upholstery production. The Teknit Company offers three-dimensional knit upholstery for the office chair market. Teknit creates shaped three-dimensional polyester seat covers that compete against woven fabric, which


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requires a cutting and sewing process [43]. According to Teknit, lead times are substantially lower than conventional woven fabric and the office chairs covered with seamless knitted fabric are their fastest selling line. The company also has the capability of promoting rapid design changes by using sophisticated CAD systems [46]. Additionally, seamless shaped knitting with its inherent stretch characteristics follows the contours of the seat, providing better seat trimming [46]. It enhances appearance and enables users to feel more comfortable by eliminating ridges caused by a sewing or a linking process.

### 4.3. Automotives

Courtaulds and General Motors Corporation developed the three-dimensional knitting technique to produce seat covers in 1985 [40]. Marjorie Sorge proposed that automotive seat covers made by seamless knitting also provide great potential for the automotive market in that the three dimensional knitting process cuts lead time by eliminating cut-and-sew operations, brings down warranty costs and adds quality [40]. Lear Corporation which owns patents on three-dimensional knitting technologies claimed the ability to design new seats using a predictive computer model which reduced the time needed for seat design by 25% [31]. Seamless knitting for automotive also provides a potential for designing a more ergonomic seat through the ability to alter the knitted tube size.

### 4.4. Medical textiles

Recently, specialty textiles created by three-dimensional flat bed knitting machines have also been applied to medical textiles. Tubular typed knitted structures such as bandages, orthopedic supports, and medical compression stockings have been developed. In the future, it is expected that more advanced and sophisticated medical textiles created by seamless knitting technology would be produced. The incorporation of high performance fibers and additional sensors or electronics could provide further opportunities for seamless products in healthcare applications.

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*Figure 4.1. Seam free garment created on Shima Seiki WholeGarment® Machine* (Shima Seiki, 2003)



*Figure 4.2. Claud 9™ Chair created by NeutralPosture®* (*NeutralPosture, 2004*)



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Each of these market applications has specific performance requirements and specialized aesthetics. In order to use this technology to fulfill these market needs, the principles of knitting and knitwear production, and the evolution of seamless knitting need to be reviewed.

## 5. EVOLUTION OF THE KNITTING PROCESS FROM CUT AND SEWN PRODUCTION TO SEAMLESS GARMENT KNITTING

As described in Table 1, the knitting industry has gradually developed since William Lee of Calverton successfully converted the actions of hand knitting with two needles into a mechanical process. Lee's work was the first attempt at mechanizing hosiery knitting in 1589 [16]. Since the invention of the frame-knitting machine, knitting technology has progressed from hand flat machines to complete garment-knitting machines. Section 5.1, 5.2, and 5.3 will explain the evolution of the knitwear process from cut-and-sew production to seamless knitting.

### 5.1. Cut and Sew Production

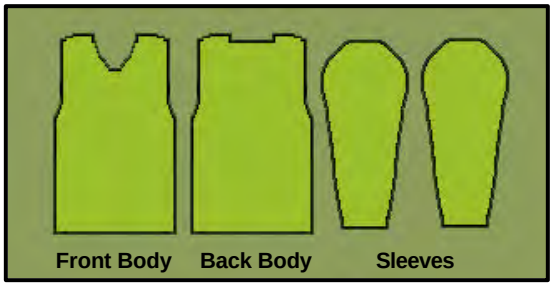



*Figure 5.1. Cut and sew production*
(Shaded area: Cutting Waste)

Cut and sew production is created by the use of one entire panel of fabric. Figure 5.1 shows the cutting layout for the front and rear body portions and also the sleeve portions required to create a sweater. Through the cutting and sewing process, the finished garment is created. However, this garment production process requires several post-knitting processes including cutting and sewing. Additionally, in this process, separately knitted trimmings and pockets need stitching. The Shima Seiki Company explains that with cut and sew production, up to 40% of the original fabric can be waste [39].

### 5.2. Fully-Fashioning

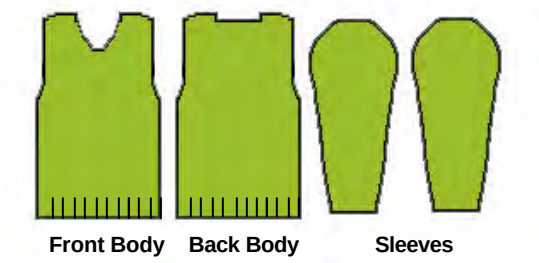


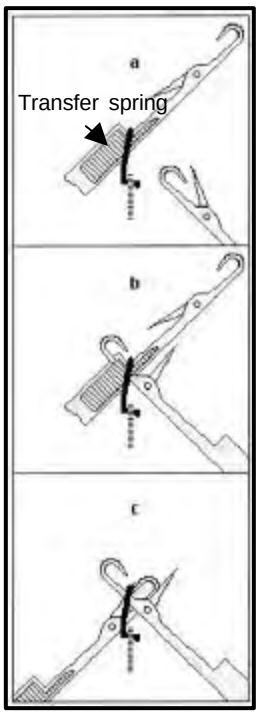

*Figure 5.2. Fully-fashioning production*

Fully-fashioned knitting means "shaped wholly or in part by widening or narrowing of piece of fabric by loop transference in order to increase or decrease of the number of wales" [3]. Thus, as the number of loops are increased or decreased, the fabric can get shaped areas as seen in Figure 5.2. To achieve fully-fashioned knitting, loop transference is necessary. The loop transference is the process that moves stitches (i.e., loops) from the needles on which they were made to other needles [49]. Figure 5.2a illustrates the mechanism of loop transference on a V-bed flat knitting machine.

In addition, the following stitch notation (Figure 5.2.1) describes how widening or narrowing occurs by loop transference on fully-fashioned machines. The fully-fashioning process allows the separate creation of shaped front and back body parts and sleeve parts by increasing or decreasing the number of loops (Figure 5.2); this eliminates the cutting operation. However, because all parts of the garment are knitted separately, the fully-fashioned knitting still requires a post sewing or linking process. Linking is defined as a process of joining side seams or edges of fabric pieces together with a row of knitting on a linking machine [19].



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a. The delivering needle is raised by a cam in the carriage. The loop is stretched over the transfer spring.

b. The receiving needle is raised slightly from its needle bed. The receiving needle enters the transfer spring of delivering needle and penetrates the loop that will be transferred.

c. The delivering needle retreats leaving the loop on the receiving needle. The transfer spring opens to permits the receiving needle to move back from its closure. Finally, loop transference is completed.

*Figure 5.2a. the mechanism of loop transference on V-bed flat knitting machine* (Raz, 1991)

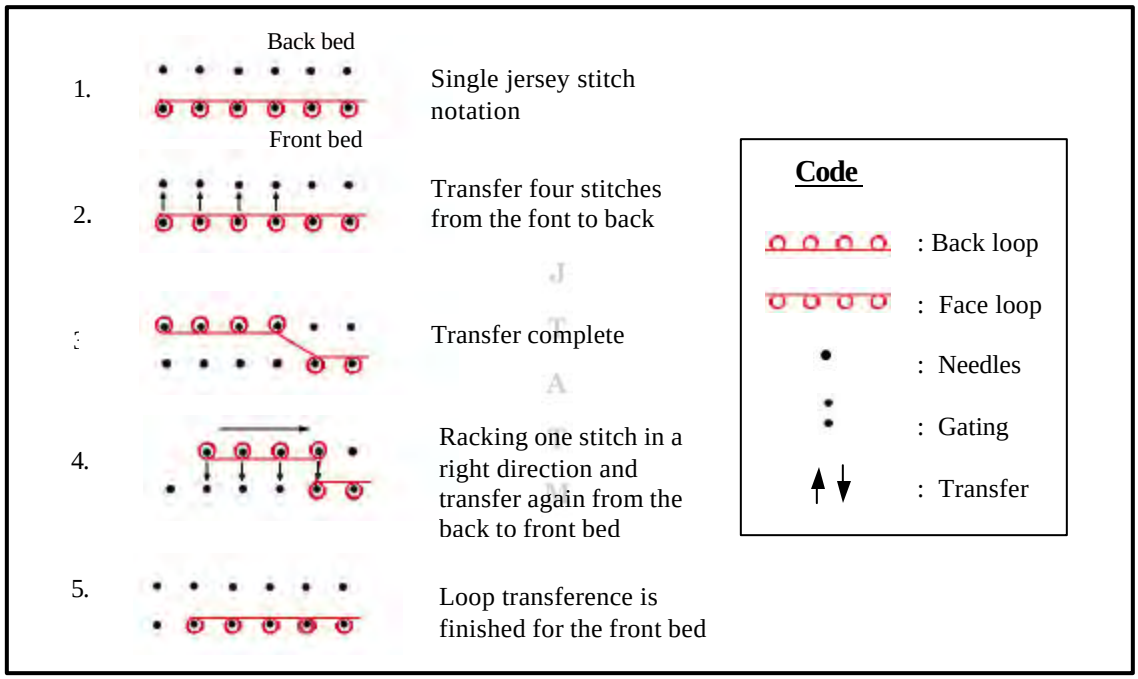



*Figure 5.2.1. Narrowing process by loop transference on flat V-bed machine*



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### 5.3. Seamless garment knitting



*Figure 5.3. Complete garment production by a seamless flat knitting machine*

"Seamless" garment knitting creates a complete garment by several different carriers (feeders) with minimal or no cutting and sewing processes (Figure 5.3). Thus, seamless knitting has the capability for production time and cost saving by removing post-knit processes such as the linking or sewing and cutting operation [39].

It also minimizes yarn consumption by reducing the cutting waste and can achieve higher productivity. Machine productivity in knitting is expressed in pattern rows per minute [41]. Complete garment knitting can be achieved either on a circular knitting machine or a flat (V-bed) knitting machine. However, seamless circular knitting machines are different from seamless flat knitting machines in that circular machines such as the Santoni create only a single tubular type of garment. Seamless flat knitting machines such as the Shima can create more than one knitted tube at the same time, and the tubes are joined together on the machine (Figure 5.3a). The complete garments knitted on circular machines may also need minimal cutting as seen in Figure 5.3a. In addition, the complete garments created by circular knitting machines still require minimal seam joining on one body tube and two sleeve tubes as well as the finished edges. Santoni has recently introduced the SM4 TL2 machine, which shapes the knitted tube and will eliminate the cutting process [35]. Consequently, seamless knitting on circular machines is not true seamless knitting.

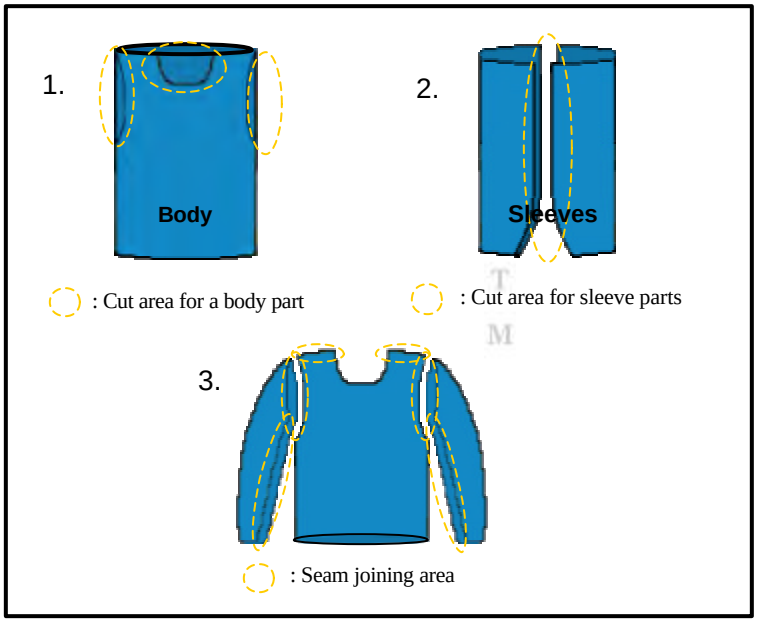



Figure 5.3a. *Complete garment production by a seamless circular knitting machine*



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In recent years, several companies have developed seamless or complete garment machines such as Santoni, Sangiacomo, and Orizio Santoni, part of the Lonati Group, is the biggest supplier of the circular knitting machinery. Lonati has recently acquired Sangiacomo, and its expanded seamless circular knitting technology is in the forefront of the industry. Santoni, whose customers include Nike, Adidas, Sara Lee et cetera [30], offers 14 different models of circular knitting machines, from 7 to 32 gauge. The machines produce swimwear, sportswear, outerwear, underwear et cetera. [35].

However, in the strict sense of the word, seamless flat V-bed knitting actually creates complete garments, which do not require any kind of cutting or sewing process. For Section 6, the knitting method of multi-tubular knitting techniques created on a V-bed knitting machine will be discussed.

## 6. V-BED MACHINE KNITTING OF SEAMLESS GARMENTS

As mentioned earlier, seamless garments on a flat V-bed machine can be created in three separate tubular forms by knitting one wider tube for the body part and two narrower tubes for the sleeve parts. Tubular knitting is created on both needle beds but front and back bed knitting are done alternately [23]. The continuously alternate knitting of all needles on front and back needle beds creates a single plain tube. Tubular type knitting is not a new technique. Since the 1800's, single jersey tubes have been produced on flat machines [8]. However, seamless garment knitting can be seen as a more advanced technique in that it can connect the three tubes together to create a sweater [6] and has the capability to increase and decrease the dimensions of the tubes [44]. Moreover, various structures such as plain, rib, and purl can be created within the seamless garment at the same time.

On the flat machine, the three tubes are knitted on a pair of front and back needle beds. The flat machine knits and transfers loops between the front needle bed and the back needle bed with different yarn carriers for one body tube (Feeder 2) and two sleeve tubes (Feeders 1 and 3) (Figure 6.1). The three-tube knitting continues to the underarm point. At the underarm point, the two carriers knitting sleeve parts (Feeders 1 and 3) are taken out of the knitting zone. The remaining carrier (Feeder 2) that knitted the main body part knits together the three tubes into one tube [10] (Figure 6.2). The tubes are joined at the underarm points, shoulders and neck points. In this manner, seamless garment knitting is accomplished. However, in order to make loop transference for performing shaping or design structures, loops should be formed by selecting alternate needles [17] (Figure 6.3).

Figure 6.4 reveals how loop transference occurs on complete garment knitting by using empty needles. By loop transference using the alternate needles, single jersey tubes as well as rib type tubes can be knitted on the complete garment machine. Figure 6.5 depicts how the 2X2 rib structure can be created on the complete garment V-bed knitting machine. However, due to the alternate needle selection on seamless machines, the garment tends to be more open and less elastic than a traditional fully-fashioned garment [27]. This requires the use of more elastic yarns on the seamless knitting machine compared to the other regular V-bed machines such as fully-fashioned machines.

In addition, the number of tubes knitted on the machine depends on the desired type of knitted product. The complete garment machine does not have to create three tubes all the time. For instance, to create a sweater, it requires three tubular typed forms. On the other hand, a seat cover may require only one type of tube for the complete cover, but could also provide an integrated attachment tube.


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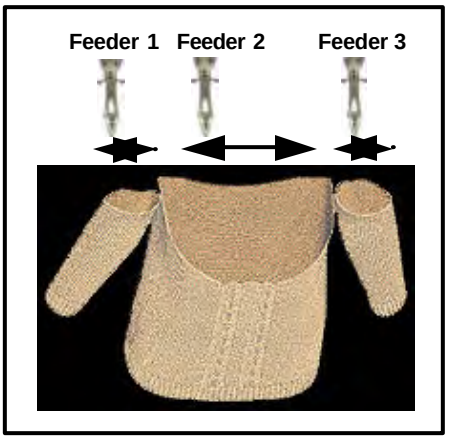



*Figure 6.1. Three-dimensional complete garment knitting until underarm point* (Shima Seiki)

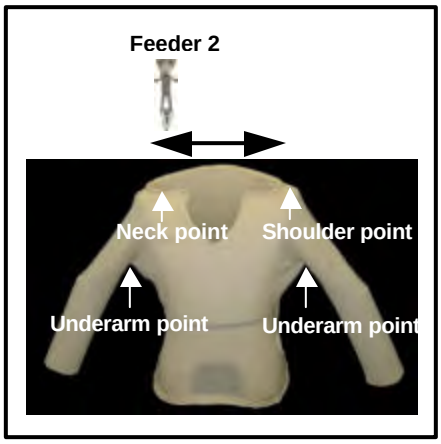



*Figure 6.2. Three-dimensional complete garment knitting after underarm point*

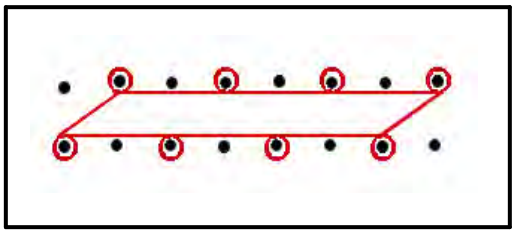


*Figure 6.3. Alternate stitch notation on complete garment knitting*

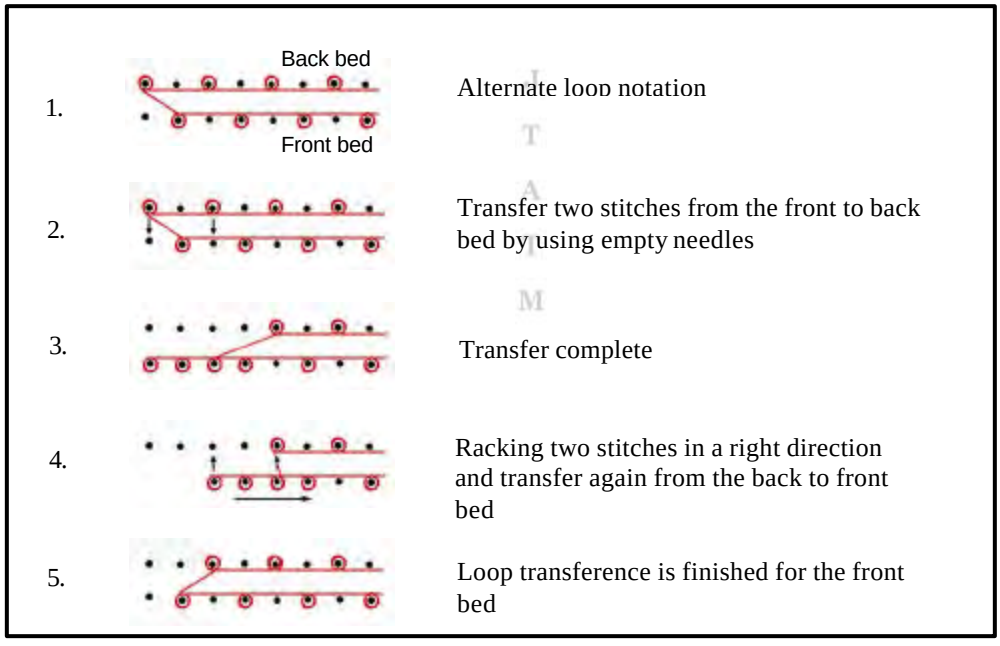
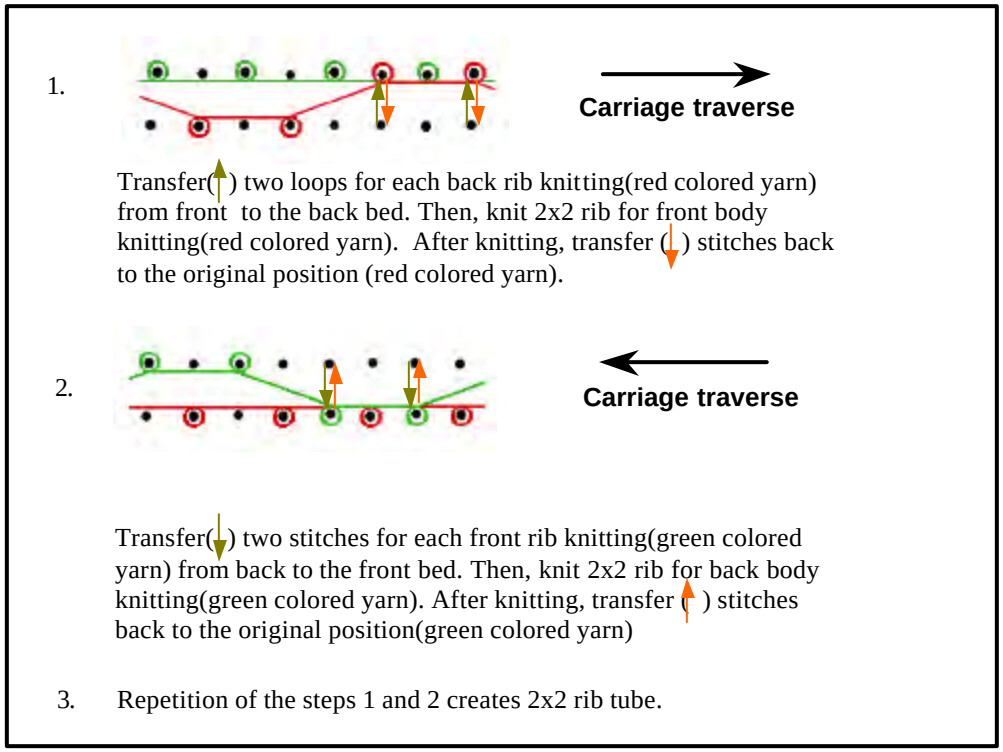



*Figure 6.4. Loop transference on complete garment knitting*



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** The upper figures show 2x2 rib tubular type knitting. Green colored yarn and red colored yarn represent the same yarn. In order that loop notation is seen easily, two different colors are*

*Figure 6.5. Tubular knitting of 2x2 rib on complete garment machine*

## 7. SEAMLESS MACHINES

For seamless flatbed knitting machines, two suppliers, Shima Seiki and Stoll, are the leaders in machine manufacturing. They offer solutions for the knitting of complete garments on computerized V-bed knitting machines. In Section 7, the two companies, Shima Seiki and Stoll, and their seamless knitting machine systems will be introduced and compared.

### 7.1. Shima Seiki

The Shima Seiki company invented the WholeGarment® machine and introduced the commercial complete garment knitting (SWG-V machine) in 1995 at ITMA (International Textile Machinery Association) [24]. Since the beginning of WholeGarment® machine production, about 3500 WholeGarment® machines have been manufactured and sold worldwide [11]. The seamless garment machines of Shima Seiki have different range of gauges from 5 to 18 gauge (needles per inch) and knitting widths ranging from 50 inches to 80 inches. Shima Seiki produces five versions of the innovative WHOLEGARMENT® machine that can produce a one-piece three-dimensional complete garment with no stitching, linking or sewing processes. Figure 7.1 illustrates the SWG-V WholeGarment® knitting machine system that shows various machine features such as a machine tuning screen, a computer controller, top tension devices, yarn carriage, et cetera.


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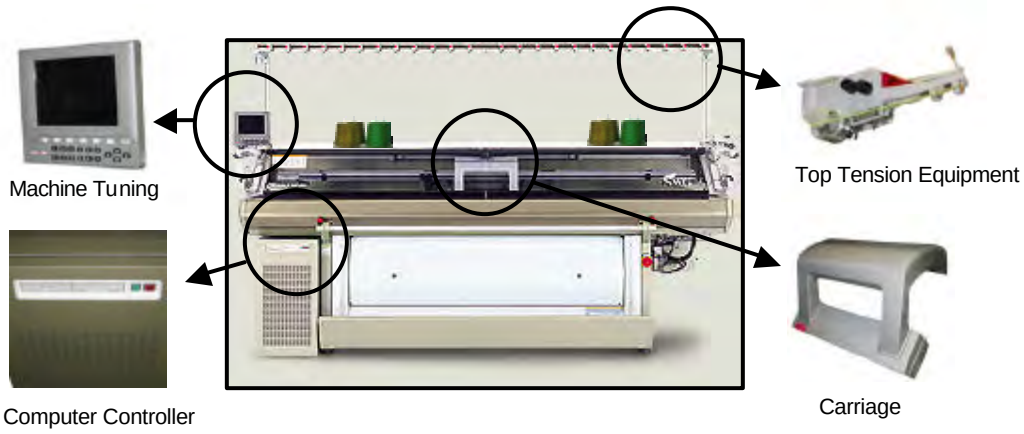



*Figure 7.1. SWG-V® machine*

### 7.1.1. Shima Seiki CAD system and machines

Figure 7.1.1 shows the Shima Seiki® knitting machine system. In general, knit patterns can be created on the CAD (Computer-Aided Design) system and all data can be saved to a diskette. The saved data can then be transferred to the Shima Seiki knitting machine and the machine can be operated. The machine-tuning screen allows operator interface with the settings of the machine. Finally, one complete three-dimensional garment can be knitted on the machine.

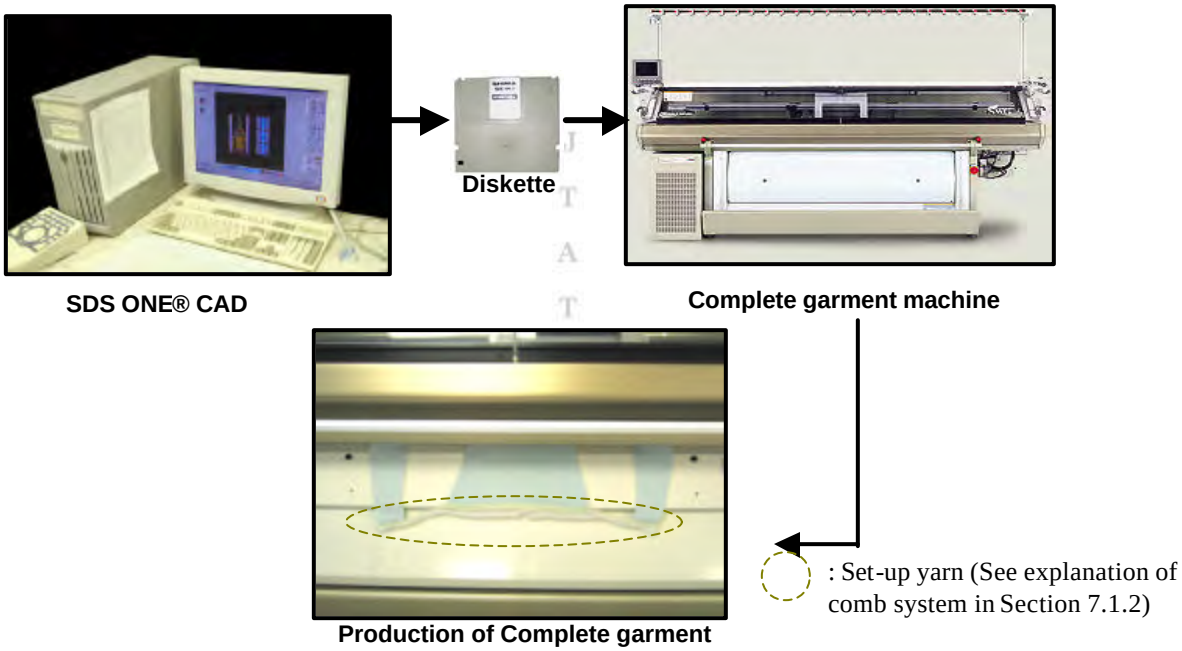


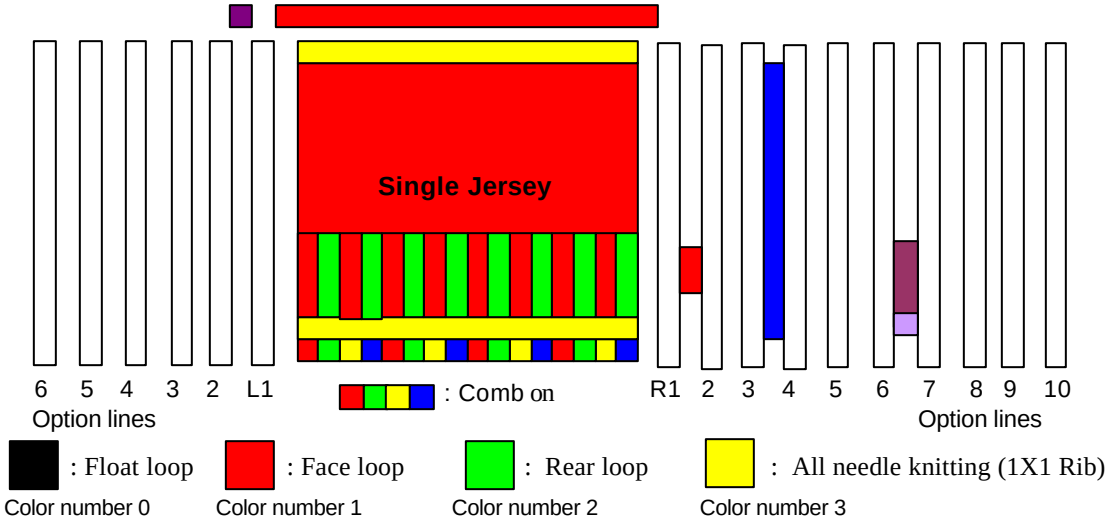

*Figure 7.1.1. Shima Seiki Knitting machine system*



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### 7.1.2. Shima Seiki CAD system

The Shima SDS ONE® CAD system is a totally integrated knit production system that allows all phases including planning, design, evaluation and production [44]. Specifically, the loop simulation program permits quick estimation of knit structures without any kind of actual sample making [8]. The program provides an opportunity to see knit problems and to try out diverse knit structures on the computer system before beginning the actual knitting. In the Shima CAD system, each different type of knitting loop is represented by different colored squares (Figure 7.1.2a). For example, as seen in the following figure 7.1.2a, color number 1(red) indicates a jersey (face loop) and color number 2 (green) indicates a reverse jersey (rear loop). Thus, the following red colored figure shows how a single jersey structure can be displayed on fully-fashioned CAD system of Shima Seiki machine.




* A Comb on a V-bed knitting machine is used to set up the yarn required to knit. The comb hooks the set-up yarn, and moves up and down, pulling down the set-up yarns connected with a knitted garment.
* Option line is used to control the data for a knit structure on the CAD system. For example, the right side of option line number 1 is utilized to decide repetition of a pattern area. Each option line represents specific functions of the machine knitting.

*Figure 7.1.2a. Shima Seiki CAD system for fully-fashioned*

The CAD patterning of the seamless garment knitting is more complicated than that of the fully-fashioned knitting due to alternate needle selection. The bottom figure (Figure 7.1.2b) depicts a single course notation of the tubular-formed knitting. In Figure 7.1.2b, the first row indicates front bed knitting (color number 1) and the second row indicates back bed knitting (color number 2). Accordingly, continuous knitting in a lateral direction between the front and back needle beds forms a tubular-typed fabric. In Figure 7.1.2c, it shows how loop transference for complete garment knitting can occur and how it can be displayed on the CAD system. The empty needles thus can be used for the loop transference. For the loop transference on complete garment knitting, at least two loops are transferred in a right or a left direction due to alternate needle selection such as Figure 7.1.2c. Note that only even number of loops can be transferred for seamless knitting on V-bed knitting machines.


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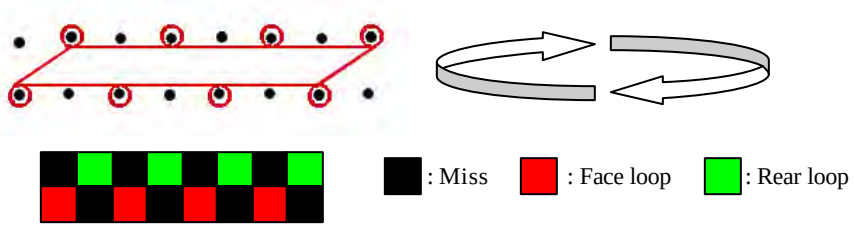



*Figure 7.1.2b. Stitch notation for seamless knitting and CAD design on Shima Seiki CAD system*




*Figure 7.1.2c. Loop transference on front bed for seamless garment knitting*

By utilizing the principle of the alternate stitch notation, two-dimensional design can be created on the CAD system as seen in Figure 7.1.2d. This represents a three-dimensional tubular typed garment. Figure 7.1.2d displays a whole garment designed on the Shima Seiki CAD system.

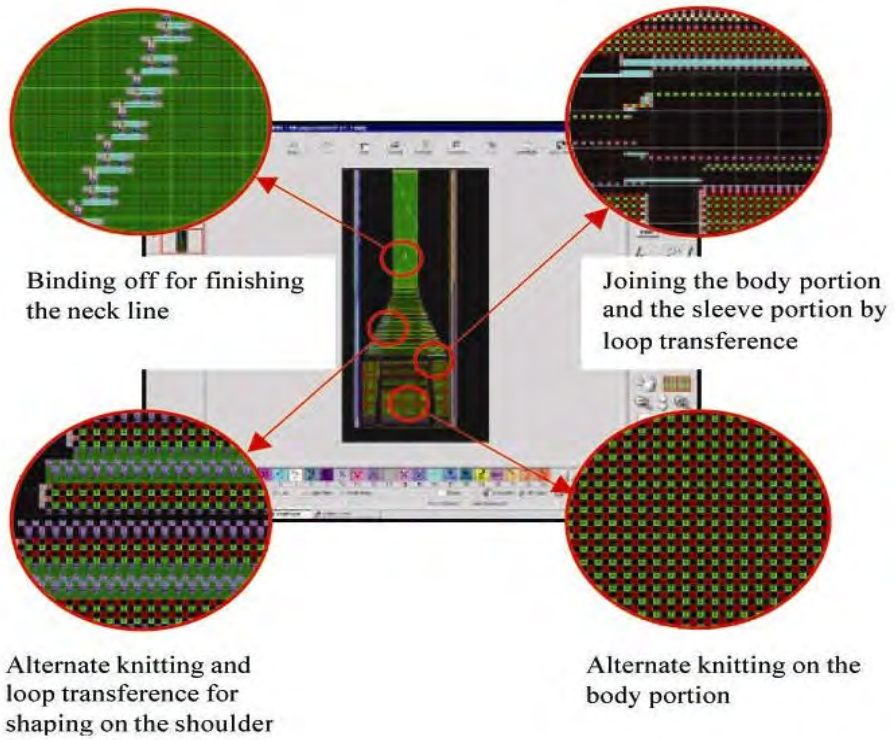



*Figure 7.1.2d. Design for complete garment on Shima Seiki CAD system*

Binding-off: The process that sequentially moves the stitches to the next loop from the edge [38]. This technique is generally utilized to finish edge lines.



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The interface between the knitwear designers and the knit technicians is critical to the success of new sample development. The designer's concept sketch must be realized through the capabilities of the machine governed by the technical expertise of the technician. Shima Seiki addresses this interpretative process through its enhanced Shima Seiki SDS ONE® CAD system. "Knit designs created in the paint program are simultaneously converted to knit programming data, so that designers and technicians can keep in close communication with each other over the same job" [39]. The combination of knit structures and yarn selections available in the design system will allow virtual simulation of potential garments without actual knitting.

Recently, Shima Seiki created a large pattern structure database of knitted parts including collars, plackets, cuffs et cetera. Knit and garment designs can be easily changed at will (Figure 7.1.2.e and 7.1.2f) [39]

### 7.1.3. Types of Shima Seiki Seamless knitting machines

Shima Seiki offers a line of machines capable of seamless knitting. These five different machines have special attributes, which can be selected according to application or end use. Gauge and needle type are the primary distinguishing factors.

#### 7.1.3.1. SWG-V®

The Shima Seiki's SWG-V® machine, which comes in 5 gauge and 7 gauge, is the first commercial application of Wholegarment® technology (See Figure 7.1) [39]. The SWG-V® machine uses a latch needle where the latch closes into the hook of needle as it pulls the yarn through a loop to form a new loop [33] (Figure 7.1.3.1a). The latch needles used in flat bed machines require an additional attachment, a transfer spring, in order to transfer a loop as can be seen in Figure 7.1.3.1a. However, due to the transfer spring, the needles cannot be located in the center of the needle groove, which results in a slightly asymmetrical loop formation. This will be discussed on Sections 7.1.3.4 and 7.1.3.5.

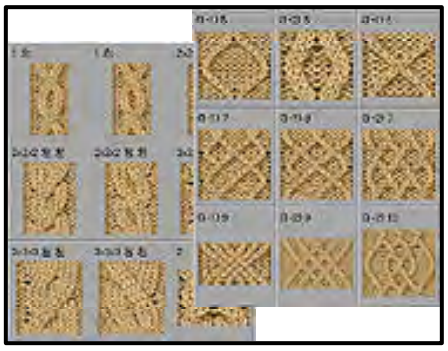


*Figure 7.1.2e. Structure pattern database*



*Figure 7.1.2f Virtual sampling* (Shima Seiki)


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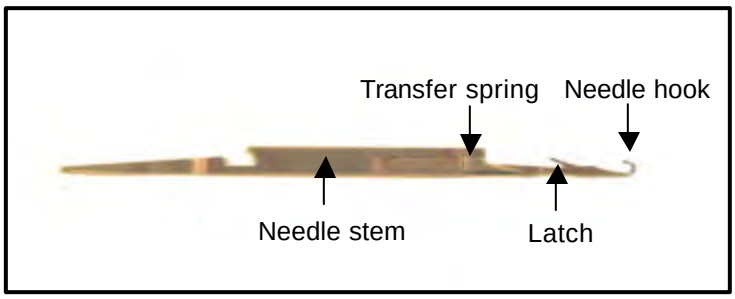



*Figure 7.1.3.1a.*
*Latch needle on SWG-V® machine*

Shima Seki introduced a version of the SWG-V® machine, with its enhanced technical capabilities such as the yarn carrier kickback device and increased memory capacity [39]. The New SWG-V® machine also has a special twin gauge needle configuration (Figure 7.1.3.1b) that includes a pair of needles working together in each needle slot. Complete garment knitting with loop transference requires two sets of needles, for the front and back of the garment, unlike a traditional single jersey tube that has only one set of needles [10]. Therefore, this twin needle configuration allows the needles to more effectively create widening or narrowing as well as diverse knit structures for complete garment knitting.



*Figure 7.1.3.1b. twin gauge needles*
(Shima Seiki)

### 7.1.3.2. SWG-X®

The SWG-X® machine is used to produce fine gauge knitwear, which has either 12 gauge or 15 gauge. Fine gauge knitting is produced by the slide needle and pull-down device, which independently controls takedown tension for front and back body portions. Specifically, the SWG-X® is configured for complete garment knitting with four separate needle beds and an additional loop presser bed [39]. This is the reason why the SWG-X® machine is the only machine that can knit complete garments without alternate needle technique. As can be seen in Figure 7.1.3.2, front body knitting can be achieved on needle beds 1 and 2, whereas back body knitting can be done between beds 3 and 4.

Actually, a machine that includes four needle beds and four cam plates is much more expensive to produce than a V-bed machine with two needle beds [10]. The reason Shima Seiki chose the more expensive four-bed route for fine gauge is in that if the machine was to take the half-gauge route for the fine gauge, the gauge would be just too fine for flat knitting technology [10]. The half gauge route on two needle beds for 12 or 15 gauge knitting is too fine to endure rigorous racking or transferring for complete garment knitting. The needle hook is also too small to accept the yarn required for 12 or 15 gauge knitting.



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This multi-needle bed configuration permits complete garment production with sufficient stitch density. Moreover, stitch transference can be more easily accomplished to create tubular ribs. In addition, various knit structures can be knitted at the same time with required stitch densities (Figure 7.1.3.2).

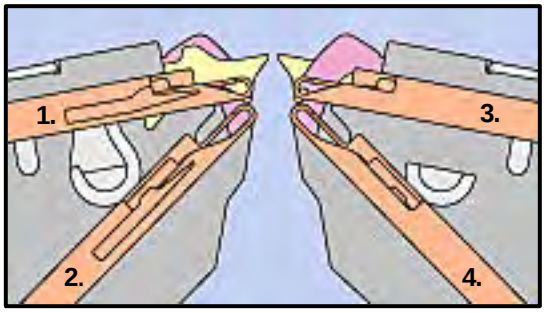



*Figure 7.1.3.2. Cross section Diagram of the SWG-X® four-needle bed configuration* (Shima Seiki)

### 7.1.3.3. SES-S.WG®

As with the SWG-V® machine, the SES-S.WG® has the capability to knit complete garments with latch needles. However, unlike the SWG-V's twin-needle configuration, the SES-S.WG® uses the standard latch needles and spring-type sinkers at the same pitch. This enables the machine to knit fine-gauge shaping as well as integral knitting, and it also makes possible multiple-gauge knitting. In multiple-gauge knitting, a number of different gauges can be knitted in a single course. Multiple-gauge knitting is different from fixed gauge knitting in that an assortment of gauge sizes may be knitted in a single garment [39] (Figure 7.1.3.3). The multiple gauges contain a combination of techniques, such as half-gauging, intarsia technique, using different numbers of yarn ends, and blocks of different gauges of needles each working with its corresponding count of yarn and yarn carriers [44]. Shima Seiki explains that this capacity responds to the change of seasons and trends without investing in a machine for every gauge. As a result, it saves time by eliminating the task of gauge conversion from one machine to another machine. Product variety can be greatly enhanced by achieving more interesting and sophisticated design patterns [39].

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*Figure 7.1.3.3. multiple-gauge knitting sample with 12G and 7G mixed side by side* (Shima Seiki)



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### 7.1.3.4. SES-C.WG®

The SES-C.WG® is a flexible machine in that it can achieve quality knitting in a range of production styles. The SES-C.WG® machine has the capability to perform shaping and integral knitting similar to the other SES-series. In addition, this machine can knit coarser gauge complete knitwear. By using compound needles and a take down system featuring a pull-down device, the SES-C.WG® can produce a high-quality coarse gauge seamless garment. The compound needle, in which the hook and hook closing portions are separately controlled [22], is generally used in warp knitting machines [13] (Figure 7.1.3.4a). However, Shima Seiki applied the concept of compound needles to the flat bed machine.

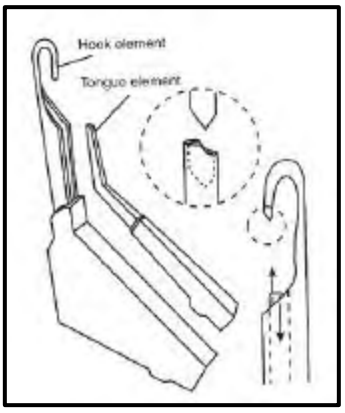



*Figure 7.1.3.4a. Compound needle* (Kadolph and Langford, 1998)

Compared to traditional latch needles, the compound needle is more complex and expensive to manufacture [44]. However, the compound needle gives higher operational stability, which is required for larger needle sizes. According to Shima Seiki, the compound needle offers significant reduction in needle stroke to allow for similar reductions in needle bed and carriage size [39]. Thus, the short stroke knitting helps reduce space in the carriage and permits smaller and lighter carriage [6]. According to John Ward [50], a technician at Shima Seiki USA Inc., the compound needle eliminates the necessity for a brush on the carriage, because the needle has a slider that opens and closes the hook of the needle unlike a latch needle. The slider moves up and down by the movement of the cam system, which is timed to work closely with the movement of the needle. This increases the stability of knitting, and there are no brushes to be worn out.

Another feature of the compound needle is that it does not have to be raised as high because there is no latch that must be cleared which increases knitting stability at higher speeds. However, one drawback of both the latch and the compound needle is that both needles have to be off center in the trick wall to allow for the transfer spring. This puts the needle hook closer to the knock-over bit on one side, resulting in a slightly imbalanced stitch. To solve the problem of imbalance, the Shima Seiki developed the slide needle [50]. The slide needle will be discussed in Section 7.1.3.5.

### 7.1.3.5. First®

This machine executes all types of production from fully fashioning and three-dimensional shaping to seamless production. All this capability is accomplished through the development of the slide needle instead of the latch needles, which uses a unique two-piece, slide mechanism [39] (Figure 7.1.3.5a).



*Fig 7.1.3.5a. Slide needle* (Shima Seiki)

Shim Seiki points out "A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove. The slide needle thereby achieves perfectly symmetrical loop formation for knitting the highest possible



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quality fabrics (Figure 7.1.3.5b and 7.1.3.5c)" [39]. Accordingly, by using the slide needle, the machine provides better quality and stable knitting as well as higher productivity. However, in order to transfer loops by slide needles, the First® machine needs an additional transfer bed that can only move stitches [51]. The machine also requires an extra cam system to control the slider on the slide needle [51]. In consequence, the additional equipments make the machine with slide needles more expensive than a machine with latch needles.

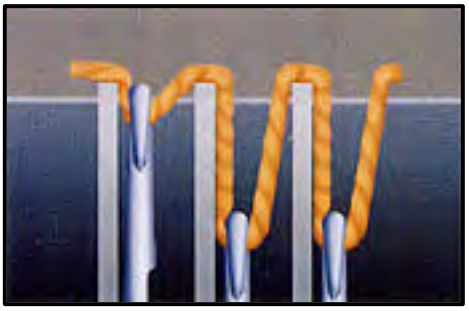


*Fig 7.1.3.5b. Conventional latch needles offset slots* (Shima Seiki)



*Fig 7.1.3.5c. Slide needles centered in slots*

Another distinctive feature of the First® machine is its takedown system. "Precision pull down of the garment is independently controlled by tiny pins mounted on front and rear panels which feature adjustable working width through individually controlled 1.5 inch wide sections. This precise control of takedown tension permits 3-dimensional shaping of complete garment items" [10].

The following Table 2 shows the five-versions of Shima Seiki WholeGarment® knitting system. All sources are cited from the Shima Seiki company website, www.shimaseiki.co.jp.

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**Shima Seiki WholeGarment® Systems**
(Sources from www.shimaseiki.co.jp, 2004)

| | First® | New SWG-V® | SWG-X® | New SES-S.WG® | New SES-C.WG® |
|---|---|---|---|---|---|
| Knitting Width | 126-181cm 50-72" | Max 183cm 72" | Max 172cm 68" | 183cm 72" | 203cm 80" |
| Gauge | 12 - 18 gauge | 5, 7 gauge | 12, 15 gauge | 8, 10, 12, 14, 16 gauge | 5 gauge(capable of producing 3G fabric) |
| Knitting Speed | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.3m/sec | Max 1.1m/sec |
| Racking | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) | Max 1.5-inch racking in each direction (3 inches total) |
| Knitting system | 3 or 4 system | Triple Knitran® system. Single carriage | 3 system (1 knitting system + 2 transfer system) | Triple Knitran® system. Single carriage | Ultra-compact 2-system (1 knitting system + 1 transfer system) |
| Transfer | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction | Simultaneous Transfer, Independent of carriage direction, Split stitch | Simultaneous Transfer, Independent of carriage direction, Split stitch |
| Sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system | Fixed sinker system | Spring-type movable full sinker system | Spring-type movable full sinker system |
| Yarn Carriers | 12-16 | 13 | 12 | 13 | 16 |
| Take down device | Main/sub rollers, Changeable 31 levels | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear | Main/sub rollers, Changeable 31 levels | Special pulldown mechanism with independent operation on front and rear |
| Needle selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Electromagnetic direct selection | Full-jacquard solenoid selection |
| Needle | Slide needle | Latch needle | Slide needle | Latch needle (Standard layout of needles) | Compound Needle |
| Production | Everything from full-fashioning, rib shaping to 3-dimensional shaping, as well as seamless | | High quality fine gauge knitwear | Fine-gauge shaping and integral knitting, even multi-gauge knitting | Coarse gauge knitting |

*Table 2. The Shima Seiki WholeGarment® machine Systems*


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## 7.2. Stoll



*Figure 7.2. STOLL Knit and Wear® Machine* (Stoll)

The other major machinery producer for seamless knitting considered in this research is Stoll. The Stoll system is examined in comparison with the Shima Seiki based on research at Cotton Inc. with Emmett Hylton, Knitting Manager [5]. This section considers the CAD system, the knitting equipment and the seamless systems available. Seamless garment knitting systems from Stoll and Shima are similar, and a comparison of the complete garment knitting systems offered by Shima Seiki and Stoll are considered in this section. Stoll has manufactured flat knitting machines for more than 130 years and has today more than 1,100 employees worldwide [45]. The Stoll machine also markets complete garment knitting machines called "Knit and Wear®". The range of gauge for Stoll Knit and Wear® machine is from E2.5 to E9.2 gauge and the knitting width is from 72 inches to 84 inches. The Stoll Company also has a multiple gauge system, which permits different gauge areas to be knitted in one single course [45].

### 7.2.1. Stoll CAD system

According to Spencer [44], the Stoll SIRIX® (M1) CAD system is a complete design, patterning, and programming system, and it utilizes two windows to graphically develop knitting programs for the Stoll machines. In the Stoll CAD system, all knit structures are displayed by real modules. Figure 7.2.1 shows how 2X2 rib and single jersey can be displayed on the Stoll M1 CAD system.

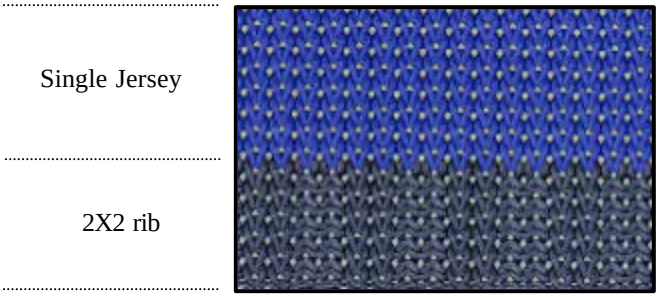



Figure 7.2.1. *2X2 Rib and single jersey displayed on the Stoll M1 CAD system*

As in the Shima CAD system, Stoll's M1 CAD system offers two different windows for designers and technicians who need different information for the same design (Figure 7.2.2). The technical window shows the developing design in the form of running yarn notations and technical data, while the design window presents design as a knitted structure [44]. Both windows can be easily displayed and automatically converted. Therefore, it is expected to minimize miscommunication between designers and technicians in knitting industry. By understanding the knit structures, it is possible to improve collaborative efforts and resulting samples.

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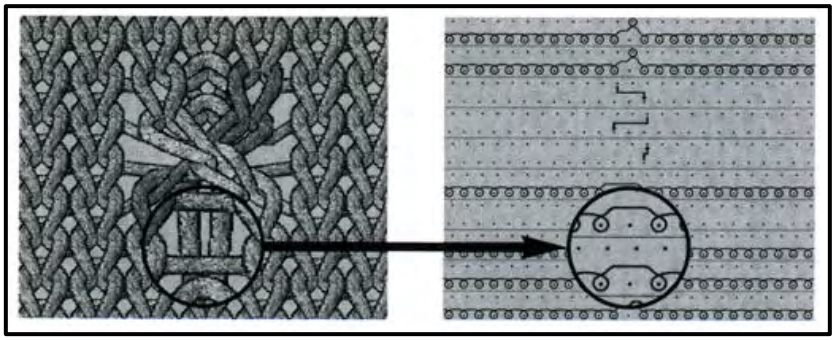


*Figure 7.2.2. Linked windows options of fabric design view and technical view*
(Spencer, 2001)

### 7.2.2. Types of Stoll seamless knitting machines

#### 7.2.2.1. CMS 330 and CMS 340 TC Knit and Wear® machines

CMS 330 TC and 340 TC knit and wear® machines have a 72-inch (183 cm) knitting width. The CMS 330 TC knit and wear® machines cover three systems and a gauge range from E6.2 to E7.2. E6.2 provides a range from E6 to E12 and E7.2 gives a range from E7 to E14. On the other hand, the CMS 340 TC knit and wear® machine has four systems that combine the knitting and the transfer system, and a gauge range from E2, 5.2 to E9.2. Technically, the CMS 330 TC machine is capable of producing fully fashioned, multiple gauge as well as intarsia fabrics. An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (or textures), so that both sides of the fabric are equal [48]. Its three systems yield a high level of production. The CMS 340 TC machine has the capability of multiple-gauge knitting such as Shima Seiki New SES-S.WG [45].

#### 7.2.2.2. CMS 330 TC-T Knit and Wear®

This machine offers a 72-inch (183 cm) knitting width and the range of the gauge is between E6.2 and E7.2. By using its three systems and two additional needle beds with transfer elements and independent racking front and rear, fine gauge knitting is possible in gauges E12 and E14 with all needles [45]. This machine is also capable of multiple-gauge knitting in order to create an interesting knit structure between finely knit areas knitted with all needles and coarser areas knitted only with every second needle [45].

#### 7.2.2.3. CMS 330 TC-C Knit and Wear®

CMS 330 TC-C knit and wear® machine has a three-system capability and a working width of 84 inches (213 cm). This width can easily produce coarse gauge knitwear in extra-large sizes. The gauge E2,5.2, in conjunction with knitting and transferring systems designed especially for this application and a new type of holding-down technology, allows the production of seamless garment knitting [45].

#### 7.2.2.4. CMS 340 TC-M Knit and Wear®

This machine is equipped with a new extra wide working width of 84 inches (213 cm) for producing triple XL sized seamless sweaters [13]. The four system model features a gauge range from E2, 5.2 to E7.2 (up to 14 cut) and the machine also offers gauge conversion capability. It also can be used efficiently for fully-fashioned, multiple-gauge and intarsia fabrics. Thus, it joins the advantages of the comb machines with those of multi piece knitting. Consequently, profitability can be enhanced and even multi-piece fully-fashioned knitting can be achieved [45]. For instance, two front pieces, two back pieces, and four sleeve pieces can be sequentially knitted in the necessary sizes. In two-piece knitting,



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the left fabric can be knitted by the two left knitting systems, and the right fabric can be knitted by the two right knitting systems (Figure 7.2.2.4). This figure also shows the two separate yarn carriages. Two-piece knitting significantly increases productivity compared to one-piece seamless knitting [45]. "This machine knits complete garment panels as multi-layer applications and also as racked and structured patterns in multi layer knits and an absolute novelty in the sector – two gauges in one fabric" [36]. In addition, this machine is capable of producing ultra-coarse gauge garments with the fabric appearance of 2-gauge with a hand-knitted look [13].

With new take-down technology, this machine offers a new shoulder solution, the so-called "French shoulder". This style of shoulder features the connection between the front and back body portions of the garment not in the middle of the shoulder but at the top of the back. This new knitting sequence demonstrates that the shoulder part of the garment can be produced with greater quality with a wide range of possible variations in terms of visual appearance and elasticity [45]. Table 3 shows the five-versions of the Stoll Knit-and-Wear® knitting system. All sources are cited from the Stoll website, www.stoll.de.

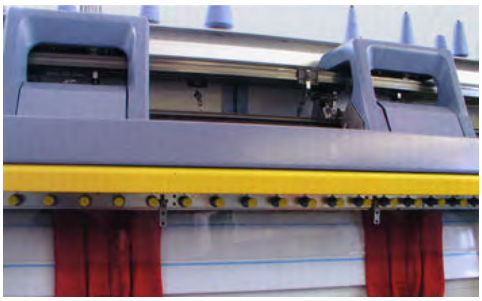


*Figure 7.2.2.4. Two piece fully fashioning* (Stoll)

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**Type of Knit–and–Wear® machines**
(Sources from www.stoll.de, 2004)

| | CMS 330 TC Knit and Wear | CMS 340 TC Knit and Wear | CMS 330 TC-T Knit and Wear | CMS 330 TC-C Knit and Wear | CMS 340 TC-M Knit and Wear |
|---|---|---|---|---|---|
| Knitting Width | 183 cm 72” | 183 cm 72” | 183 cm 72” | 213 cm 84” | 213 cm 84” |
| Gauge | E2,5.2- E7.2 | E2,5.2- E9.2 | E6.2-E7.2 | E2,5.2- E2,5.2 | E2,5.2- E7.2 |
| Knitting Speed | Max 1.2m/sec | Max 1.2m/sec | Max 1.2m/sec | Max 1m/sec | Max 1.2m/sec |
| Racking | Max 4” | Max 4” | Max 4” | Max 4” | Max 4” |
| Knitting system | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation (4 combined knitting/transfer systems) | Independent knitting systems with split function for optimum system allocation (3 systems) | Independent knitting systems with split function for optimum system allocation | Independent knitting systems with split function for optimum system allocation (4 systems) |
| Transfer | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions | Simultaneous transfer in both directions |
| Sinker system | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down sinkers | Moveable holding-down spring loaded sinkers: enables manufacturers to knit ultra coarse garment with a hand-made look (Mowbray, 2004). | Moveable holding-down sinkers |
| Yarn Carriers | 16 | 16 | 16 | 16 | 16 |
| Take down device | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb | Main / upper take-down and take-down comb |
| Needle selection | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system | Electronic selection system |
| Production | Multi-gauge, Intarsia fabric | Multi-gauge, Flexible gauge | Fine gauge knitting, Multi-gauge | Coarse gauge knitting, | Coarser gauge knitting, Fully-Fashion, Multi-gauge, Intarsia fabric |

*Table 3. The Stoll knit and wear® machine system*


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### 7.3. Comparison of Complete Garment Knitting Systems between Shima Seiki & Stoll

Table 4 compares seamless garment knitting systems between two companies, Shima Seiki and Stoll. The characteristics of the machines are generally comparable except in a few features. The main difference between two offerings is that Shima Seiki machines employ three different types of needles for complete garment knitting such as latch needles, compound needles and slide needles, whereas Stoll machines employ only latch needles. Table 4 shows the machines of two companies have quiet similar characteristics.

**A comparison of complete garment knitting systems between Shima Seiki and Stoll**
(Sources from www.shimaseiki.co.jp and www.stoll.de, 2004)

| | Shima Seiki WholeGarment® Machines | Stoll Knit-and-Wear® Machines |
|---|---|---|
| Knitting Width | 50" – 80" (126 – 203 cm ) | 72" – 84" (183 – 213 cm) |
| Gauge | 5 - 18 gauge | 5 -18 gauge |
| Knitting Speed | Max 1.3m/sec | Max 1.2m/sec |
| Racking | Max 3" total | Max 4" total |
| Knitting System | 3 – 4 systems | 3 – 4 systems |
| Transfer | Simultaneous transfer | Simultaneous transfer |
| Sinker System | Spring-type movable full sinker system | Spring-type moveable holding-down sinker system |
| Yarn Carriers | Up to 16 | Up to 16 |
| Take-down Device | Main/sub take down rollers | Main/upper take down rollers |
| Needle Selection | Electric selection system | Electric selection system |
| Needle | Latch needles, Compound needles, Slide needles | Latch needles |
| CAD system | Integrated knit production system allowing planning, design, evaluation and production | Complete design, patterning, and programming system |

*Table 4. Comparisons of complete garment knitting systems between Shima Seiki and Stoll*


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## 8. CONCLUSIONS

Seamless garment knitting on V-bed machines creates one entire complete garment by using several different carriers eliminating the need for additional cut and sewn operations. The garment can be created in tubular forms: one wider tube for the body portion and two narrower tubes for the sleeve portions. Two leading companies, Shima Seiki and Stoll, manufacture seamless or complete garment V-bed knitting machines. Both companies develop various complete garment machines according to the machine gauge, types of needles, sinker systems, take down systems, and application of knit structures.

For seamless garment knitting, the machines have the capability not only to create shaped knitting, but also to make various knit design structures in the complete garment by utilizing alternate needle selection. Alternate needle selection, however, creates fabrics more open and less elastic than conventional fully-fashioned garments. Nevertheless, complete garment knitting provides major benefits for the market as well as for technical production. (See Table 5) Manufacturers do not have to rely on the cutting and sewing process. As a result, it is believed to offer savings in terms of production times and cost, and it minimizes yarn consumption. In addition, seamless garment knitting provides more consistent and homogeneous product quality, which gives lightness and comfort in the garments. It also offers knit designers more creative knit possibilities.

Three-dimensional seamless knitting with its diverse capabilities can be applied to numerous products such as fashion, upholstery, automotives, aerospace, medical textiles, et cetera. Seamless knitting is forecasted to continue growing and could be one of the largest next generation knitting technologies.

| **Potential benefits of seamless knitting** |
|---|
| 1. Minimizing or eliminating labor intensive cutting and sewing process |
| 2. Savings in production times and cost |
| 3. Minimal yarn consumption |
| 4. Higher productivity |
| 5. Multi-gauge knitting |
| 6. Lightness and softness |
| 7. No bulky and irritating stitches/seams |
| 8. More constant product quality |
| 9. Better trimmability for finished edge lines |
| 10. Better look, better fit and more comfortable |
| 11. More creative possibilities for knitwear designers |
| 12. Quick-response production for size and pattern changes |
| 13. Just-in-time production |
| 14. Mass customization |

*Table 5. Potential proposal for seamless garment knitting*



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## Glossary

Barre' : Barre' means a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit fabric.

Bearded needle: the needles having an extended terminal hook or beard that can be flexed to close the hook.

Binding-off: The process that sequentially moves the stitches to the next loop from the edge. This technique is usually utilized to finish edge lines.

Brushes: The aim of brushes is to open the latches at the first course when the machine starts to knit and to avoid closing of the latches.

Cable stitch: Cable stitch is a stitch formed by small groups of plain wales plaited with one another in ropelike fashion.

Carriage: Carriage that has cam boxes travels along the beds forcing the needle butts in its way to follow the curved shape of the cam.

Cam: The device which converts the rotary machine drive into suitable reciprocating action for the needles.

Circular knitting machine: Needles are set radically or parallel in one or more circular beds. Used without further qualification, the term generally refers to a weft-knitting machine of this type.

Comb: Comb on V-bed knitting machine is used to set up a yarn required to knit. The comb hooks the set-up yarn, and moves up


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and down, pulling down the set-up yarns connected with a garment.

Compound needle: The hook and hook closing portions are separately controlled. The compound needle gives higher operational stability at higher speed compared to latch needle.

Flat knitting machine: Flat knitting machine employs straight needle beds carrying independently operated, usually latch needles.

Flechage: Course shaping in knitting. A term increasingly used to define two and three-dimensional shaping of knitted fabric by increasing and/or decreasing the length of succeeding knitted courses to a pre-planned series. Beret knitting is also a term used to describe this process. The term is derived from the French for wedge. (http://www.resil.com/dictionary/f.htm)

Fully-fashioned knitting: Fully-fashioned knitting is shaped wholly or in part by widening or narrowing by loop transference to increase or decrease of the number of wales.

Gauge (cut): Gauge indicates the number of needles per inch.

Holding down: Holding down is one of functions of sinkers. It prevents previous loops from riding with needles. Thus, it gives tighter structures with improved appearance.

Intarsia fabric: An intarsia fabric is a flat knit fabric with patterns knitted in solid colors (textures), so that both sides of the fabric are equal.

Interlock: a double-faced rib-based structure consisting of two 1X1 rib joined by interlocking sinker loops.

Interlock gating: The opposed alignment of one set of needles with the other on a knitting machine.

Knitting: The process of forming a fabric by the intermeshing of loops of yarn.

Knocking over: Knocking over is one of functions of sinkers. It supports the old loop as the new loop is drawn though it.

Latch needle: It has a latch or swinging fingers that closes into the hook of needle as it pulls the yarn through a loop to form a new loop.

Linking: Linking is a process of joining side seams or edges of a piece of fabrics together with a row of knitting on a linking machine.

Loop transference: Loop transference is the process that moves stitches from the needles on which they were made to other needles for the purpose of shaping or design.

Mass customization: It is the use of technology and management methods to offer product variety and customization through flexibility and quick response. It owes its success partially to computer-based information, design and manufacturing technology.

Miss stitch: A knitting cycle where a needle or needles do not take a yarn and produce a float loop either intentionally or as the result of knitting fault.

Multiple-gauge knitting: Multiple-gauge knitting is a number of different gauges can be knitted in a single course.

Productivity: Machine productivity is expressed in pattern rows per minutes.

Racking: Racking is the lateral movement of a needle bed or point bar across a predetermined distance on a flat knitting machine.

Rib gating: The alternate alignment of one set of needles with the other on a machine equipped with two sets of needles arranged to knit rib fabrics.


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Sinker: Sinker helps loop formation, holding-down, and knocking-over on a machine.

Slide needle: A flexible two-piece slide mechanism splits and extends beyond the needle hook for increased potential especially in complex transfers. Using the slider mechanism for transfer effectively eliminates the transfer spring, allowing the needle to be mounted in the center of the needle groove.

Take down rollers: Take down rollers are required in order that the previous loop which is located in the hook enclosure is prevented from the riding up with ascending needle.

Tubular knitting: Tubular knitting is created on both needle beds but front and back bed knitting are done alternately.

Warp knitting: Warp knitting is composed of loops formed in a vertical direction.

Weft knitting: Weft knitting is composed of loops formed in a horizontal direction.

Welt: Welt in knitting is a secure edge of a fabric. The welts are usually at the starting end of the fabric.

Yarn carrier (feeder): The yarn coming from a single yarn feeder is feeding the needle in a sequential order and by doing so connects the adjacent loops into a course.

J
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M



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# Exhibit O

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# The development of 3D shaped knitted fabrics for technical purposes on a flat knitting machine

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The use of a new electronic flat knitting machine (Shima Seiki SES 122FF) for producing three-dimensional shaped fabrics for technical purposes is described. The three methods which can be applied to knit to shape, i.e. using different structural combinations, using different loop lengths, and altering the number of knitting needles and knitted courses, are discussed. Further, the different knitted elements (tubular forms, spherical forms, box forms and car seat covers) developed on the SES 122FF machine are described in detail.

**Keywords:** Flat knitting machine, Knitted fabrics, Loop structure, Technical textiles, Three-dimensional shaped knitted fabrics

## 1 Introduction

Technical textiles have been applied in different fields such as protection clothing, transportation related textiles (cars, planes and space crafts), geotextiles, building construction related textiles, packaging materials, military related textiles, medical textiles, sports related textiles, etc.

For many years, technical textiles were considered as very high-modulus fabrics, exhibiting extremely high structural stability and made of high-tenacity, low-elongation yarns. With the further development of new end uses, it has been realized that each technical product requires a different technical textile, with a different set of characteristics and some of these characteristics might be found in "loop based" structures.

Flat knitting machines are traditionally used for producing pullovers and other outerwear garments. One of the main advantages is the facility of these machines to knit fabric pieces to a particular shape or form. The combination of the individual needle selection technique and the use of the presser foot or holding down sinkers on the new generation of computer-controlled flat knitting machines increase this ability a great deal. By using the new flat knitting machines,it is possible not only to knit the new loop structures which are not possible on the conventional flat knitting machines, but also knit fully fashioned garments. This is very important to reduce the waste of expensive materials during cutting as well as in eliminating the additional making up operation. If the ability of knitting to shape of the flat knitting machines is used to produce 3D knitted technical textiles, it is not difficult to foresee their new end uses in the future.

This work describes the use of the new flat knitting machines to knit 3D structures by using different techniques in the Shima Seiki SES 122FF flat knitting machine. It is thought that these knitted shapes can be interesting as technical textiles and may also stimulate the imagination towards new applications.

## 2 Short Description of the Shima Seiki SES 122FF Flat Knitting Machine

The SES 122FF machine is one of the new generation of computer-controlled flat knitting machines. The main features of this machine are as follows:

- —the double cam system for knitting and transfer facilities at each cam system in which 31 different stitch lengths can be set;
- —the combination of holding down sinkers and presser foot is the machine facility which enables the knitting of fancy stitch effects and knit to shape;
- —the belt drive system gives smooth and high-speed carriage travel which enables the yarn to be picked-up or not, as required;
- —the set-up device and finely tuned take-down system for added take-down requirements; and
- —the machine controller which is programmed for knitting and shaping from a micro compu-

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ter with floppy disc drive, and has a screen resolution of 1024 × 1024 pixels.

The major advantage of this machine is that it has overcome former restrictions in knitting design and shaping, thus enabling the development of 3D knitted structures for technical purposes.

## 3 Techniques for Knitting to Shape

On flat knitting machines, it is possible to use the following techniques for knitting to shape:

- —using different structural combinations;
- —using different loop lengths; and
- —altering the number of operating needles from course to course.

### 3.1 Using Different Structural Combinations

It is not difficult to reach the objective of knitting a 3D shape by using different loop structural combinations when knitting a technical course, because the different loop structures have different geometrical shapes under conditions in which the yarn counts and the loop lengths are the same. The new flat knitting machine can knit most weft-knitted structures, and so the combinations of different structures for knitting to shape are easily realised. However, it is necessary to bear in mind that this technique is not suitable in cases in which a technical product requires homogeneous properties in all parts, as the parts knitted with different structures present different properties.

### 3.2 Using Different Loop Lengths

Fabrics knitted with the same knitted structure but using different loop lengths have different geometrical dimensions. If one fabric is knitted with different loop lengths in different courses, shaping can take place. One simple example is circular jersey fabric knitting in separate needle beds. It is not difficult to change the circumference by changing the loop length from course to course. On the new flat knitting machines, the stitch cams can be automatically adjusted during knitting and so changing of loop length is very easy. It offers the facility of knitting to shape by changing loop lengths.

### 3.3 Altering the Number of Operating Needles from Course to Course

This technique is widely used in flat knitting for the production of fully fashioned panels. Two operations can be performed: increasing and decreasing the number of operating needles. On the new flat knitting machines, these two operations are very easily realised due to electronic single needle selection.

It is necessary to note that during the increasing (widening) or decreasing (narrowing) operations (Fig. 1), some needles are rendered inactive for a long time while retaining their loops. The tension applied to the fabric by the take-down rollers is, in this case, transferred solely to these needles, distorting the loops and subsequently breaking the yarn. For this reason, the use of the presser foot is necessary.

The presser foot (Fig. 2) is a metal wire which is securely fixed to the carriage by the presser foot mechanism, and moves across the machine with the carriage. During knitting, the presser foot precedes the needles which are rising. The wire

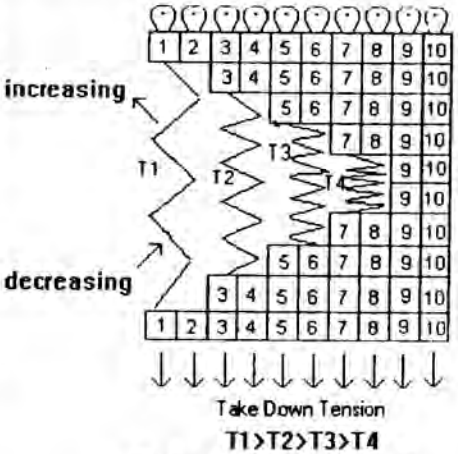



**Fig.1** - Fashioning operation: decreasing and increasing the number of knitting needles in one needle bed

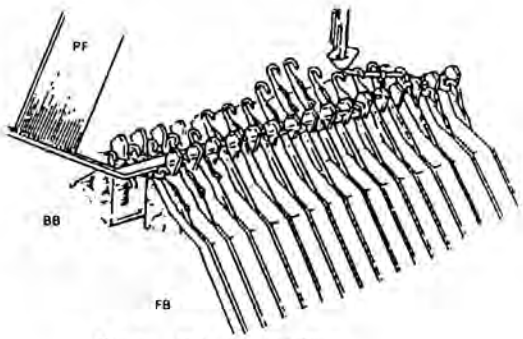



**Fig.2** - PF - Presser Foot
FB - Front needle bed
BB - Back needle bed

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slides just underneath the crossing or intersecting opposing needles on both needle beds and presses against the stitch laying between the two needle beds. As a result of this the take-down tension given to the fabric by the take-down rollers becomes unnecessary.

The absence of take-down tension allows stitches to be held on idle needles which are temporarily inactive, while neighbouring needles continue to knit normally. This is just one of the requirements of knitting to shape.

When this method is used to knit three-dimensional structures, the main technique consists in transferring the three-dimensional form to two-dimensional patterns, because the fashioning operation (increasing or decreasing the number of knitting needles) is only determined according to two-dimensional patterns. The three-dimensional shaped knitted fabrics presented in this work are all knitted by using this technique.

## 4 Three-Dimensional Shaped Knitted Fabrics Developed on the Shima Seiki SES 122FF Machine

### 4.1 Tubular Forms

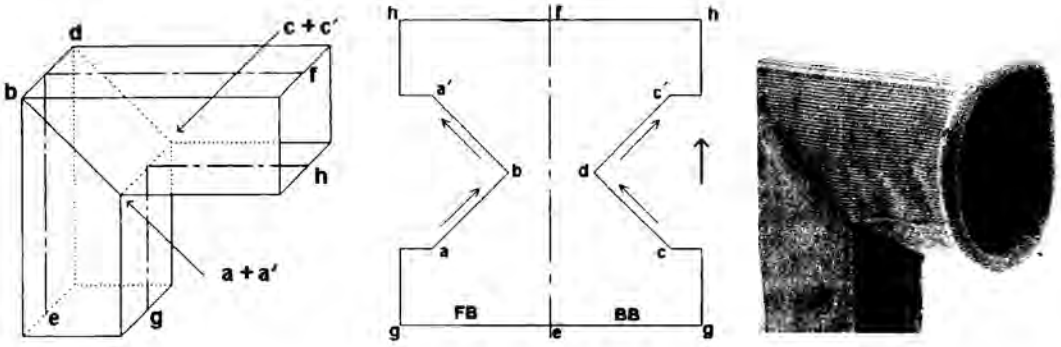
The tubular forms are knitted on both needle beds. When the number of operating needles in one bed is changed, a "knee" form is developed. The different tubular forms knitted on the SES 122FF flat knitting machine are shown in Figs 3-6. These types of structures can be used as tube connections for reinforcing purposes to enhance flexibility and strength, while preventing fatigue and cracking.

The tubular form in Fig. 3 is one version at right angle with the rectangular cross-section. The knitting operation for this, which is very similar to knitting a hose, is shown in Fig. 3(2). The ab and cd lines represent the operation of decreasing the number of operating needles, while ba' and dc' represent the operation of increasing the number of operating needles. During these operations, the needles which are temporarily inactive hold the stitch on them so that the decreasing and increasing lines become one connecting line after knitting. When the decreasing and increasing lines are at a 45° angle with the wales, a right angle is formed.

Fig. 4 shows another right angle tubular form but in this case with a circular cross-section. The radius $R$ of the "knee" can be chosen according to the application requirements. For knitting this form, first of all it is necessary to determine the decreasing and increasing knitting curvature [Fig. 4 (2)], i.e. establishing the relation between the number of operating needles and the number of consecutive knitted courses produced with those needles ($C$). This relation can be determined by the following equation:

$$C = \frac{N[1-\cos(\pi n/N)]}{4\alpha M} \qquad \ldots(1)$$

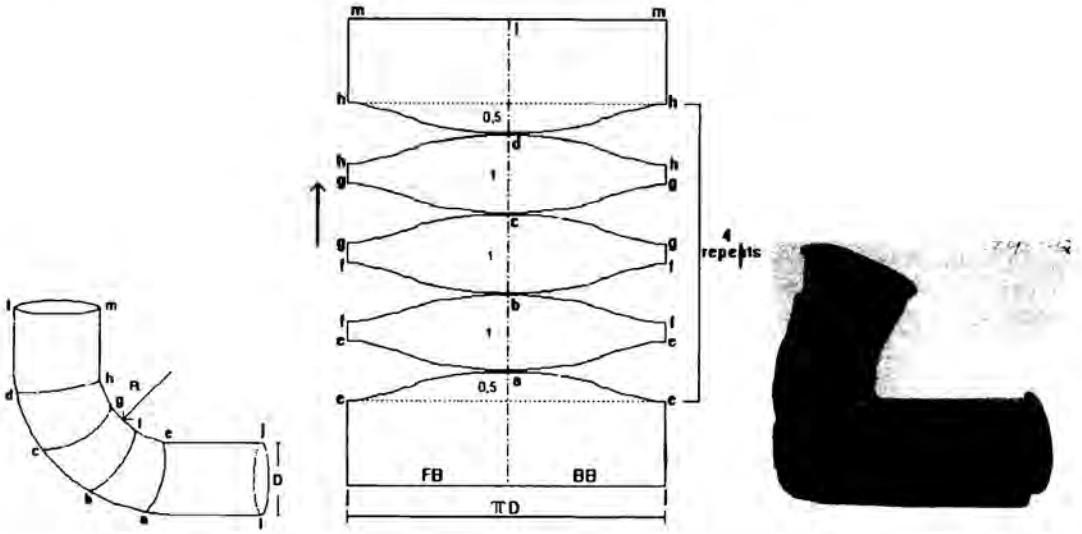
where $C$ is the number of knitted courses; $N$, the total number of active needles in one needle bed (depends on the required diameter of tube); $n$, the number of operating needles during an increasing (widening) or decreasing (narrowing) operation;




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

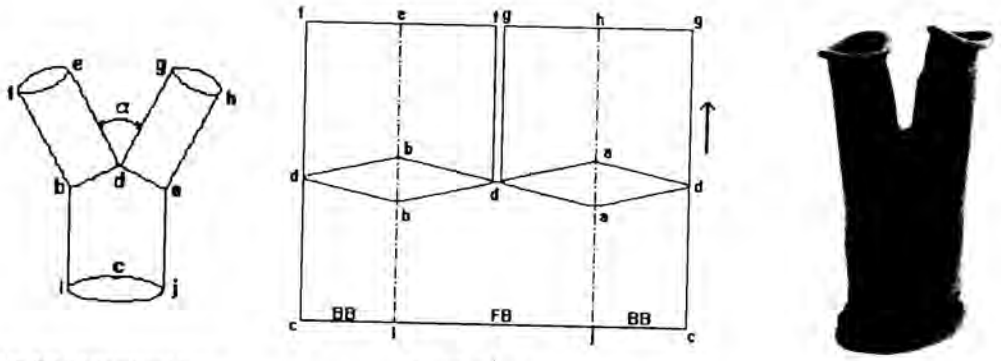
**Fig.3** - Tubular form with rectangular cross-section
( ↑ - Take-down direction )
FB = front needle bed
BB = back needle bed

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(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.4** - Tubular form with circular cross-section




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.5** - Tubular form : one main tube connected to two smaller tubes

$M$, the number of increasing/decreasing repeats; and $\alpha$, the loop shape factor (Poisson ratio).

The tubular forms shown in Figs 5 and 6 have the required shape to connect one larger tube to two smaller ones in a "Y" shape. The angle $\alpha$ between the two smaller tubes can be changed according to the requirements. During knitting, the two smaller tubes are separately knitted with two cam systems.

#### 4.2 Spherical Forms

It is not difficult to knit a spherical form in the SES 122FF flat knitting machine. To knit a spherical form with a radius $R$, it is necessary to start by transferring the three-dimensional concept to a two-dimensional pattern, as shown in Fig. 7, and then establishing the relation between the number of operating needles and the number of knitted courses as follows:

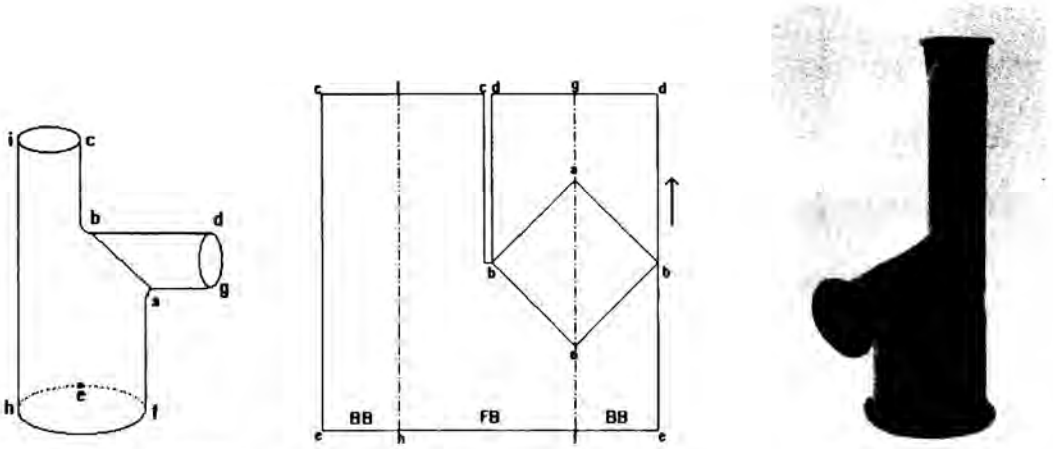
$$C=\frac{N\sqrt{1-\sin^2(\pi n/N)}}{2\alpha M} \qquad \ldots (2)$$

For knitting this type of article, a double knitted structure is normally used. In this case, it is possible to introduce a weft inlay thread to enhance the dimensional stability of the fabric.

#### 4.3 Box Forms

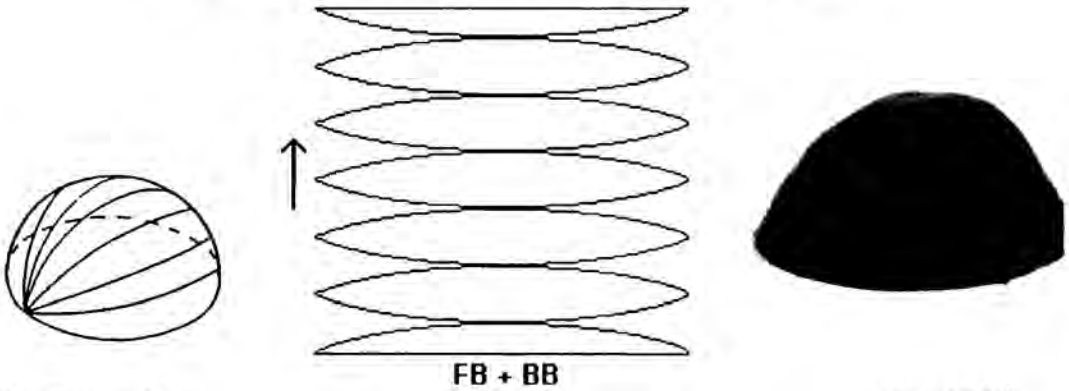
The box form (Fig. 8) is another example of

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(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.6** - Tubular form : one main tube connected with two smaller tubes




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.7** - Spherical form

three-dimensional knitted fabric on the SES 122FF machine. As shown in Fig. 8(2), the increasing and decreasing lines are linear at 45° with the direction of knitting (wales direction). This type of form is also knitted with a double knitted structure introducing a weft inlay thread.

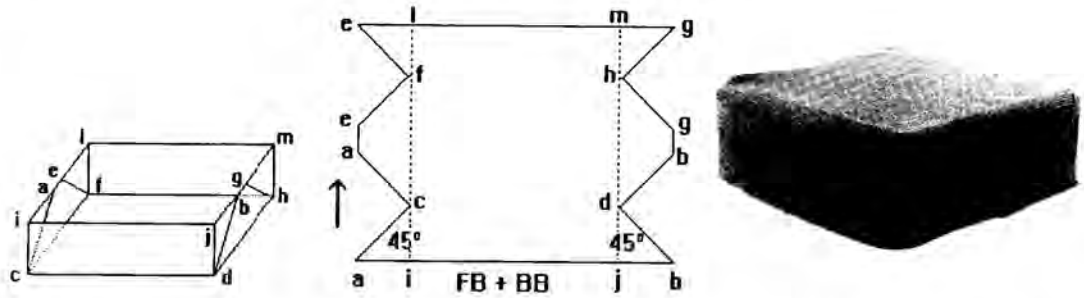
#### 4.4 Car Seat Covers

Knitted fabrics have been widely used in the automotive industry. At present, the most used knitted fabrics are circular weft knitted and warp knitted fabrics. In the last few years, however, the flat knitted fabrics have also been used for this purpose. The advantages of using the flat knitting machine to produce car seat covers are as follows:

- knitting directly the 3D shapes can overcome fabric waste and diminish the labour cost inherent to the use of two-dimensional fabrics which have to fit the variable geometry of a three-dimensional seat bum. Automation, despite several attempts, has not been as successfully applied to this sector as it has to others, using two-dimensional fabrics.
- the capability of electronic flat machines can be used to produce fabrics in greater structural and pattern variety than in any other type of knitting machine.

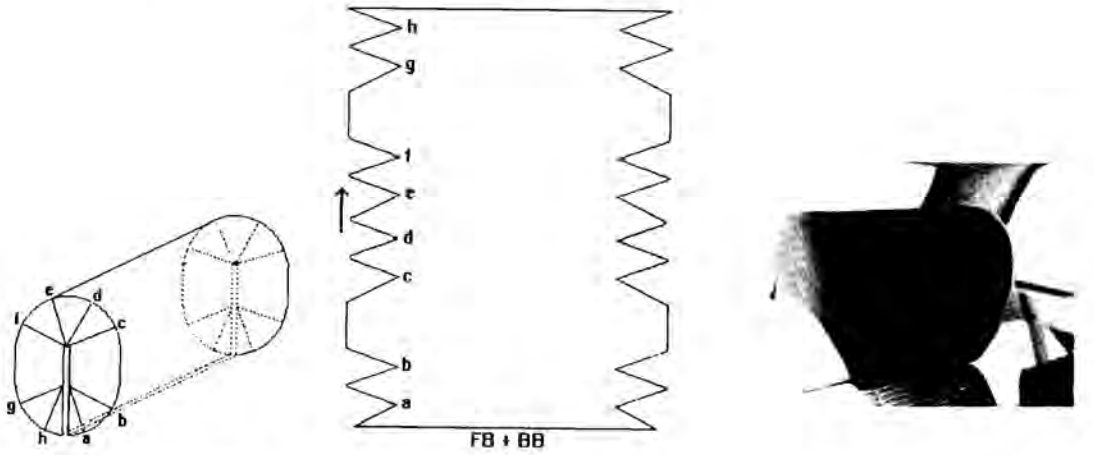
There are different types of seat covers. In order to knit a complete cover, the knitting process might be extremely complex. The conventional electronic flat knitting machines have difficulties in producing this type of fabric. For this reason, a simple form of car seat cover (head rest) developed on the SES 122FF is presented (Fig. 9).

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(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig. 8** - Box form




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig. 9** - Car seat cover (head rest)

## 5 Conclusions

The three-dimensional shaped knitted fabrics presented in this paper are only examples which have been developed on the SES 122FF flat knitting machine. By exploiting the capacity of this machine, it is possible to knit more types of three-dimensional knitted fabrics. The properties of fabrics knitted on the flat knitting machine are different from those of other types of textiles. Woven and multiaxial fabrics are stiffer than conventional weft knitted fabrics and so more suitable when high tenacity/low strain is required. If weft inlay threads are introduced, the stiffness of these fabrics can be increased at least in one direction.

If it is required to produce technical textiles (or parts) on flat knitting machines, the end-products should be able to exploit at least one specific advantage of the machine. For the production of large pieces of fabrics for technical textiles, weaving machine, warp knitting machines or even the circular knitting machines may be more suitable.

The flat knitting machine is more suitable for small shaped pieces and it is in this area that it will find its uses in the future.

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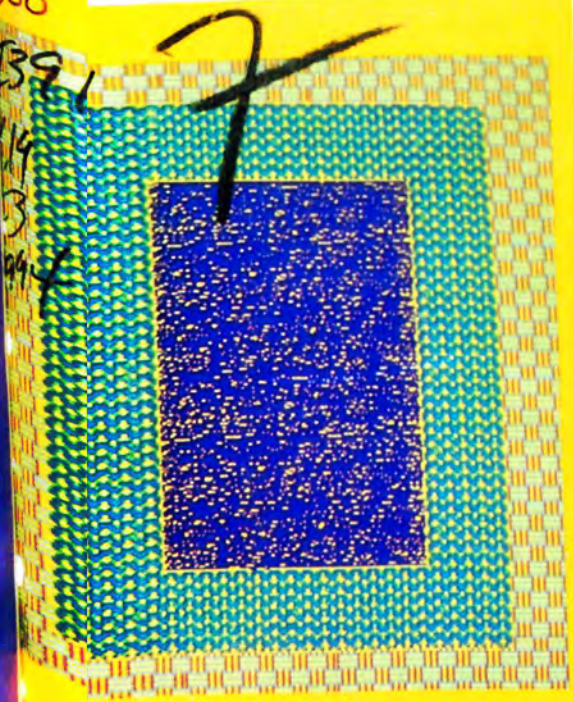
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Vol. 19, September 1994, pp. 189-194

# The development of 3D shaped knitted fabrics for technical purposes on a flat knitting machine

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The use of a new electronic flat knitting machine (Shima Seiki SES 122FF) for producing three-dimensional shaped fabrics for technical purposes is described. The three methods which can be applied to knit to shape, i.e. using different structural combinations, using different loop lengths, and altering the number of knitting needles and knitted courses, are discussed. Further, the different knitted elements (tubular forms, spherical forms, box forms and car seat covers) developed on the SES 122FF machine are described in detail.

**Keywords:** Flat knitting machine, Knitted fabrics, Loop structure, Technical textiles, Three-dimensional shaped knitted fabrics

## 1 Introduction

Technical textiles have been applied in different fields such as protection clothing, transportation related textiles (cars, planes and space crafts), geotextiles, building construction related textiles, packaging materials, military related textiles, medical textiles, sports related textiles, etc.

For many years, technical textiles were considered as very high-modulus fabrics, exhibiting extremely high structural stability and made of high-tenacity, low-elongation yarns. With the further development of new end uses, it has been realized that each technical product requires a different technical textile, with a different set of characteristics and some of these characteristics might be found in "loop based" structures.

Flat knitting machines are traditionally used for producing pullovers and other outerwear garments. One of the main advantages is the facility of these machines to knit fabric pieces to a particular shape or form. The combination of the individual needle selection technique and the use of the presser foot or holding down sinkers on the new generation of computer-controlled flat knitting machines increase this ability a great deal. By using the new flat knitting machines,it is possible not only to knit the new loop structures which are not possible on the conventional flat knitting machines, but also knit fully fashioned garments. This is very important to reduce the waste of expensive materials during cutting as well as in eliminating the additional making up operation. If the ability of knitting to shape of the flat knitting machines is used to produce 3D knitted technical textiles, it is not difficult to foresee their new end uses in the future.

This work describes the use of the new flat knitting machines to knit 3D structures by using different techniques in the Shima Seiki SES 122FF flat knitting machine. It is thought that these knitted shapes can be interesting as technical textiles and may also stimulate the imagination towards new applications.

## 2 Short Description of the Shima Seiki SES 122FF Flat Knitting Machine

The SES 122FF machine is one of the new generation of computer-controlled flat knitting machines. The main features of this machine are as follows:

- —the double cam system has knitting and transfer facilities at each cam system in which 31 different stitch lengths can be set;
- —the combination of holding down sinkers and presser foot is the machine facility which enables the knitting of fancy stitch effects and knit to shape;
- —the belt drive system gives smooth and high-speed carriage travel which enables the yarn to be picked-up or not, as required;
- —the set-up device and finely tuned take-down system for added take-down requirements; and
- —the machine controller which is programmed for knitting and shaping from a micro compu-

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ter with floppy disc drive, and has a screen resolution of 1024 × 1024 pixels.

The major advantage of this machine is that it has overcome former restrictions in knitting design and shaping, thus enabling the development of 3D knitted structures for technical purposes.

## 3 Techniques for Knitting to Shape

On flat knitting machines, it is possible to use the following techniques for knitting to shape:

—using different structural combinations;
—using different loop lengths; and
—altering the number of operating needles from course to course.

### 3.1 Using Different Structural Combinations

It is not difficult to reach the objective of knitting a 3D shape by using different loop structural combinations when knitting a technical course, because the different loop structures have different geometrical shapes under conditions in which the yarn counts and the loop lengths are the same. The new flat knitting machine can knit most weft-knitted structures, and so the combinations of different structures for knitting to shape are easily realised. However, it is necessary to bear in mind that this technique is not suitable in cases in which a technical product requires homogeneous properties in all parts, as the parts knitted with different structures present different properties.

### 3.2 Using Different Loop Lengths

Fabrics knitted with the same knitted structure but using different loop lengths have different geometrical dimensions. If one fabric is knitted with different loop lengths in different courses, shaping can take place. One simple example is circular jersey fabric knitting in separate needle beds. It is not difficult to change the circumference by changing the loop length from course to course. On the new flat knitting machines, the stitch cams can be automatically adjusted during knitting and so changing of loop length is very easy. It offers the facility of knitting to shape by changing loop lengths.

### 3.3 Altering the Number of Operating Needles from Course to Course

This technique is widely used in flat knitting for the production of fully fashioned panels. Two operations can be performed: increasing and decreasing the number of operating needles. On the new flat knitting machines, these two operations are very easily realised due to electronic single needle selection.

It is necessary to note that during the increasing (widening) or decreasing (narrowing) operations (Fig. 1), some needles are rendered inactive for a long time while retaining their loops. The tension applied to the fabric by the take-down rollers is, in this case, transferred solely to these needles, distorting the loops and subsequently breaking the yarn. For this reason, the use of the presser foot is necessary.

The presser foot (Fig. 2) is a metal wire which is securely fixed to the carriage by the presser foot mechanism, and moves across the machine with the carriage. During knitting, the presser foot precedes the needles which are rising. The wire

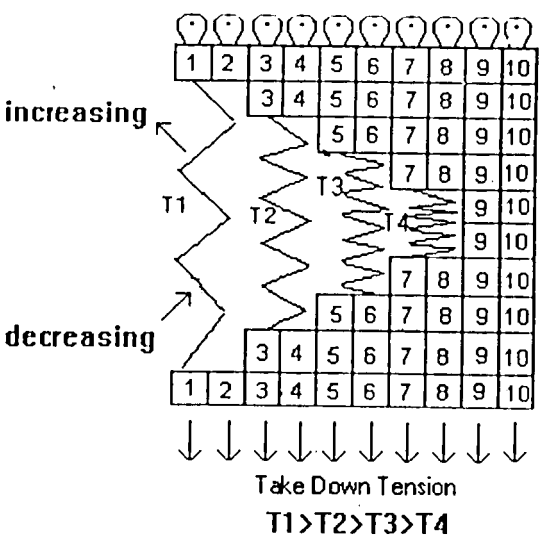



**Fig.1** - Fashioning operation: decreasing and increasing the number of knitting needles in one needle bed

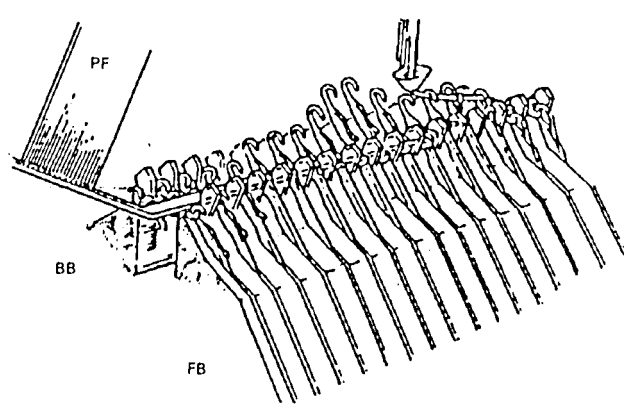



**Fig.2** - PF - Presser Foot
FB - Front needle bed
BB - Back needle bed

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slides just underneath the crossing or intersecting opposing needles on both needle beds and presses against the stitch laying between the two needle beds. As a result of this the take-down tension given to the fabric by the take-down rollers becomes unnecessary.

The absence of take-down tension allows stitches to be held on idle needles which are temporarily inactive, while neighbouring needles continue to knit normally. This is just one of the requirements of knitting to shape.

When this method is used to knit three-dimensional structures, the main technique consists in transferring the three-dimensional form to two-dimensional patterns, because the fashioning operation (increasing or decreasing the number of knitting needles) is only determined according to two-dimensional patterns. The three-dimensional shaped knitted fabrics presented in this work are all knitted by using this technique.

## 4 Three-Dimensional Shaped Knitted Fabrics Developed on the Shima Seiki SES 122FF Machine

### 4.1 Tubular Forms

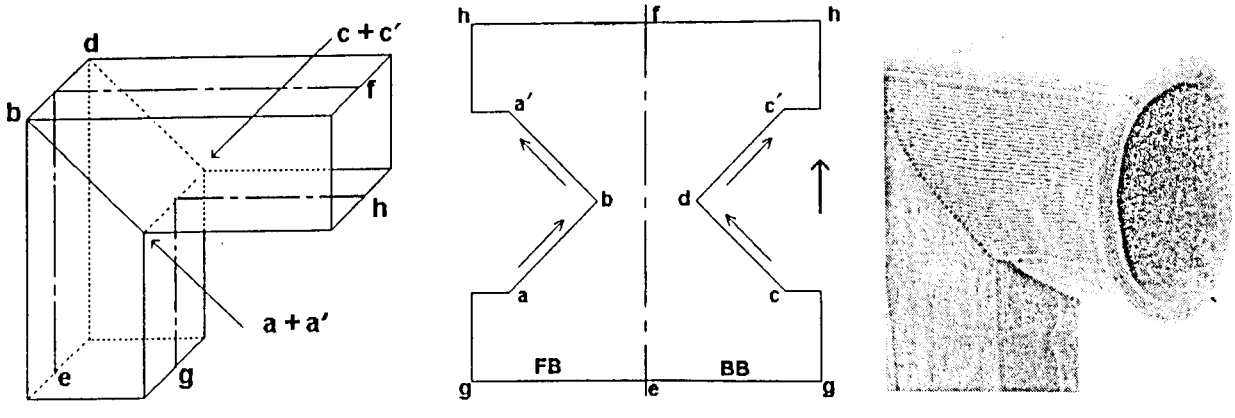
The tubular forms are knitted on both needle beds. When the number of operating needles in one bed is changed, a "knee" form is developed. The different tubular forms knitted on the SES 122FF flat knitting machine are shown in Figs 3-6. These types of structures can be used as tube connections for reinforcing purposes to enhance flexibility and strength, while preventing fatigue and cracking.

The tubular form in Fig. 3 is one version at right angle with the rectangular cross-section. The knitting operation for this, which is very similar to knitting a hose, is shown in Fig. 3(2). The ab and cd lines represent the operation of decreasing the number of operating needles, while ba′ and dc′ represent the operation of increasing the number of operating needles. During these operations, the needles which are temporarily inactive hold the stitch on them so that the decreasing and increasing lines become one connecting line after knitting. When the decreasing and increasing lines are at a 45° angle with the wales, a right angle is formed.

Fig. 4 shows another right angle tubular form but in this case with a circular cross-section. The radius $R$ of the "knee" can be chosen according to the application requirements. For knitting this form, first of all it is necessary to determine the decreasing and increasing knitting curvature [Fig. 4 (2)], i.e. establishing the relation between the number of operating needles and the number of consecutive knitted courses produced with those needles ($C$). This relation can be determined by the following equation:

$$C = \frac{N[1-\cos(\pi n/N)]}{4\alpha M} \quad \ldots(1)$$

where $C$ is the number of knitted courses; $N$, the total number of active needles in one needle bed (depends on the required diameter of tube); $n$, the number of operating needles during an increasing (widening) or decreasing (narrowing) operation;




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.3** - Tubular form with rectangular cross-section
( ↑ - Take-down direction )
FB = front needle bed
BB = back needle bed

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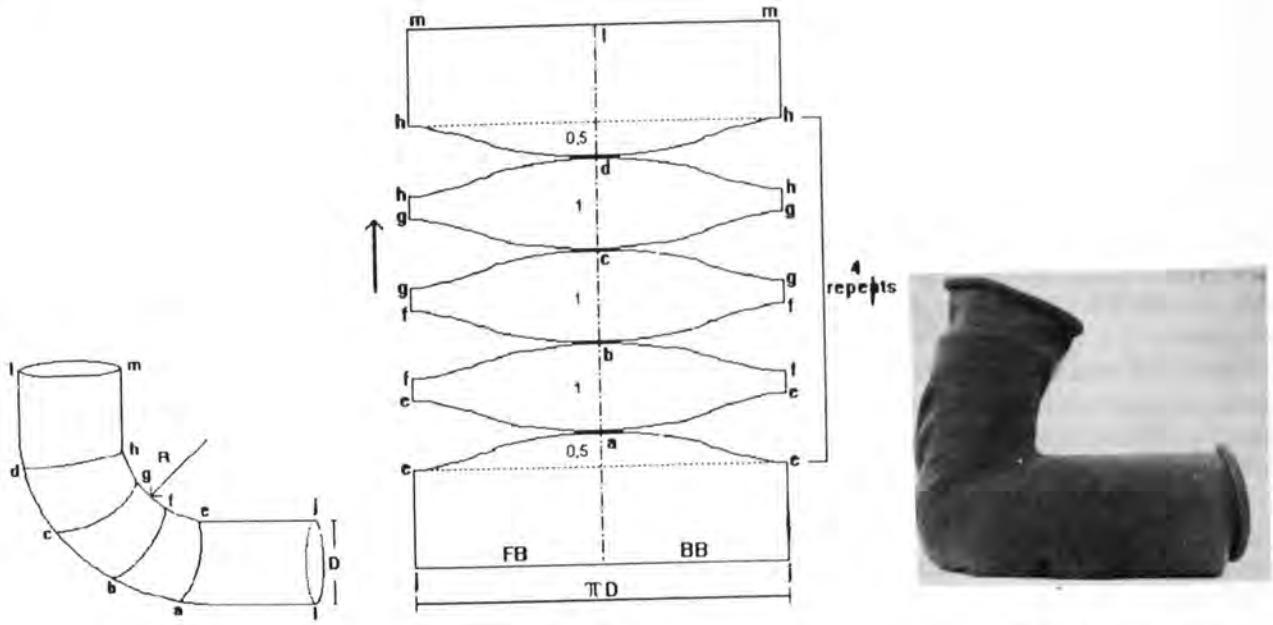



**Fig.4** - Tubular form with circular cross-section

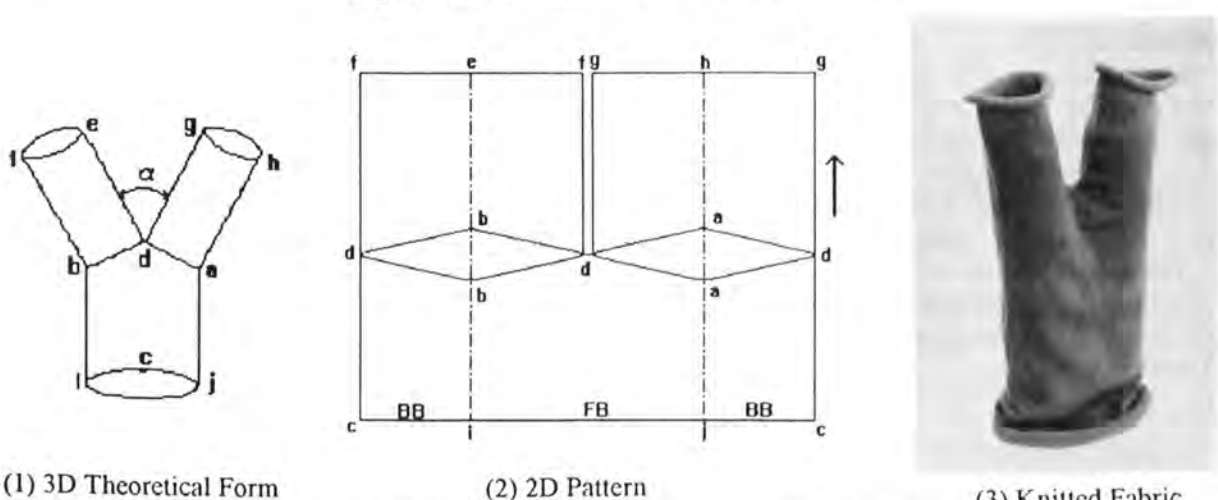



**Fig.5** - Tubular form : one main tube connected to two smaller tubes

$M$, the number of increasing/decreasing repeats; and $\alpha$, the loop shape factor (Poisson ratio).

The tubular forms shown in Figs 5 and 6 have the required shape to connect one larger tube to two smaller ones in a "Y" shape. The angle $\alpha$ between the two smaller tubes can be changed according to the requirements. During knitting, the two smaller tubes are separately knitted with two cam systems.

#### 4.2 Spherical Forms

It is not difficult to knit a spherical form in the SES 122FF flat knitting machine. To knit a spherical form with a radius $R$, it is necessary to start by transferring the three-dimensional concept to a two-dimensional pattern, as shown in Fig. 7, and then establishing the relation between the number of operating needles and the number of knitted courses as follows:

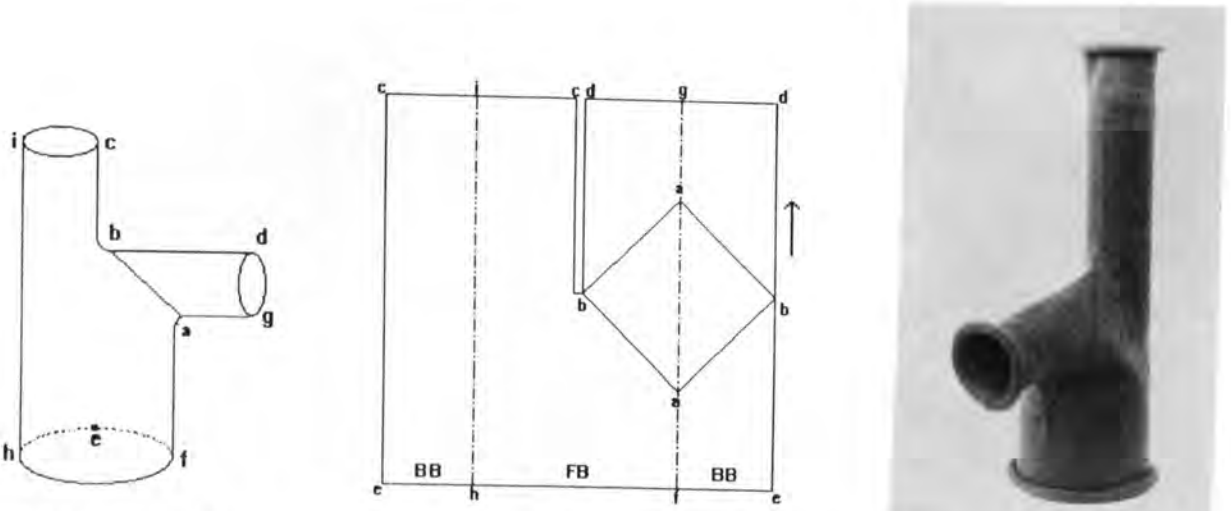
$$C=\frac{N\sqrt{1-\sin^2(\pi n/N)}}{2\alpha M} \qquad \ldots(2)$$

For knitting this type of article, a double knitted structure is normally used. In this case, it is possible to introduce a weft inlay thread to enhance the dimensional stability of the fabric.

#### 4.3 Box Forms

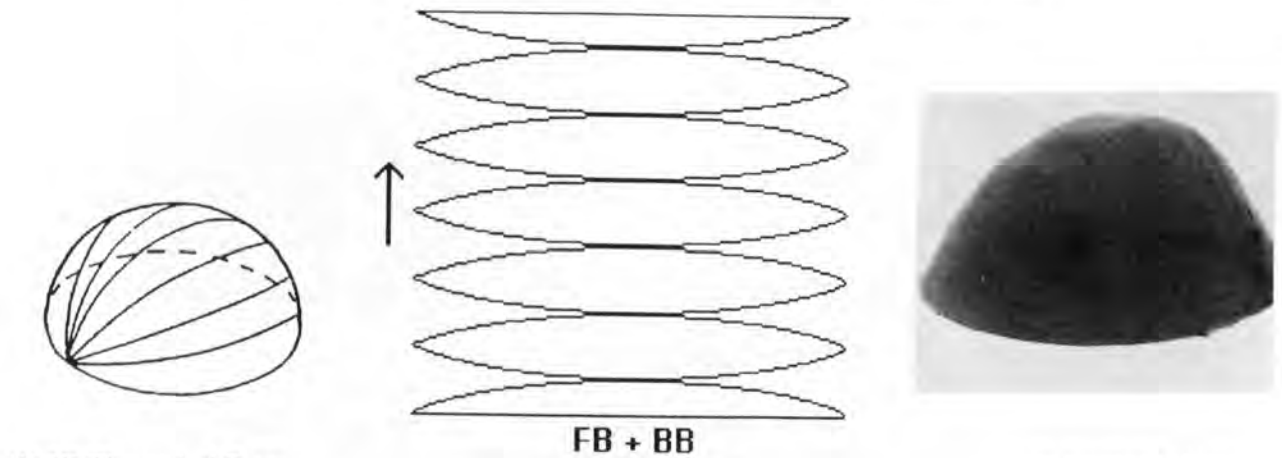
The box form (Fig. 8) is another example of

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(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.6** - Tubular form : one main tube connected with two smaller tubes




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.7** - Spherical form

three-dimensional knitted fabric on the SES 122FF machine. As shown in Fig. 8(2), the increasing and decreasing lines are linear at 45° with the direction of knitting (wales direction). This type of form is also knitted with a double knitted structure introducing a weft inlay thread.

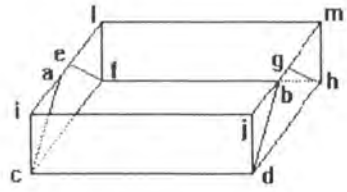
#### 4.4 Car Seat Covers

Knitted fabrics have been widely used in the automotive industry. At present, the most used knitted fabrics are circular weft knitted and warp knitted fabrics. In the last few years, however, the flat knitted fabrics have also been used for this purpose. The advantages of using the flat knitting machine to produce car seat covers are as follows:

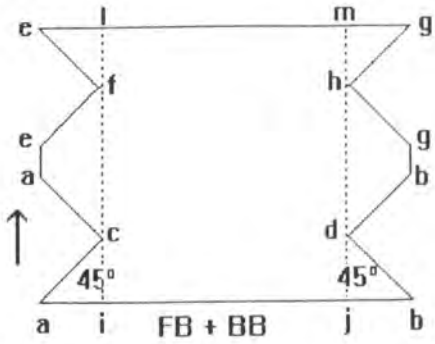
- knitting directly the 3D shapes can overcome fabric waste and diminish the labour cost inherent to the use of two-dimensional fabrics which have to fit the variable geometry of a three-dimensional seat bum. Automation, despite several attempts, has not been as successfully applied to this sector as it has to others, using two-dimensional fabrics.
- the capability of electronic flat machines can be used to produce fabrics in greater structural and pattern variety than in any other type of knitting machine.

There are different types of seat covers. In order to knit a complete cover, the knitting process might be extremely complex. The conventional electronic flat knitting machines have difficulties in producing this type of fabric. For this reason, a simple form of car seat cover (head rest) developed on the SES 122FF is presented (Fig. 9).

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(1) 3D Theoretical Form

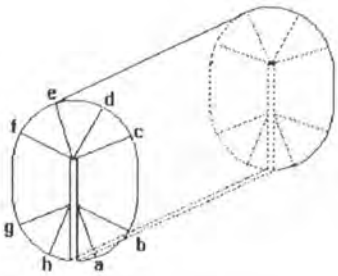



(2) 2D Pattern

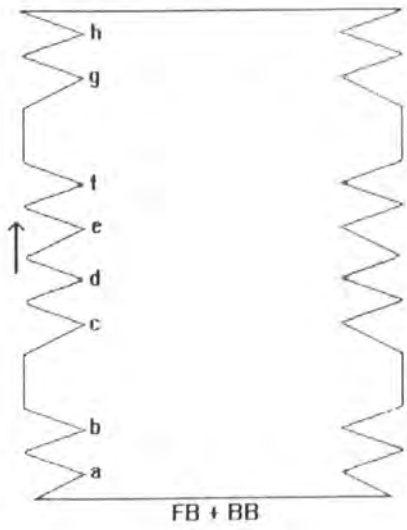


(3) Knitted Fabric

**Fig. 8** - Box form




(1) 3D Theoretical Form




(2) 2D Pattern



(3) Knitted Fabric

**Fig. 9** - Car seat cover (head rest)

## 5 Conclusions

The three-dimensional shaped knitted fabrics presented in this paper are only examples which have been developed on the SES 122FF flat knitting machine. By exploiting the capacity of this machine, it is possible to knit more types of three-dimensional knitted fabrics. The properties of fabrics knitted on the flat knitting machine are different from those of other types of textiles. Woven and multiaxial fabrics are stiffer than conventional weft knitted fabrics and so more suitable when high tenacity/low strain is required. If weft inlay threads are introduced, the stiffness of these fabrics can be increased at least in one direction.

If it is required to produce technical textiles (or parts) on flat knitting machines, the end-products should be able to exploit at least one specific advantage of the machine. For the production of large pieces of fabrics for technical textiles, weaving machine, warp knitting machines or even the circular knitting machines may be more suitable.

The flat knitting machine is more suitable for small shaped pieces and it is in this area that it will find its uses in the future.

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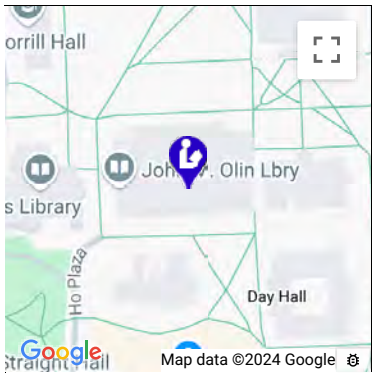
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# Exhibit U

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## Work Experience

Professor, School/Dept. of Library and Information Science, Catholic University of America, 1990-2022 (Assistant Professor, 1990-1996; Associate Professor, 1997-2004; Professor 2004-2022; Professor Emerita 2022)

Co-Chair, Dept. of Library and Information Science, Catholic University of America, June 2015-August 2016.

Acting Dean, School of Library and Information Science, Catholic University of America, January 2010-June 2012.

Cataloger, Dept. of Legislative Reference Library, Annapolis, Maryland, 1989-1990.

Lecturer, School of Library and Information Studies, University of Wisconsin-Madison, 1988.

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Cataloger, Health Sciences Library, University of Wisconsin-Madison, 1984-1986.

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## Grants & Honors

Cultural Heritage Information Management Project. IMLS grant. Amount: $498,741. Period: Aug. 2012 to July 2015. Co-PI with Dr. Youngok Choi.

D.C. Health Information Technology (HIT4): Building Capacity & Providing Access in Our Nation's Capital. Dept. of Labor H2B Training Grant. Grant amount: $4,175,500. Grant period: Nov. 2011 to Dec. 2015. Partner with the Metropolitan School of Professional Studies of the Catholic University of America, Children's National Medical Center, D.C. Department of Employment Services, Holy Cross Hospital, Howard University, Center for Urban Progress, Providence Hospital, and Sibley Memorial Hospital.

Capital Health Careers Project. Department of Labor Healthcare Sector and Other High Growth and Emerging Industries Grant. Grant amount: $4,953,999. Grant period: March 2010 – February 2013. Awarded to a group of healthcare organizations and educational institutions in Washington, D.C. Providence Health Foundation of Providence Hospital (Lead institution). Part of the grant supported the development of a Master's degree program in Information Technology with a concentration in Health Information Technology offered by the School of Library and Information Science.

The Washington D.C. School Librarians Project. IMLS grant. Grant amount: $412,660. Grant period: Aug. 2007 – June 2011. The School partnered with the District of Columbia Public Schools (DCPS) and the District of Columbia Library Association to educate and mentor school media specialists for the DCPS system. PI, Jan. 2010 to June 2011.

SIG Member of the Year, American Society for Information Science and Technology (2009).

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HEA Title IIB Fellowship (Dept. of Education) (1989)

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Beta Phi Mu (1985).

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Hsieh-Yee, I. (1996). Student Use of Online Catalogs and Other Information Channels. *College & Research Libraries,* 57: 161-175.

Hsieh-Yee, I. (1995). Ten entries in James S. C. Hu (Ed.), *Encyclopedia of Library & Information Science*, 913, 1028-29, 1036, 1037, 1145-46, 1514, 1575, 1763-64, 2216-27, 2378-79. Taipei, Taiwan: Sino-American Publishing. (Topics include "Advanced Technology/Libraries," "Information Ethics," "Instruction on Cataloging and Classification," "Instruction on Reference Services.")

Hsieh-Yee, I. (1993). Effects of Search Experience and Subject Knowledge on Online Search Behavior: Measuring the Search Tactics of Novice and Experienced Searchers. *Journal of the American Society for Information Science,* 44: 161-174. (Received the 1993 Best JASIS Paper Award.)

## Works in Progress

Hsieh-Yee, I. Actionable lessons for debunking false information: A comparative analysis of literacy lessons in communication and library and information science

Hsieh-Yee, I. Representing diverse voices and communities in cataloging and indexing: The evolution of controlled vocabularies

Hsieh-Yee, I. Information Organization and Retrieval in Practice (a monograph scheduled for completion and publication in 2023)

## Presentations

Bailey, T. & Hsieh-Yee, I. (February 2020). The Phenomena of Sharing Misinformation and the Need for Information Literacy. Presented at the 2020 Bridging the Spectrum Symposium, Washington, D.C., February 14, 2020.

Hsieh-Yee, I. and Fragan-Fly, J. (May 2018) Trends, Design & Strategies for Digital Scholarship Services. Presented at the 2018 Maryland/Delaware Library Association Conference, Cambridge, MD.

Hsieh-Yee, I. (February, 2018) Research Data Management: What It Takes to Succeed. Presented at the 10th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (February, 2017) *Research Data Management: New Competencies and Opportunities for Information Professionals*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. and Lawton, P. (February, 2017) *Enhancing Catholic Portal Searches with User Terms and LCSH*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (2016, October) *Visualizing Data for Information*. Presented at the 2016 Virginia Library Association Conference, Hot Springs, VA.

Hsieh-Yee, I. (2016, August) *Religious Materials Toolbox for Archivists: Solutions to Problems Facing the Profession*. Presented at Archives * Records 2016, Atlanta, GA.

Hsieh-Yee, I. and Lawton, P. (2016, March) *Enhancing Retrieval of Catholic Materials with LCSH Knowledge Structure*. Presented at the 2016 Catholic Library Association Conference, San Diego, CA.

Fagan-Fry, J. and Hsieh-Yee, I. (2016, February) *Approaches to Digital Scholarship at Top Universities around the World: Scholarly Publishing in the Digital Age.* Presented at the 8th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee and Fagan-Fry, J. (2016, January) *Innovative Services for Digital Scholarship at Top 100 Research Libraries of the World*. Poster presented at the 2016 Annual Conference of the Association for Library and Information Science Education, Boston, Mass.

Hsieh-Yee, I. and Lawton, P. (2015, June). *Crowdsourcing terms for CRRA portal themes.* Poster presented at the third CRRA symposium and annual meeting, Bringing the created toward the Creator: Liturgical art and design since Vatican II. Catholic Theological Union, Chicago, Illinois.

Hsieh-Yee, I. and Lawton, P. (2015, February). *Crowdsourcing terms for thematic exploration in the Catholic Portal.* Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I., James, R., and Fagan-Fry, J. (2015, February). *Support for digital scholarship at top university libraries of the world*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2015, February). *Thus said the end users: Summon experience and support for research workflows*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Yontz, E., Hsieh-Yee, I., & Houston, S. (2015, February). *Healthy Heroes Summer Reading Club: Developing healthy youth at public libraries.* 11th Annual Jean Mills Health Symposium, Greenville, North Carolina.

Yontz, E., Hsieh-Yee, I., and Houston, S. (2015, January). *Healthy youth and libraries: A pilot study.* Association for Library & Information Science Education (ALISE) Annual Conference, Chicago, Illinois.

Hsieh-Yee, I. (2014, May). *Linking CRRA resources to portal themes via authority files*. Presented at the Catholic Research Resources Alliance 2014 Membership Meeting, Marquette, WI.

Hsieh-Yee, I. (2014, April). *Enhancing subject access to CRRA resources*. Presented at the 2014 Catholic Library Association Conference, Pittsburgh, PA.

Hsieh-Yee, I. (2014, January). *Health Information Technology Program: Educational entrepreneurship in action*. Presented at the 2014 annual Conference of the Association for Library and Information Science Education, Philadelphia, PA

Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2014, January). *Discovering information through Summon: An analysis of user search strategies and search success*. Paper presented at the 6th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (2012, December). *National Digital Stewardship Alliance and SLIS at CUA: An Educational Partnership*. Paper presented at Best Practices Exchange: Acquiring, Preserving, and Providing Access to Government Information in the Digital Era, Annapolis, MD

Choi, Y. and Hsieh-Yee, I. (2010, January). *Finding Images in an OPAC: Analysis of User Queries, Subject Headings, and Description Notes*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. and Coogan, J. (2010, January). *Google Scholar vs. Academic Search Premier: What Libraries and Searchers Need to Know*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, November). *Information Science Education: An LIS School's Perspective*. Paper presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada.

Hsieh-Yee, I., Menard, E., Ya-Ning Chen, A., Shu-Jiun Chen, S., Kalfatovic, M. R., Wisser. K. M. (2009, November). *Information Organization in Libraries, Archives and Museums: Converging Practices and Collaboration Opportunities*. Presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada. (Organizer and moderator of this panel.)

Hsieh-Yee, I. and Coogan, J. (2009, July). *Catching up to Google Scholar: The Retrieval Power of Academic Search Premier and Google Scholar*. Poster presented at American Library Association Conference, Chicago, Illinois.

Hsieh-Yee, I., with the CUA Scholarly Communications Project Team. (2009, January). *Digital Scholarship@CUA: Developing an Institutional Repository for CUA*. Poster presented at 1st Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Wise, M., Cylke, K., and Hsieh-Yee, I. **(**2009, January). *Digital Talking Books: Meeting the Needs of the Blind and the Handicapped*. Paper presented at the Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, January). *User Expectations of MERIC*. Presented at the Information Organization Competencies for the 21st Century Discussion Session of the 2009 Conference of the Association for Library and Information Science Education, Denver, Colorado.

Choi, Y., and Hsieh-Yee, I. (2008,November). *Subject Access for Images in an OPAC.* Annual Meeting of the American Society for Information Science and Technology, Columbus, Ohio. (Also co-organized a panel on Retrieving and Using Visual Resources: Challenges and Opportunities for Research and Education.)

Hsieh-Yee, I. (2008, June). *Educating Cataloging Professionals in a Changing Information Environment*. National Taiwan University, Taipei, Taiwan.

Vellucci, S. L., Moen, W.E., Hsieh-Yee, I., Marson, B., and Wisser, K. (2008, January) *Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input*. A panel presented at the 2008 Conference of the Association for Library and Information Science Education, Philadelphia, Pennsylvania.

Hsieh-Yee, I., Choi,Y. and Kules, B. (2007, October). *Searching for Books and Images in OPAC: Effects of LCSH, TOC and Subject Domains.* A poster presented at the American Society for Information Science and Technology Annual Meeting, Milwaukee, Wisconsin.

Hsieh-Yee, I. and Coogan, J. (2007, August) *Google Scholar vs. Academic Search Premier: A Comparative Analysis.* Presented to the Faculty and Staff of the University of the District

of Columbia.

Hsieh-Yee, I. and Coogan, J. (2007, June). *Google Scholar vs. Academic Search Premier: A Comparative Analysis*. Presented to the Washington Research Library Consortium Community, Catholic University of America, Washington, D.C.

Hsieh-Yee, I., Choi, Y., and Kules, B.. (2007, June). *What Users Need for Subject Access: Table of Contents or Subject Headings?* A poster presented at the 2007 American Library Association Annual Conference, Washington, D.C., June 2007.

Choi, Y., Hsieh-Yee, I., and Kules, B. (2007, June). *Retrieval Effectiveness of TOC and LCSH.* A paper presented at the Joint Conference on Digital Libraries 2007, Vancouver, Canada.

Vellucci, S. L., Hsieh-Yee, I., and Moen, W.E. (2007, May). *If We Build It, Will They Come? Building a Community of Practice for Metadata Stakeholders.* A poster presented at the Rutgers University Research Day, Bridgeton, New Jersey.

Hsieh-Yee, I. (2007, May). *Federated Searching: User Experience & Perceptions.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May). *Search Performance of Google Scholar and Academic Search Premier.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May) *MERIC: Building a Digital Commons for Metadata Education & Research.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I., and Coogan, J. (2007, March/April). *A Comparative Analysis of Google Scholar and Academic Search Premier.* Poster presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland.

Vellucci, S. L. and Hsieh-Yee, I. (2007, March/April) *They Didn't Teach Me That in Library School! Building a Digital Teaching Commons to Enhance Metadata Teaching, Learning and Research*. On-site presentation and Webcast by Elluminate. A contributed paper presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland. The acceptance rate for contributed paper was 20%. This paper was one of 10 conference papers chosen for live webcast during the conference.

Moen, W., Hsieh-Yee, I. and Vellucci, S.L. (2007, January) *A DSpace Foundation for a Teaching & Research Commons: The Metadata Education and Research Information Commons.* A poster session presented at the Open Repositories Conference 2007, San Antonio, Texas.

Tang, R., Hsieh-Yee, I., and Zhang, S. (2006, November) *User Perception of MetaLib Combined Search*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas, Nov. 2006.

Hsieh-Yee, I. (2006, November). *Federated Searching: User Perceptions, System Design, and Library Instructions.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter).

Hsieh-Yee, I. (2006, November). *Building a Digital Teaching Commons to Enhance Teaching and Learning: The MERIC Experience and Challenges.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter)

Hsieh-Yee, I. (2006, September). *Search Performance of Google Scholar and Academic Search Premier.* Paper presented at the ERIC Publishers Meeting, Washington, D.C.

Hsieh-Yee, I., Zhang, S., and Rong Tang, R. (2006, June). *User Perceptions of a Federated Search System*. Poster presented at Joint Conference on Digital Libraries, Chapel Hill, North Carolina.

Hsieh-Yee, I. and Zhang, S. (2006, June). *Preparing Users for Federated Search: Implications of a MetaLib User Perceptions Study.* Paper presented at the 2006 Ex Libris User Groups of North America Conference, Knoxville, Tennessee.

Hsieh-Yee, I. (2006, January). *MERIC Organizations and Navigation*. Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2006, January). *Metadata and Cataloging Education: Recommended Competencies.* Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2005, November). *Digital Library Evaluation: Progress & Next Steps.* Presentation at the Annual Meeting of the American Society for Information Science & Technology, Charlotte, North Carolina.

Hsieh-Yee, I. (2005, August). *Providing Access to Digital Content: Issues for DL Managers.* Presentation at MDK12 Digital Library Steering Committee Meeting, Columbia, Maryland.

Hsieh-Yee, I. (2005, April). *Enhancing Teaching and Learning: The Role of School Library Media Specialists.* Presentation at Meeting of the Baltimore County Public School System School Media Specialists, Baltimore, Maryland.

Hsieh-Yee, I. (2005, January). *Subject Access and Users: Insights & Inspirations from Marcia J. Bates.* Paper presented at the Historical Perspectives SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2005, January). *Electronic Resource Management: Practice, Employer Expectations, & CE Interests.* Paper presented at Technical Services Education SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2004, October). *Library Professionals for the Digital Age: Competencies & Preparation.* Paper presented at Bibliographic Access Management Team meeting, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2004, January). *Cataloging and metadata expertise for the digital era.* Presented at Preparing 21st Century Cataloging and Metadata Professionals: A Workshop for Educators and Trainers, San Diego and sponsored by ALCTS, ALISE, LC, and OCLC.

Hsieh-Yee, I. (2004, January). *Educating catalogers for the digital era.* Paper presented at the Technical Services SIG, 2004 Conference of the Association for Library and Information Science Education, San Diego.

Hsieh-Yee, I. (2003, July). *Cataloging Education for the 21st Century.* A presentation at the Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2002, January) *Metadata Education and Research Priorities: A Delphi Study of Metadata Experts.* Presentation at the 2002 Conference of the Association for Library and Information Science Education, New Orleans.

Hsieh-Yee, I. (2001, November). *A Delphi Study of Metadata: Preliminary Findings.* Poster session at the 2001 Annual Meeting of the American Society for Information Science & Technology, Washington, D.C.

Hsieh-Yee, I. (2001, June). *Resources on Asian American Children: Analysis of Retrieval by Search Engines and WorldCat.* Presentation at the National Conference on Asian Pacific American Librarians, San Francisco.

Hsieh-Yee, I. (2001, January). *Delphi Study on Metadata: Project Design.* Presentation at Research Awards Session, Association for Library & Information Science Education, Washington, D.C.

Hsieh-Yee, I. (2000, May). *Web Search Behavior Research: Progress and Implications.* Presentation at the Symposium on Evaluating Library and Information Science Research, University of Wisconsin-Madison, Madison, Wisconsin.

Hsieh-Yee, I. (2000, March). *ERIC User Services: Evaluation in a Decentralized Environment.* Presentation at the National ERIC Joint Directors/Technical Meeting, Arlington, Virginia.

Hsieh-Yee, I. (2000, January). *Enhancing Learning with Web Technology.* Presentation at Faculty Conversations, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2000, January). *From Surrogates to Objects: CUA's Approaches to Organizing Electronic Resources.* Paper presentation at the Annual Conference of the Association for Library and Information Science Education, San Antonio, Texas.

Yee, P., and Hsieh-Yee, I. (1997, November). *Individual Differences in Search Behavior on the WWW.* A poster session presented at the 38th Annual Meeting of the Psychonomic Society, Philadelphia, Pennsylvania.

Hsieh-Yee, I. (1997, April). *Research + Marketing + Preparation = Job!* Presented at the "Workshop on Resume and Interview Techniques," Special Libraries Association, Student Chapter, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Creating CyberCatalogers: Education and Training.* Presentation at ALA's Midwinter Meeting, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study.* Presented at the Conference of the Association for Library and Information Science Education, Washington, D.C.

Hsieh-Yee, Ingrid. "Beginning Your Special Library/Information Center Career." Presented at SLA's "Career Day," Jan. 11, 1997, Catholic University of America.

Hsieh-Yee, I. (1996, September). *The Roles of Library and Information Scientists in Managing Electronic Information.* Presentation at Hamilton College, Clinton, New York.

Hsieh-Yee, I. (1996, May). *The Future of Cataloging as a Profession.* Presented at "The Cataloging Forum, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (1994, October). *The Impact of the Internet on OPACs.* Presented at the Third Workshop on User Interfaces for OPACs, Library of Congress, Washington, D.C.

## Reports

Hsieh-Yee, I., with Knowledge Management Competencies and Performance Action Group of the Federal Knowledge Management Initiative. "From Knowledge Management Competencies to Improved Organizational Performance." April 9, 2009.

Hsieh-Yee, I., with Knowledge Practices Action Group of the Federal Knowledge Management Initiative. "KM Practice in Government Agencies: Findings and Recommendations." April 9, 2009.

Hsieh-Yee, I. "Delphi Study on Metadata." 2001. Three quarterly reports submitted to the Association for Library and Information Science Education.

Hsieh-Yee, I. "College Students' Information Channels: Patterns of Use and Possible Factors in Channel Selection." 1995. Submitted to the Catholic University of America.

Hsieh-Yee, I. "The Information-Seeking Patterns of Scholars and Their Use of an Online Information System." 1994. Submitted to the Council on Library Resources.

## Book Reviews

Review of *The Measurement and Evaluation of Library Services*, by Sharon L. Baker and F. Wilfrid Lancaster. *Information Processing and Management* 30 (1994): 450-52.

Review of *Subject Access to Films and Videos, by Sheila S. Intner and William E. Studwell; and Cataloging Unpublished Nonprint Materials*, by Verna Urbanski with Bao Chu Chang and Bernard L. Karon. *Information Processing and Management* 30 (1994): 449-50.

Review of *Automated Information Retrieval in Libraries: A Management Handbook*, by Vicki Anders. *Journal of Library and Information Science* 19 (1993): 98-100.

Review of *Full Text Databases*, by Carol Tenopir and Jung Soon Ro. *Information Processing and Management* 28 (1992): 667-68.

Review of *Descriptive Cataloging for the AACR2R And USMARC: A How-to-Do It Workbook*, by Larry Millsap and Terry Ellen Ferl. *Information Processing and Management* 28 (1992): 809-11.

Review of *MARC Manual: Understanding and Using MARC Records*, by Deborah J. Byrne. *Information Processing and Management* 28 (1992): 537-38.

## Service

### Professional Associations and Societies

- Library of Congress. RDA Training Program for the Profession. Co-authored with Tim Carlton. 2013-2014.
- 2014 Digital Preservation Outreach & Education Survey. Contributed to the design of the survey, 2014.
- National Digital Stewardship Alliance. Outreach Committee. 2011-2014.
- National Digital Stewardship Residency Program. Advisory Group, 2012-2013.
- FEDLINK Health Information Technology Advisory Council, 2011-2015.

- 2012 Joint Conference on Digital Libraries. Program Planning Committee, Pre-Conference Proposals Review Committee, 2012
- Catholic Research Resources Alliance. Five-Year Strategic Plan Task Force, 2011-2012
- Institute of Museum and Library Services. Grant reviewer. 2004, 2005, 2010.

- Association for Library and Information Science Education.
  * ALISE Bodan Wynar Research Paper Award Committee, 2015, 2016, 2017
  * ALISE Eugene Garfield Dissertation Award Competition, Jury, 2013, 2014
  * ALISE Research Grant Competition Committee. Chair, 2012
  * Pratt-Severn Faculty Innovation Award. Chair, 2009, 2010
  * ALISE Doctoral Poster Jury, 2012
  * "Information Organization Competencies for the 21st Century" Discussion session leader. 2009 Conference of the Association for Library and Information Science Education.
  * Assisted Technical Services SIG Convener in organizing a program, ""Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input" for the 2008 ALISE conference.
  * Association for Library Collections and Technical Services/Association for Library and Information Science Education (ALCTS/ALISE) Metadata Education and Research Information Center (MERIC) Advisory Board, Co-Chair (with Sherry Vellucci), 2005-2007. Chair, 2008-2009 (leading the effort to build MERIC, a repository and collaborative space for metadata educators, practitioners, and researchers)
  * Technical Services SIG, Convener, 2004-2005. Organized a program on "Electronic Resources Management: Current Practices, Employer Expectations, and Teaching Strategies" for the 2005 conference in Boston, Massachusetts.
  * Technical Services SIG, Convener, 2003-2004. Organized a program on "Organizing Information with Metadata: Desired Competencies and Teaching Innovations" for the 2004 conference.
  * Technical Services SIG, Convener, 1999-2000. Organized a program on "Teaching the Organization of Electronic Resources" for the 2000 conference.
  * Curriculum SIG, Co-convener (with Sibyl Moses), 1996-97. Organized a program on "Government Information Policy" for the 1997 conference.

- American Society for Information Science & Technology.
  * Reviewer, Conference program panel submissions and poster submissions, 2005, 2006, 2007, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017
  * Nomination Committee, 2009-2011
  * Information Science Education Special Interest Group. American Society for Information Science and Technology. Chair-Elect, 2007-2008. Chair 2008-2009.
  * Committee on Information Science Education. 1999-2006.
  * Committee on Information Science Education. Organizing Committee for an orientation program for students at ASIS annual meetings, 1999-2001
  * Committee on Information Science Education. Sub-committee on Student Welfare (focusing on issues related to master's education), 1998-2001

* SIG ED. Organizing Committee for the "Seminar on Research and Career Development" for junior researchers. 1995-96 (chair), 1997-2001
* ISI Doctoral Dissertation Proposal Scholarship Jury, 1997; 2001, 2002
* Pratt-Severn Best Student Research Paper Award Jury. Chair. 1997
* 1998 Midyear Meeting (referee of contributed papers), 1997
* Organizer and moderator of the ASIS Doctoral Forum and the Doctoral Research Seminar 1994-1995
* SIG Human Computer Interaction. Chair-Elect, Chair, 1993-1995
* Doctoral Forum Award Jury, 1995
* Best Student Paper Award Jury, 1995

- American Library Association.
  * Committee on Accreditation, External Review Panelist, 2009- (site visiting team 2013-2014; site visiting team 2016-2017)
  * Association for Library Collections and Technical Services Task Force on Competencies and Education for a Career in Cataloging, member, 2008-2009
  * Facilitator for "What They Don't Teach in Library School: Competencies, Education and Employer Expectations for a Career in Cataloging," an Association for Library Collections and Technical Services Preconference, June 22, 2007 in Washington, D.C. Also a local liaison for bringing this program to the Catholic University of America.
  * Facilitator for a discussion on "Effect of Electronic Resources on Technical Services" at ALA's Midwinter Meeting held in Feb. 1997 in Washington, D.C.
  * International Relations Committee, Subcommittee Task Force for IFLA and China, 1994-1997

- Virginia Association of School Librarians. Scholarships and Awards Committee. 2010-2012

- Federal Knowledge Management Initiative, Knowledge Management Practices Action Group. Member. 2009 (leading the effort to build a knowledge management repository)
- Federal Knowledge Management Initiative, Knowledge Management Competencies & Learning Action Group. Member. 2009 (developing an action plan for helping government knowledge workers and government agencies to develop knowledge management competencies)
- National Center for Education Statistics. Technical Review Panel. 2008.
- External evaluator for a case of promotion to full professorship. University of Tennessee. 2008.
- National Information Standards Organization (NISO). Advisory Board, Revision of "IMLS Framework of Guidance for Building Good Digital Collections," 2004, 2007.
- Library of Congress, Bibliographic Control of Web Resources: A Library of Congress Action Plan. Principal Investigator of Action Item 5.1, focusing on cataloging and metadata education for students and new librarians, 2002-2003. (worked with the Association for Library Collections and Technical Services, Education Task Force)

- Chinese American Librarians Association
  * Chinese American Librarians Association Outstanding Library Leadership Award in Memory of Dr. Margaret Chang Fung, Award Committee, 2016-2017
  * Achievement Award Jury, 2000-2001
  * CALA Goal 2000 Task Force, 1997
  * Scholarship Committee, 1995, 1996-1997 (chair)
  * Board of Directors, 1994-1997
  * Publication Committee, 1993-1995
  * International Relations Committee, 1993-1996

- Sailor[SM] Assessment Advisory Group (An impact study of Sailor, Maryland's Public Information Network), 1995

- Editorial boards
  Journal of Library & Information Science. Editorial Board, 2012-
  Chinese American Librarians Association, *Occasional Papers Series*. Editorial Board, 2009-2016.
  *Library Quarterly.* Editorial Board, 2003-2008
  *Bulletin of the Medical Library Association*, 1994-97
  Newsletter editor for the Chinese American Librarians Association, 1989-92

- Referee for the following journals
  *Information Processing and Management*
  *Journal of Digital Information*
  *Journal of Education for Library and Information Science*
  *Journal of Information Science*
  *Journal of Library & Information Science*
  *Journal of Library Metadata*
  *Journal of the American Society for Information Science & Technology*
  *Library and Information Science Research*
  *Library Quarterly*

- Expert reviewer, "Digital Library" course, Evaluation module, University of North Carolina, Chapel Hill, 2007-2008.
- Expert reviewer, "Information Organization" course, University of Michigan, Ann Arbor. 2007.

**Catholic University of America**

- Academic Senate Committee on Appointments and Promotions, 2005-2008
- Academic Senate Committee on Committees and Rules, 2009-2012, 2019-2022
- Academic Senate representative (for School of Arts & Sciences), 2017-2020

- Academic Senate representative (for School of Library & Information Science) 2003-2012
- Academic Senate Library Committee, Interim Chair (2007), Member, 2008-2012
- Academic Senate Committee on Computing, 1995-2003

- President's Administrative Council, 2010-2012
- Deans' Council, 2010-2012
- Academic Leadership Group, 2010-2012
- Graduate Board, 2010-2012

- School of Arts & Sciences, Committee on Appointments and Promotions, 2015-2019
- School of Arts & Sciences, Academic Council, 2015-2016.
- School of Arts & Sciences, Ordinary Professor Group, 2013-
- Doctoral Dissertation Defense Committee, Chair, Dept. of Psychology, 2016, 2017, 2018, 2019, 2020, 2021, 2022
- Doctoral Dissertation Defense Committee, Chair, Dept. of Education, 2014, 2015, 2017, 2018, 2019
- Doctoral Dissertation Defense Committee, Chair, National Catholic School of Social Services, 2019, 2020, 2021
- Doctoral Dissertation Defense Committee, Chair, School of Nursing, 2006, 2008
- CUA Scholarly Communication Project Team, Member (2007), Chair, 2008-2009
- Dean Search Committee, 1992-1994, 1998-1999, 2002-2003, 2006-2007
- Fulbright Review Panel, 2006
- CUA Service Learning Advisory Board, 2001-2002
- CUA Faculty Conversations on Enhancing Teaching and Learning through Technology, Planning Group, 1999-2001
- CUA Initiative on Technology and Teaching, 1998-2001

**Dept. of Library and Information Science**

- Admissions Committee, 2007-2009, Chair 2010-2012, Member 2013-2015, Member 2018-2022
- Appointments and Promotions Committee, 1991-2022
- Student advisement, 1990-2022
- 4+1 Bachelor to Master program, Program Advisor, 2014-2022
- LIS Minor, Advisor, 2017-2022
- Curriculum Committee, 2020-21 (Member), 2021-2022 (Chair)
- Scholarship & Awards Committee, 2016-2018, 2020-21
- Comprehensive examination editor, 2020-21
- Symposium, Colloquium, Lecture Series Committee, May 2018-May 2020 (Chair)
- Symposium and Colloquium Committee, fall 2016-May 2018
- Bridging the Spectrum Symposium session moderator, 2018, 2019, 2020, 2021

- Organization of Information Core Course Outcomes Assessment, 2019, 2020
- The Information Professions in Society Core Course Outcomes Assessment, 2019, 2020
- Community Services Librarianship, Course of Study Review and Revision, 2020
- Organization of Information, Course of Study Review and Revision, 2019
- Organization of Information, Competency and Course Offerings Review, 2018-2019
- Accreditation presentation, Chair, June 2015-August 2016
- Interim Co-Chair, June 2015-August 2016.
- Blended/OWL Learning Committee, spring 2016-2018
- Technology Committee, fall 2016-2017
- Comprehensive examination editor, 2016-2017, reader (every year since 1990)
- LIS Advisory Board, 2015-2016 (chair); fall 2016- May 2018 (member)
- Committee on Planning and Assessment, 2015-2016 (chair)
- Senior Faculty Committee, 2014-2016.
- Accreditation Steering Committee, 2014-2016 (Chair, 2015-2016)
- Accreditation Students Standard Committee, co-chair, 2014-2016
- Accreditation Mission, Goals, and Objectives Standard Committee, co-chair, 2014-2016
- Accreditation Curriculum Standard, member 2014-2-16
- Accreditation Administration and Finance Standard, member 2014-2016
- Cultural Heritage Information Management Project (IMLS-funded), Co-PI, 2012-2015
- Cultural Heritage Information Management Forum (scheduled for June 2015), Co-Organizer, 2013-2015
- Health Information Technology Interim Review Committee, 2015 (chair)
- Health Sciences Librarianship Advisory Group, 2015- (chair)
- Comprehensive examination editors, 2013-2014, 2016-2017
- National Digital Stewardship Alliance liaison, 2011-2014
- Advisory Board, Chair 2010-2012
- Academic Honesty Committee, Chair, 2008-2012
- Blended Learning Committee, 2010-2012
- Colloquium Committee, 2010-2012
- Comprehensive Examination Administration, 2010-2012
- Cultural Heritage Information Management Advisory Committee, 2010-2012 (chair), 2013-
- Curriculum Committee, 1991-2003, 2007-2009, Chair 2010-2012, member 2013-
- Curriculum Subcommittee on Comprehensive Examination, Chair 2009-2012
- Health Information Technology Advisory Board, Chair 2010-2012. Member 2013-
- Health Sciences Advisory Committee, 2009, Chair 2010-2012. Member 2013-
- HIT Expert Forum, Chair 2012. Member 2013-2015
- Health Information Technology Student Group Advisor, 2011-2012
- State Council for Higher Education of Virginia, SLIS Representative, 2010-2012
- Symposium Planning Committee, 2010-2012
- Website Management Team, Chair, 2010-2012
- Urban School Librarianship Project (IMLS-Funded), PI, 2007-2011 (chair, 2010-11)

- Failing Grades Committee, 1995-1997 (chair), 2000-2001 (chair), 2004-2005 (chair), 2007 (chair)-2011
- Faculty Search Committee, 1994-1998, 2002-2004, 2006 (chair), Fall 2007-2009, Chair fall 2009-2012
- Recruitment Committee, Chair 2010-2012
- Strategic Planning Committee, Chair 2010-2012
- Technology Committee, 2010-2012
- Accreditation Advisory Committee, 2007-2009
- Accreditation Coordinating Committee, 2007-2009
- Accreditation Steering Committee, 2007-2009
- SLIS Advisory Group, 2007-2009
- Accreditation Curriculum Standard Committee, Co-chair, 2007-2009
- Accreditation Faculty Standard Committee, Co-chair, 2007-2009
- LSC 551 Information Organization Review Team, Co-chair, 2008-2009, 2015-2016.
- Curriculum Subcommittee on Portfolios, 2009
- LSC 555 Information Systems in Libraries and Information Centers Review Team, contributor, 2008-2009
- Redesign of LSC 730 Use and Users of Libraries and Information. 2009-
- Development of a metadata institute that was taught as LSC 715 Organization of Internet Resources in 2008. The institute is being revised and will be offered in 2010 under a new course title.
- Development of lesson plans, assignments, and evaluation rubrics for LSC 606, Cataloging and Classification, for the School's NCATE accreditation. 2008
- Howard and Mathilde Rovelstad Scholarship Committee, Chair, 2004-2007
- Assistant Dean Search Committee, Chair, Fall 2007
- Liaison to the Association for Library Collections and Technical Services to bring its preconference program, Cataloging Education and Employer Expectations, to CUA during the 2007 American Library Association Annual Meeting in Washington, D.C.
- Organizer of the colloquium presentation and reception for Tamar Sadeh of Ex Libris on PRIMO June 2007
- Practicum review and design (work with potential supervisors, such as the American Indian Museum internship description revision) 2006-
- Comprehensive examinations (edits, proctoring, and grading), 1990-
- SLIS Web site redesign: Comments and suggestions. Fall 2007
- Conducted surveys of current students and alumni in preparation for the 2005 re-accreditation, 2004-2005
- Technology Committee, 1992-1999 (chair, 1996-1998), 2002-2003 (member)
- Colloquia Committee 1997-1999, 2002-2003.
- Advisor of the CUA Student Chapter of the American Society for Information Science and Technology, 2002-2003
- Visiting Professor Search Committee, 1999, 2000, 2001
- Leader, Participation in the CORC experiment, 1999-2000
- Advisor of the Special Libraries Association Student Chapter, 1993-1999; the group was recognized for outstanding leadership by SLA in 1999.

- COA planning Committee, Task Force on Electronic Presentation of SLIS Reports (team leader) 1997-1998
- COA Planning Committee, Subcommittee on Technology 1996-1998
- NLM practicum coordinator, 1997-1998
- Computer Literacy Workshops: Assisted with the development and evaluation of the workshops, 1996-1998
- Leader, Participation in the InterCat project, 1995-1997

# Exhibit V

# MARC 21 Reference Materials

Part VII: A Summary of Commonly Used MARC 21 Fields
Part VIII: A List of Other Fields Often Seen in MARC Records
Part IX: The Leader
Part X: Field 008 for Books

## Part VII:

## A Summary of Commonly Used MARC 21 Fields

**This is a summary of the MARC 21 tags used most frequently by libraries in entering their own bibliographic records.** For full listings of all MARC 21 tags, indicators, and subfield codes, see *MARC 21 Format for Bibliographic Data*.

In the explanations on these pages:

**Tags --** The tags (3-digit numbers) are followed by the names of the fields they represent. In this summary, and in the *MARC 21 Format for Bibliographic Data*, if a tag can appear more than once in one bibliographic record, it is labeled repeatable (R). If it can only be used once, it is labeled non-repeatable (NR). For example, a catalog record can have several subjects, so the tags for subject added entries (6XX) are labeled repeatable (R).

**Indicators --** The use of indicators is explained in fields where they are used. Indicators are one-digit numbers. Beginning with the 010 field, in every field -- following the tag -- are two character positions, one for Indicator 1 and one for Indicator 2. The indicators are not actually defined in all fields, however. And it is possible that a 2nd indicator will be used, while the 1st indicator remains undefined (or vice versa). When an indicator is undefined, the character position will be represented by the character # (for blank space).

**Subfield codes --** All the data in each field (beginning with the 010 field) is divided into subfields, each of which is preceded by a delimiter-subfield code combination. The most common subfield codes used with each tag are shown. Each subfield code is preceded by the character $, signifying a delimiter. The name of the subfield follows the code.

In general, every field MUST have a subfield 'a' (**$a**). One exception that is often seen is in Field 020 (ISBN), when the ISBN information (subfield **$a**) is unavailable but the price (subfield **$c**) is known. Some subfields are repeatable. In this summary, repeatability is noted for only the more common repeatable subfields.

**Examples:** Examples follow the explanation for each field. For clarity, one space has been placed between the tag and the first indicator, one space has been placed between the second indicator and the first delimiter- subfield code, and one space has been inserted between the delimiter-subfield code and the subfield data.

**010 Library of Congress Control Number --** (LCCN)
(NR, or Not Repeatable

*Indicators undefined.*
*Subfield used most often:*
**$a** -- Library of Congress control number

```
Example:    010 ##  $a ###86000988#
```

**020 International Standard Book Number --** (ISBN)
(R, or Repeatable)

*Indicators undefined.*
*Subfields used most often:*
**$a** -- International Standard Book Number
**$c** -- Terms of availability (often a price)
**$z** -- Cancelled/invalid ISBN (R)

```
Example:    020 ##  $a 0877547637
```

**040 Cataloging source --** (NR)

*Indicators undefined.*
*Subfields used most often:*
**$a** -- Original cataloging agency
**$c** -- Transcribing agency
**$d** -- Modifying agency (R)

```
Example:    040 ## $a DLC
                   $c DLC
                   $d gwhs
```

**100 Main entry -- Personal name --** (primary author)
(NR; there can be only one main entry)

*Indicator 1:* Type of personal name entry element
0 -- Forename
1 -- Surname (this is the most common form)
3 -- Family name
*Indicator 2 undefined.*
Indicator 2 became obsolete in 1990. Older records may display 0 or 1
*Subfields used most often:*
**$a** -- Personal name
**$b** -- Numeration

**$c** -- Titles and other words associated with a name (R)
**$q** -- Fuller form of name
**$d** -- Dates associated with a name (generally, year of birth)

```
Example:    100 1# $a Gregory, Ruth W.
                   $q (Ruth Wilhelme),
                   $d 1910–
```

**130 Main entry -- Uniform title --** (NR)

*Indicator 1:* Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

*Indicator 2 undefined.*

Indicator 2 became obsolete in 1990. (See 100 above.)

*Subfields used most often:*

**$a** -- Uniform title
**$p** -- Name of part/section of a work (R)
**$l** -- Language of a work
**$s** -- Version
**$f** -- Date of a work

```
Example:    130 0# $a Bible.
                   $p O.T.
                   $p Psalms.
```

**240 Uniform title** (NR)

*Indicator 1:* Uniform title printed or displayed

0 -- Not printed or displayed
1 -- Printed or displayed (most common)

*Indicator 2:* Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

*Subfields used most often:*

**$a** -- Uniform title
**$l** -- Language of a work
**$f** -- Date of a work

```
Example:    240 10 $a Ile mystérieuse.
                   $l English.
                   $f 1978
```

### 245 Title Statement (NR)

*Indicator 1:* Title added entry

(Should the title be indexed as a title added entry?)

0 -- No title added entry

(indicates a title main entry; i.e. no author is given)

1 -- Title added entry

(the proper indicator when an author given in 1XX; the most common situation)

*Indicator 2:* Nonfiling characters

0-9 -- Number of nonfiling characters present, including spaces; usually set at zero, except when the title begins with an article; e.g., for *The robe*, the second indicator would be set to 4. The letters *T*, *h*, *e*, and the space following them are then ignored in alphabetizing titles. The record will be automatically filed under "*r*" -- for *Robe*.

*Subfields used most often:*

**$a** -- Title proper

**$h** -- Medium (often used for non-book media)

**$p** -- Name of part/section of a work (R)

**$b** -- Reminder of title (subtitles, etc.)

**$c** -- Remainder of title page transcription/Statement of responsibility

```
Example:    245 14 $a The DNA story :
                   $b a documentary history of gene
                      cloning /
                   $c James D. Watson, John Tooze.
```

### 246 Varying form of title (R)

*Indicator 1:* Note/title added entry controller

1 -- Note, title added entry

3 -- No note, title added entry

*Indicator 2:* Type of title

# -- No information provided

0 -- Portion of title

1 -- Parallel title

4 -- Cover title

8 -- Spine title

*Subfield used most often:*

**$a** -- Title proper

```
Example:    246 3# $a Four corners power review
```

### 250 Edition statement (NR)

*Indicators undefined.*
*Subfield used most often*:
**$a** -- Edition statement

```
Example:    250 ## $a 6th ed.
```

**260 Publication, distribution, etc.** (Imprint) (R)
*Indicator 1:* Sequence of publishing statements
# -- No information provided
*Indicator 2: Undefined*
*Subfields used most often:*
**$a** -- Place of publication, distribution, etc. (R)
**$b** -- Name of publisher, distributor, etc. (R)
**$c** -- Date of publication, distribution, etc. (R)

```
Example:    260 ## $a New York :
                   $b Chelsea House,
                   $c 1986.
```

**300 Physical description** (R)
*Indicators undefined.*
*Subfields used most often:*
**$a** -- Extent (number of pages) (R)
**$b** -- Other physical details (usually illustration information)
**$c** -- Dimensions (cm.) (R)
**$e** -- Accompanying material (for example, "teacher's guide" or "manual")

```
Example:    300 ## $a 139 p. :
                   $b ill. ;
                   $c 24 cm.
```

**440 Series statement / Added entry--Title**
This field was made obsolete in 2008 to simplify the series statement. See 490 and 830.

**490 Series statement** (No added entry is traced from field) (R)
*Indicator 1:* Specifies whether series is traced (whether an 8XX tag is also present)
0 -- Series not traced
1 -- Series traced (8XX is in record)
*Indicator 2 undefined.*
*Subfield used most often:*

**$a** -- Series statement (R)
**$v** -- Volume number (R)

```
Example:    490 1# $a Colonial American craftsmen
```

**500 General note** (R)

*Indicators undefined.*
*Subfield used most often:*

**$a** -- General note (Used when no specialized note field has been defined for the information. Examples: Notes regarding the index; the source of the title; variations in title; descriptions of the nature, form, or scope of the item.)

```
Example:    500 ##  $a Includes index.
```

**504 Bibliography, etc. note** (R)

*Indicators undefined.*
*Subfield used most often:*

**$a** -- Bibliography, etc. note

```
Example:    504 ## $a Includes bibliographical
                      references.
```

**505 Formatted contents note** (R)

*Indicator 1:* Type of contents note
0 -- Complete contents
1 -- Incomplete contents (used with multivolume set when some volumes are not yet published)
2 -- Partial contents
*Indicator 2:* Level of content designation
# -- Basic
*Subfield used most often:*

**$a** -- Formatted contents note

```
Example:    505 0# $a Pride and prejudice -- Emma
                      -- Northanger Abbey.
```

**520 Summary, etc. note** (R)

*Indicator 1:* Display constant controller
# -- Summary

1 -- Review
2 -- Scope and content
3 -- Abstract

*Indicator 2 undefined*

*Subfields used most often*

**$a** -- Summary, abstract, or annotation
**$b** -- Expansion of summary note

```
Example:    520 ## $a This basic guide to parliamentary
                     procedure tells how to conduct
                     and participate in a meeting
                     properly.
```

**600 Subject added entry -- Personal name** (R)

*Indicator 1:* Type of personal name entry element

0 -- Forename
1 -- Surname (this is the most common form)
3 -- Family name

*Indicator 2:* Subject heading system/thesaurus (identifies the specific list or file which was used)

0 -- Library of Congress Subject Headings
1 -- LC subject headings for children's literature
2 -- Medical Subject Headings
3 -- National Agricultural Library subject authority file
4 -- Source not specified
5 -- Canadian Subject Headings
6 -- Répertoire de vedettes-matière
7 -- Source specified in subfield $2

(Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

*Subfields used most often:*

**$a** -- Personal name (surname and forename)
**$b** -- Numeration
**$c** -- Titles and other words associated with a name (R)
**$q** -- Fuller form of name
**$d** -- Dates associated with a name (generally, year of birth)
**$t** -- Title of a work
**$v** -- Form subdivision (R)
**$x** -- General subdivision (R)
**$y** -- Chronological subdivision (R)
**$z** -- Geographic subdivision (R)
**$2** -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Comedies
                   $x Stage history.
```

```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Knowledge
                   $z Rome
                   $v Congresses.
```

Notice that subfields $v, $x, and $z in the 600 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

**610 Subject added entry -- Corporate name** (R)

*Indicator 1:*Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

*Indicator 2:* Subject heading system/thesaurus.

See indicator 2 under 600

*Subfields used most often:*

**$a** -- Corporate name or jurisdiction name as entry element

**$b** -- Subordinate unit (R)

**$v** -- Form subdivision (R)

**$x** -- General subdivision (R)

**$y** -- Chronological subdivision (R)

**$z** -- Geographic subdivision (R)

**$2** -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    610 10 $a United States.
                   $b Army Air Forces
                   $v Biography.
```

**650 Subject added entry -- Topical term** (Most subject headings fit here.) (R)

*Indicator 1:* Level of subject

# -- No information provided

*Indicator 2:* Subject heading system/thesaurus

(identifies the specific list or file which was used)

0 -- Library of Congress Subject Headings

1 -- LC subject headings for children's literature

2 -- Medical Subject Headings
3 -- National Agricultural Library subject authority file
4 -- Source not specified
5 -- Canadian Subject Headings
6 -- Répertoire de vedettes-matière
7 -- Source specified in subfield $2

Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

*Subfields used most often:*

**$a** -- Topical term
**$v** -- Form subdivision (R)
**$x** -- General subdivision (R)
**$y** -- Chronological subdivision (R)
**$z** -- Geographic subdivision (R)
**$2** -- Source of heading or term used with 2nd indicator of 7)

```
Example:    650 #0 $a Theater
                   $z United States
                   $v Biography
                   $v Dictionaries.
```

Notice that subfields $v, $x, and $z in the 650 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

**651 Subject added entry -- Geographic name** (R)

*Indicator 1:* undefined.
*Indicator 2:* Subject heading system/thesaurus.
See indicator 2 under 600
*Subfields used most often:*

**$a** -- Geographic name
**$v** -- Form subdivision (R)
**$x** -- General subdivision (R)
**$y** -- Chronological subdivision (R)
**$z** -- Geographic subdivision (R)
**$2** -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    651 #0 $a United States
                   $x History
                   $v Chronology.
```

Notice that subfields $v, $x, and $z in the 651 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

**700 Added entry -- Personal name** (R)

*Indicator 1:* Type of personal name entry element

0 -- Forename

1 -- Surname (this is the most common form)

3 -- Family name

*Indicator 2:* Type of added entry

# -- No information provided (most common; co-authors, editors, etc.)

2 -- Analytical entry (The values for Indicator 2 changed in 1994 with Format Integration, and older records may display additional values. An analytical entry involves an author/title of an item contained in a work.)

*Subfields used most often:*

**$a** -- Personal name

**$b** -- Numeration

**$c** -- Titles and other words associated with a name (R)

**$q** -- Fuller form of name

**$d** -- Dates associated with a name (generally, year of birth)

**$e** -- Relator term (such as ill.) (R)

**$4** -- Relator code (R)

*Example:* 700 1# $a Baldridge, Letitia.

**710 Added entry -- Corporate name** (R)

*Indicator 1:* Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

*Indicator 2:* Type of added entry.

See Indicator 2 under 700

# -- No information provided

2 -- Analytical entry

*Subfields used most often:*

**$a** -- Corporate name or jurisdiction name as entry element

**$b** -- Subordinate unit (R)

*Example:* 710 2# $a Sunburst Communications (Firm)

**740 Added entry -- Uncontrolled related/analytical title** (R)

*Indicator 1:* Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including

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Skechers v Nike

spaces)

*Indicator 2:*Type of added entry. See Indicator 2 under 700

# -- No information provided

2 -- Analytical entry

(This field was redefined in 1994 with Format Integration. Prior to 1994, the field was also used for variant titles, such as a different wording on a spine title. In records created since Format Integration, those variant tiles appear in a 246 field.)

*Subfield used most often:*

**$a** -- Title

```
Example:    740 02 $a Uncle Vanya.
```

**800 Series added entry -- Personal name** (R)

*Indicator 1:* Type of personal name entry element

0 -- Forename

1 -- Surname

3 -- Family name

*Indicator 2 undefined.*

*Subfields used most often:*

**$a** -- Personal name

**$b** -- Numeration

**$c** -- Titles and other words associated with a name (R)

**$q** -- Fuller form of name

**$d** -- Dates associated with a name (generally, year of birth)

**$t** -- Title of a work (the series)

**$v** -- Volume number

```
Example:    800 1# $a Fisher, Leonard Everett.
                   $t Colonial American craftsmen.
```

**830 Series added entry -- Uniform title** (R)

*Indicator 1 undefined.*

*Indicator 2:* Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

*Subfield used most often:*

**$a** -- Uniform title

**$v** -- Volume number

```
Example:    830 #0 $a Railroads of America (Macmillan)
```

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## Part VIII:

# A List of Other Fields Often Seen in MARC Records

| | |
|---|---|
| 001 | Control number |
| 003 | Control number identifier |
| 005 | Date and time of latest transaction |
| 006 | Fixed-length data elements -- additional material characteristics |
| 007 | Physical description fixed field |
| 008 | Fixed length data elements (See Part X) |
| 022 | International Standard Serial Number (ISSN) |
| 037 | Source of acquisition |
| 041 | Language code |
| 043 | Geographic area code |
| 050 | Library of Congress call number |
| 060 | National Library of Medicine call number |
| 082 | Dewey Decimal classification number (the one recommended by the Library of Congress; locally-assigned call numbers may appear elsewhere) |
| 110 | Main entry -- Corporate name (less frequent under AACR2 rules) |
| 256 | Computer file characteristics |
| 263 | Projected publication date (indicates a CIP -- Cataloging in Publication -- record) |
| 306 | Playing time |
| 508 | Creation/production credits note |
| 510 | Citation/references note (review sources) |
| 511 | Participant or performer note |
| 521 | Target audience note (first indicator: 0 = reading grade level, 1 = interest age level, 2 = interest grade level, 3 = special audience characteristics, 4 = motivation interest level) |
| 530 | Additional physical form available note |
| 538 | System details note |
| 586 | Awards note |
| 656 | Index term -- Occupation |
| 730 | Added entry -- Uniform title |
| 852 | Location |
| 856 | Electronic location and access |
| 9XX | Reserved for local use. (They are used by vendors, systems, or individual libraries to exchange additional data) |

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## Part IX:

# The Leader

There are 24 positions in the Leader, numbered from 00 to 23. For fuller explanation, see the *MARC 21 Format for Bibliographic Data*.

00-04 Record length (calculated by the computer for each record)

05 Record status
- a = increase in encoding level
- c = corrected or revised
- d = deleted
- n = new
- p = increase in encoding from prepublication (previous CIP)

06 Type of record
- a = language material
- c = printed music
- d = manuscript music
- e = cartographic material
- f = manuscript cartographic material
- g = projected medium
- i = nonmusical sound recording
- j = musical sound recording
- k = 2-dimensional nonprojectable graphic
- m = computer file
- o = kit
- p = mixed materials
- r = 3-dimensional artifact or naturally occurring object
- t = manuscript language material

07 Bibliographic level
- a = monographic component part
- b = serial component part
- c = collection
- d = subunit
- i = integrating resource
- m = monograph/item
- s = serial

08 Type of control
- # = no specified type
- a = archival

09 Character coding scheme
- # = MARC-8
- a = UCS/Unicode

10 Indicator count (always "2")

11 Subfield code count (always "2")

12-16 Base address of data (calculated by the computer for each record)

17 Encoding level
- # = full level

1 = full level, material not examined
2 = less-than-full level, material not examined
3 = abbreviated level
4 = core level
5 = partial (preliminary) level
7 = minimal level
8 = prepublication level (CIP)
u = unknown
z = not applicable

18 Descriptive cataloging form
# = non-ISBD
a = AACR2
i = ISBD
u = unknown

19 Multipart resource record level
# = Not specified or not applicable
a = Set
b = Part with independent title
c = Part with dependent title

20 Length of the length-of-field portion (always "4")
21 Length of the starting-character-position portion (always "5")
22 Length of the implementation-defined portion (always "0")
23 Undefined (always "0")

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## Part X:

# Field 008 for Books

Field 008 is used for Fixed Length Data Elements ("Fixed Field Codes"). There are 40 character positions in field 008, numbered from 00-39. Undefined positions must contain either a blank (#) or a fill character ( | ). Positions 00-17 and 35-39 are defined the same way for all media.

The information shown here for positions 18-34 applies only to books. For explanation of all the positions below and for positions 18-34 for other media, see the *MARC 21 Format for Bibliographic Data*.

Note that field 008 has no indicators or subfield codes.

00-05 Date entered on file (YYMMDD),
where Y=year, M=month, and D=day

06 Type of date/publication status:
b = no dates given; B.C. date involved
e = detailed date
s = single known date/probable date
m = multiple dates
r = reprint/reissue date (Date 1) and original date (Date 2)

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n = dates unknown
q = questionable date
t = publication date and copyright date
| = no attempt to code

07-10 Date 1/beginning date of publication

11-14 Date 2/ending date of publication

Date fields contain the year(s) of publication. The type of date(s) in these elements are specified in fixed field element 06: Type of date/publication status. (For further details, see the field 008 description in the *MARC 21 Format for Bibliographic Data*.)

15-17 Place of publication, production, or execution

For example:
pk# = Pakistan
cau = California (US)

(For a full list of codes used in these positions, see the *MARC Code List for Countries*.)

18-21 Illustrations (up to 4 codes):

# = no illustrations
a = illustrations
b = maps
c = portraits
d = charts
e = plans
f = plates
g = music
h = facsimiles
i = coats of arms
j = genealogical tables
k = forms
l = samples
m = phonodisc, phonowire, etc.
o = photographs
p = illuminations
| = no attempt to code

22 Target audience:

# = unknown or not specified
a = preschool
b = primary
c = pre-adolescent
d = adolescent
e = adult
f = specialized
g = general
j = juvenile
| = no attempt to code

23 Form of item:

# = none of the following
a = microfilm

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b = microfiche
c = microopaque
d = large print
f = braille
r = regular print reproduction
s = electronic
| = no attempt to code

24-27 Nature of contents (up to 4):

# = no specified nature of contents
a = abstracts/summaries
b = bibliographies (is one or contains one)
c = catalogs
d = dictionaries
e = encyclopedias
f = handbooks
g = legal articles
i = indexes
j = patent document
k = discographies
l = legislation
m = theses
n = surveys of literature
o = reviews
p = programmed texts
q = filmographies
r = directories
s = statistics
t = technical reports
u = standards/specifications
v = legal cases and notes
w = law reports and digests
z = treaties
| = no attempt to code

28 Government publication:

# = not a government publication
i = international intergovernmental
f = federal/national
a = autonomous or semi-autonomous component
s = state, provincial, territorial, dependent, etc.
m = multistate
c = multilocal
l = local
z = other type of government publication
o = government publication -- level undetermined
u = unknown if item is government publication
| = no attempt to code

29 Conference publication:

0 = not a conference publication
1 = conference publication

| = no attempt to code

30 Festschrift:
- 0 = not a festschrift
- 1 = festschrift
- | = no attempt to code

31 Index:
- 0 = no index
- 1 = index present
- | = no attempt to code

32 Undefined (since 1990) (Earlier records may contain the values 0 or 1)
- # = Undefined
- | = no attempt to code

33 Literary form:
- 0 = not fiction (not further specified)
- 1 = fiction (not further specified)
- c = comic strips
- d = dramas
- e = essays
- f = novels
- h = humor, satires, etc.
- i = letters
- j = short stories
- m = mixed forms
- p = poetry
- s = speeches
- u = unknown
- | = no attempt to code

34 Biography:
- # = no biographical material
- a = autobiography
- b = individual biography
- c = collective biography
- d = contains biographical information
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35-37 Language:

A three-letter code. For example: eng fre ger spa rus ita

(For a full list of codes used in these positions, see the *MARC Code List for Languages*.)

38 Modified record:
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# INTERNATIONAL TEXTILE BULLETIN

2 2003 May

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**SPECIAL**

**ITMA SURVEY: THE EUROPEAN TEXTILE INDUSTRY'S EXPECTATIONS**

**SUCCESSFUL WOOL SPINNER**

**NEEDLEPUNCHED UPHOLSTERY FABRICS**

**IMPROVED MIGRATION IN WOOL DYEINGS**




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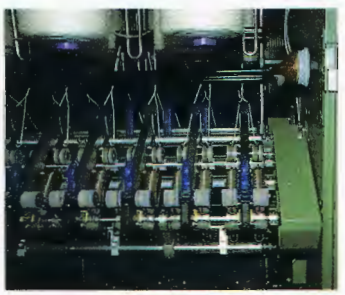
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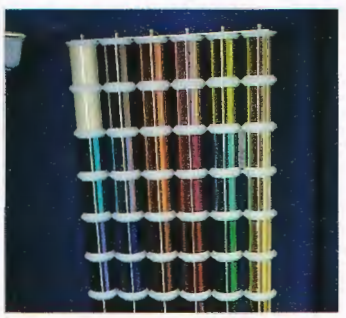
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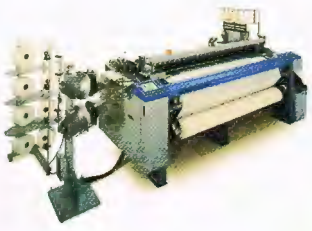


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# The future of knitting

**Speaking at a knitting congress held in Manchester (GB), a senior knitwear technologist from one of the world's most famous retail organisations outlined to an audience of nearly 200 international delegates how the pace of change is increasing, and how many new elements are having an impact on knitting innovation.**

**Derek T. Ward**

*ITS Contributing editor*

The congress was organised by the William Lee Innovation Centre. The newly formed centre has been created within UMIST to bring together multi-disciplinary expertise to form what is claimed to be Europe's first research, technology, translation and skills group focussing specifically on fibre architecture. The event drew 41 speakers from the global industry and various academic bodies.

Mervyn Davies *(Fig. 1)*, Marks & Spencer (GB), said retail customers have never demanded more than they do today, and their requirements have never been so diverse. He listed present day requirements, together with recent innovations, as including: garments that keep you safe; products that make you feel better; products that are more comfortable, especially if you are particularly sensitive; garments that fit better (virtually bespoke clothing); garments that make you more comfortable by heating up or cooling down; products that ease communication, even incorporating mobile phones; more environmentally friendly garments in terms of manufacture and disposal; those meeting the demands of a specific use, such as travel; new fibres derived from corn starch or even wool; and wool reconstituted to produce microfibres or films possessing all the natural attributes of wool – such as antibacterial, flame resistant performance and breathability.

Mr Davies said new knitting machinery technology, and the resultant innovative structures made possible, also facilitate the development of an increasing number of products for use in the medical and industrial fields.

## Colour, weight, touch and handle

Other speakers covered more specific aspects of the contemporary knitting industry. Dr Massimiliano Zegna Barufa, of Zegna Barufa Borgosesia SpA (I), said colour, weight, touch and handle are the characteristic elements of a yarn, which itself constitutes the smallest yet most important component of knitwear. He described how research and development of the initial concept of a new yarn involves close contact with trade associations, trade fair organisations, boutiques de style, fibre supplier, boutiques and general markets to identify trends and to initiate new ideas.

He said: "Sensitivity, intuition, experience, creativity, and constant commitment are the main factors required for working in the spinning industry." He claimed these factors are the basis of a craft inherited from the culture and tradition of the Biella area of Italy. Giving two examples of the effect on knitwear design, he said "Cashwool", developed in the 1980's at a time when the market wanted something different from fluffy lambswool, offers almost limitless versatility. Available in mélange, solid and mouliné colours and machine-washable forms, "Cashwool" is used for men's and women's classic, performance knitwear and may even be used with other types of yarn. The second example given was Shamir ultrafine cashmere yarns. These were created in response to an almost niche market request and rescued the appeal of cashmere at a time when conventional yarns of this type appeared to be suffering a decline in quality.



*Fig. 1:* Mervyn Davies, Marks & Spencer: «The pace of change is increasing.»
Picture: DW

## Innovative, high performance, high tech

In a paper reviewing recent developments in yarn technology, Antonino Piccolini, Fil Man Made Group (I), suggested yarns may be classified into three groups: innovative, high performance, and high tech items. He said, however, these terms are often the cause of confusion and misunderstanding.
He summarised the many ways of developing innovative yarns basically into six routes, although combinations of the six routes can also be used.

- By using a fibre based on a new polymer
- or a fibre produced by chemical modification
- or a new fibre produced by cross-section modification
- or a fibre with modified physical and mechanical features
- or by blending two or more fibres
- or a yarn produced by new spinning techniques.

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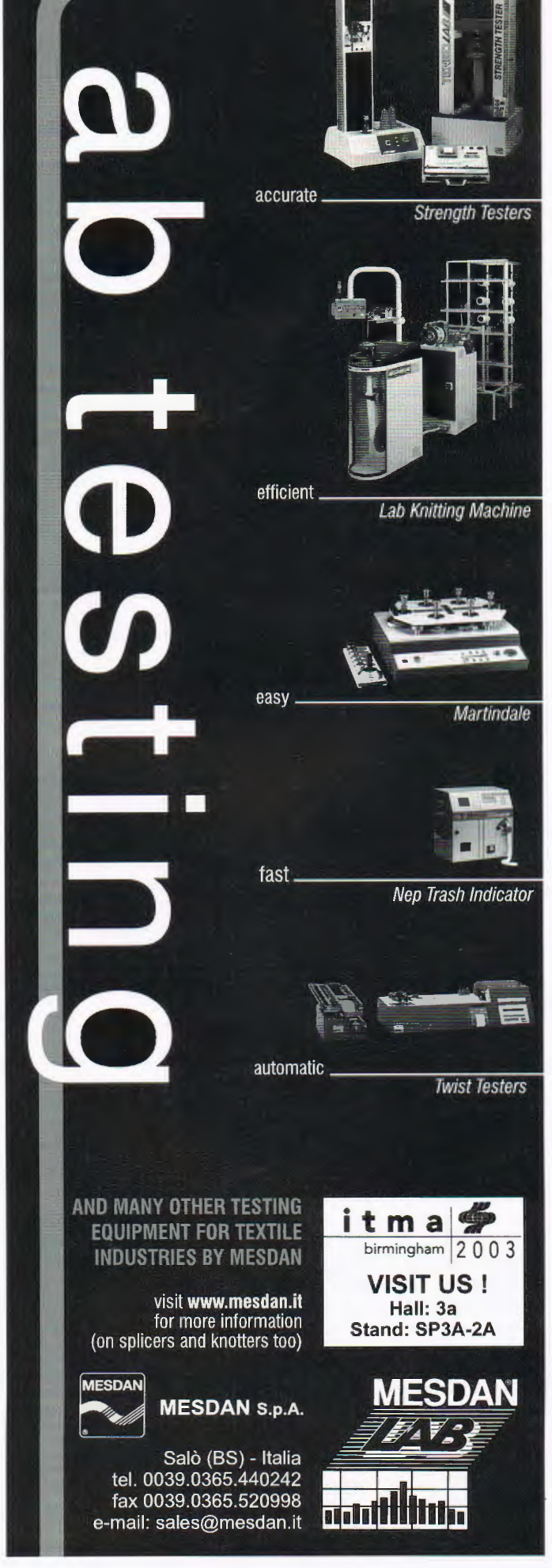
He defined a high performance yarn as being one with a "way of working or functioning clearly superior to the yarns normally intended for specific end-uses." This group included flame retardant yarns based on intrinsically flame retardant fibre, and anti-bacterial yarns based on anti-bacterial fibre.

High tech yarns were described as being usually based on "engineered organic synthetic polymers" such as para- and meta-aramids, although a number of fibres based on inorganic materials could be included. He mentioned how "Basofil" (melamine), "Zylon" (poly-phenylene-2,6benzobisoazole) and "Panox" and "Lastan" (both partially oxidized polyacrylonitrile) are already being evaluated for knitting applications although they are really still under development. Inorganic items such as carbon and various metallic fibres are also being used, alone or in blends. He noted that all the Formula-1 teams, pilots and mechanics, wear knitted underwear, socks and gloves made with high tech yarns. "The yarns are in continuous evolution, as are spun yarns based on meta- and para-arid microfibre"

In conclusion, Mr Piccolini said "Besides a marketing investigation aimed at identifying the requirements of the niche market at which the new yarn is aimed, the development of an innovative product requires expertise and, many times, significant financial effort, for the whole textile chain, including fibre producer, spinner, knitter, dyer and finisher, and manufacturer. The return on the investment is often long term."

## Whole garment knitting

A paper delivered by Hidekazu Masui, Shima Seiki Mfg Ltd (J), suggested how the concept of whole garment knitting as a means to boost productivity has become more attractive in high labour cost countries at a time of increasing competition in global markets. He explained how Shima Seiki has worked for many years to overcome





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the challenges involved in automating the process. Machine development progressed from simple chain-driven basic needle selection machines to the more sophisticated chain-driven jacquard selection stitch transfer units.

Although it had been possible for some time to produce basic shaped fully-fashioned panels, the restrictions imposed by slow production, lack of yarn control and take-down control, and the enormous amount of time needed to create the knitting machine programmes, severely hampered progress. However, in 1989, the



*Fig. 2:* High fashion style created on modern Stoll flat knitting machines. Picture: Stoll

introduction of the Shima Seiki SES122FF unit, a purpose-built V-bed, belt driven variable stroke knitting machine with individual electronic needle selection, comb set-up, digital stitch control, and many other innovations essential for the production of fully shaped panels, was a quantum leap forward.

More major progress followed with the introduction by the Japanese company of a new concept in machine programming software. This not only dramatically reduced programming times, but also offered greater versatility in patterning and shaping technologies.

In 1999, Shima Seiki launched what the speaker described as the world's first purpose-built range of whole garment knitting machines. These employed highly innovative compound slider needles, individually selectable take-down mechanism, additional auxiliary transfer, sinker and needle beds, plus a unique programming system. For the first time designers and technicians could create new types of whole garment knitted items sufficiently attractive to help revive jaded market sectors.

Collaboration between the European branch of the Japanese machinery builder and Davenport Knitwear (GB) has resulted in the latter's purchase of 48 SWGX 12 gauge units and three SDS design systems. This equipment permits the GB knitwear manufacturer to respond to customers' constantly changing requirements, caused by rapid changes in fashion trends or even weather. Deliveries in units of 50 dozen can be made within three days, thanks to the ease with which style changes can be made on the equipment.

In a second paper concerned with the commercial reality of whole garment knitting, Ali Aytemiz, Aytemizler Textile Industry & Trade Co. Ltd. (TR), reviewed the machinery available, the need for greater designer familiarity and expertise with the concept, and the marketing arguments for its use. He said targeted ideals of standardisation of fabric and garment weight control, uniformity of measurements, and finishing, have very nearly been achieved. The latest technology offers to the customer the promise of comfort, particularly in close fitting garments, children's wear and underwear tops. Mr Aytemiz said "in the near future, variable stitch density will permit garments to be knitted in more realistic body shapes. Already, the trials we have carried out have received a very good response. The excess material which occurs in traditional knitwear can be avoided, resulting in lighter garments." He said material consumption and make-up costs are significantly lower compared with those of panel knitting. The resultant cost advantage will become an important argument. High quality stitch construction combined with the use of high quality yarns will be available to customers at more affordable prices.

## Industrial textiles sector growing

A speaker from Clariant GmbH (D), in a presentation concerned with coating knitted goods for technical



*Fig. 3:* Karl Mayer's Stephan Jung: "The possibilities of the "Rascheltronic" machine are now being appreciated beyond the underwear sector and into sportswear and upholstery sectors. Picture: Karl Mayer

applications, said the global market for technical textiles is estimated to be currently worth 42 billion USD. Beate Plückhan forecast that by 2005 this value will have increased by almost 50% to 61 billion USD.

In Western Europe, turnover is expected to increase in value from 11 billion USD last year (2002) to 12.9 billion USD in 2005. Technical textiles already account for 24% of the entire textile market in Western Europe and this percentage is rising strongly. However, the greatest growth potential is seen in Asian markets, followed by North America, and then Western Europe. The use of knitted construction in the technical textiles sector, already significant, is expected to increase by around 3% annually. She said their mass: performance ratio, and favourable cost in semi-finished


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state, means they can be used advantageously in composites. They are already used widely in medical and hygiene, apparel, protective, and automotive textiles, and in geotextiles.

The speaker discussed the types of textile auxiliaries used as binders, cross-linking and water/oil repellent agents and flame-retardants commonly used. These included polymer dispersions, melamine resins, fluorocarbons, and polyphosphates. She then outlined the application processes employed for different types of products.

In conclusion, she said the technical textiles market demands positive developments to improve the properties of existing fibres and new fibre developments, more cost favourable production technologies, and new product innovations "to reinforce and support the application possibilities of knitted materials in this high growth-potential market."

## Three-dimensional structures from flat knitting machines

According to Martin Legner, H. Stoll GmbH & Co (D) in contrast to that for most other types of textile machinery, the demand for modern flat knitting machines has grown immensely in recent years and a relatively high level of machines has been sold steadily *(Fig. 2)*.

In a paper dealing with the ability of modern flat knitting machines to manufacture three-dimensional structures for fashion and technical textile products, he suggested both economic and technical reasons underlie this apparent phenomenon. These reasons include knit-friendly fashion trends, high demand for modern machines from the Far East, growth of knitwear production in other regions such as China, Turkey, Arabian and Eastern European countries, globalisation of markets and increased prosperity in many countries, and the eagerness of established knitwear industries to adopt new design and production concepts.

He suggested flat knitting units, despite their relatively slow operation, offer "scope for design options which cannot be matched in terms of implementation simplicity as regards their styling and design versatility."

Fabric characteristics are also easily modified. Martin Legner described how, for example, a spherical shaped product can be generated by a three-dimensional knitting programme, without need of a special three-dimensional forming device. He emphasised that this is not the only form of innovative structures, which can be made. Others include voluminous knits, spacer fabrics, web or interface constructions, and tubular structures. He said all these possibilities can usually be created, even jointly applied, on the same machine.

Stoll knit-and-wear technology can be used to produce complete garments on a flat bed unit. The technology employs a three-dimensional knitting process. Using it to make a pullover, for example, three fashioned tubular pieces are joined by the use of knitting, transfer and linking actions to form a finished ready-to-wear garment. This technique is extremely versatile in that, in addition to the basic structure, simple jacquard and intarsia patterns, typical knitwear formations for shoulder, neck and collar, can be achieved.

Mr Legner said that, depending upon the required design of the knitted fabric, and by the possible use of machines with addition needle or transfer beds, such as the Stoll CMS 330 TC-4 and TC-R, complete outerwear garments can be made in finer gauges. He listed labour saving, optimised yarn consumption, minimised storage, logistic and reduced waste disposal costs as advantages associated with Stoll knit-and-wear manufacturing.

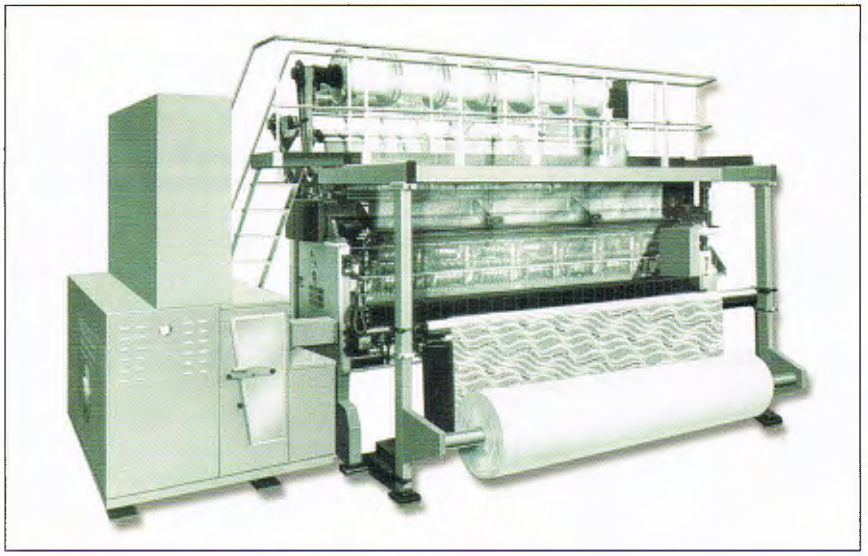


*Fig. 4:* Jacquard-patterned, elastic and rigid knitted constructions can be made on Karl Mayer's versatile "Cliptronic" units. Picture: Karl Mayer

## Impact of new machine concepts

Stephan Jung *(Fig. 3)*, Karl Mayer Textilmaschinenfabrik GmbH (D) outlined how recently introduced machine concepts are assisting the global knitting industries to meet increasingly complex demands, such as that for high and higher quality products, for greater individuality in different markets, for meeting a variety of different working methods, and for overcoming various technical problems, such as those associated with reference



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points for pattern centring and sample sizes.

Speaking about the Karl Mayer "Cliptronic" *(Fig. 4)* series of machines, for example, a variety of jacquard-patterned, elastic and rigid fabrics can be manufactured. Various machines from the range are being used primarily for making a wide variety of underwear and outerwear fabrics. "What they all have in common," he said, "is that the broché-knitted structures all have at their disposal relief-like pattern motifs which are not in any way restricted by repeats. These motifs can be specifically placed not only for design reasons but also from a functional point of view.

The fabric background can be designed independently from the patterning and can be formed by a complete jacquard bar." Detailing the wide versatility of the "Cliptronic" system, Mr Jung claimed that a manufacturer of ready-made garments is helped during further processing. Reference points for cutting and making-up can be established. "Stretching is increasingly function-oriented or limitable, more or fewer transparent zones can be created, and desired cooling functions can be introduced.

Further development of the company's "Rascheltronic" unit has added considerably to its patterning versatility when making fine jacquard-patterned, rigid and elastic fabrics. The advantages of this type of machine are now being appreciated beyond the underwear sector and into sportswear and the demanding upholstery sectors. Company logos can be incorporated, and function and design-oriented cooling openings (mesh inserts) can be included to achieve an optimum microclimate function while circumventing the necessity of expensive making-up operations.

## Hong Kong metamorphosis

The seesaw history of the Hong Kong knitting industry was outlined by Anthony Wan, senior R&D manager, Fountainset Holdings Ltd (HK). The Hong Kong textile industry was originally set up after the Second World by textile tycoons fleeing from Shanghai. By 1976 textile exports reached an all time high, accounting for 65% of Hong Kong's total exports, with 27% of the available workforce engaged.

However, booming land values in Hong Kong persuaded the tycoons to move their spinning mills to nearby Asian countries. Knitting, weaving, dyeing and garment making operations, occupying less space, remained. By 1980 the value of textile exports had slumped to 42%, although textiles remained the biggest industry. By the middle of that decade customers started demanding higher standards for their apparel.

From the early 1990's, competition from neighbouring regions, Thailand, Indonesia, Malaysia and the Philippines, and more recently Pakistan and India, became much stronger. The financial turmoil of 1997 was another blow, operating against the Hong Kong dollar, which was pegged to the USD. At the time, textile technology education was focused on production; little attention was paid to R&D. Mr Wan said product development in the knitting sector usually consisted of the "knock off" of a sample supplied by the customer. More recently, the shift towards functional and lifestyle garments has convinced Hong Kong knitters to start their own R&D programmes and work closely with yarn spinners and chemical suppliers.

Today's Hong Kong textile industry is vastly different. The association of the electronic and computer industries with the textile industry has presented both challenges and opportunities. In the knitting sector, R&D is now seen as the key to success, together with better supply chain management and production planning. "Without doubt, Hong Kong's knitting industry will remain a major player in the supply of knitted fabrics. But the industry will find it difficult to compete on the basic items, as part of this business will be dominated by those located in the developing countries." Speed, quality, price and innovation are now being considered the vital necessities for survival.

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# EDITORIAL

JUN 1 8 2003
UMASS DARTMOUTH



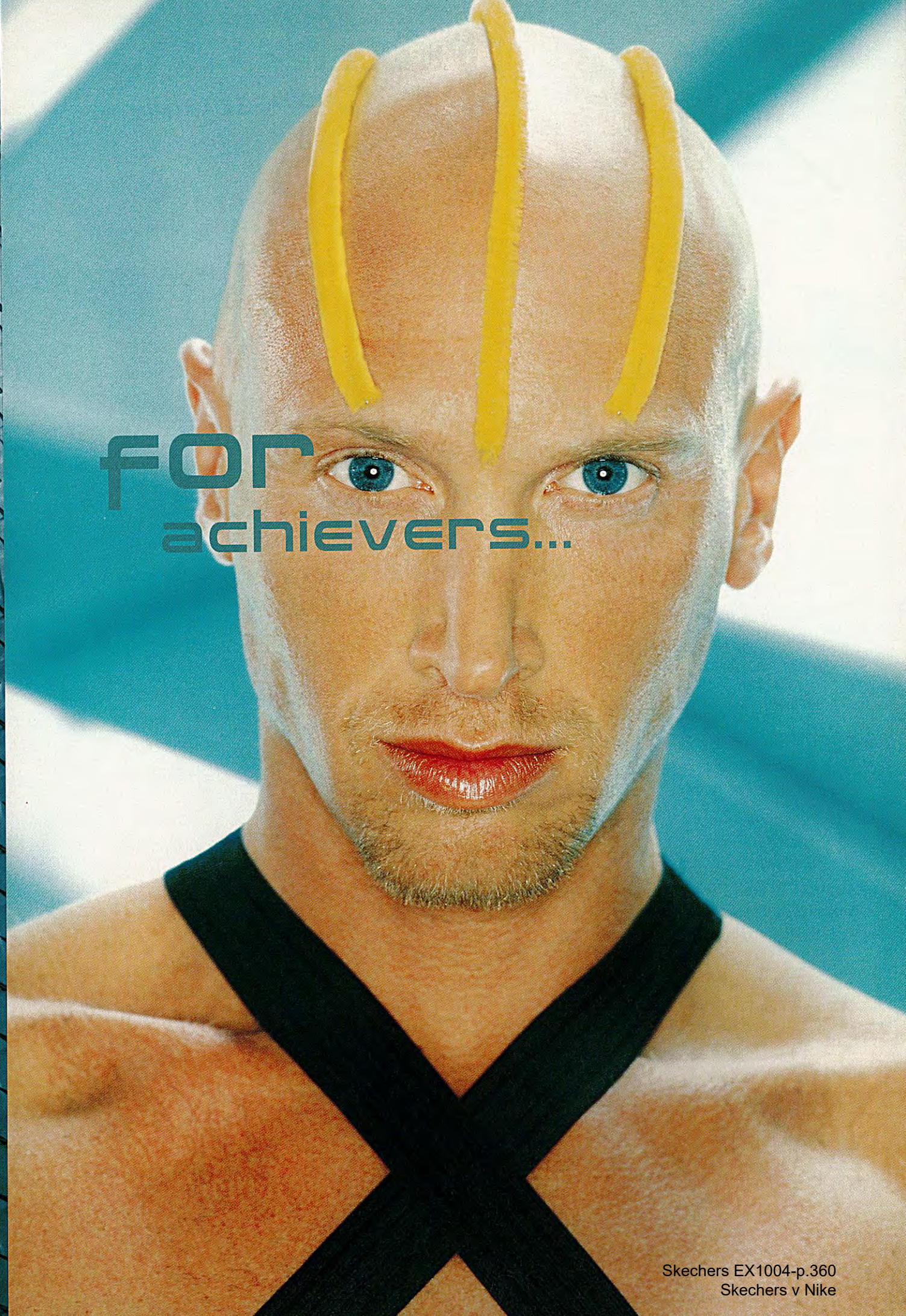
*A murmur has been running through the international press. Switzerland, an inland country, has won the world's oldest sports trophy – the Americas Cup. Noses were turned up in many places – they weren't just Swiss, those crew members came from all over the world. Right, that's how it was. Despite that, the idea, the energy and of course the money for the challenge came from the Swiss national Ernesto Bertarelli. What's all this got to do with the European textile machinery industry? Indirectly, a great deal.*

*In the last few editions of the INTERNATIONAL TEXTILE BULLETIN, and also in this edition, we published reports on European textile firms, which, despite all rumours of gloom and doom and maximum competitive pressure from Asia, are operating in the market with great success, as ever.*

*In this edition, you can read, among other things, the European textile industry's answers to our ITMA questionnaire. With foresight, smart ideas, the requisite amount of courage and the necessary will to succeed, these entrepreneurs are defending their leading position in the market.*

*As a Swiss national, Ernesto Bertarelli has achieved the impossible in sailing terms: with his iron will, he has taken top place in sailing. Only those who dream the impossible will achieve the possible. And, as long as these words can still be put into action, there will be a successful European textile industry.*

Jürg Rupp
Editor-in-Chief


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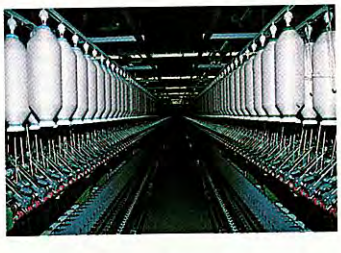


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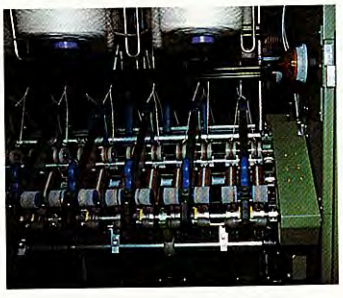
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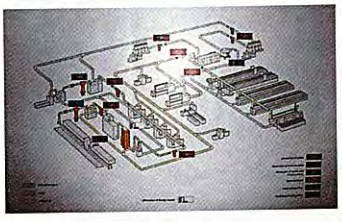
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What counts for Swiss sailors counts for the European textile industry too: aim for top position with a will and an experienced team
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# The future of knitting

**Speaking at a knitting congress held in Manchester (GB), a senior knitwear technologist from one of the world's most famous retail organisations outlined to an audience of nearly 200 international delegates how the pace of change is increasing, and how many new elements are having an impact on knitting innovation.**

**Derek T. Ward**

*ITS Contributing editor*

The congress was organised by the William Lee Innovation Centre. The newly formed centre has been created within UMIST to bring together multi-disciplinary expertise to form what is claimed to be Europe's first research, technology, translation and skills group focussing specifically on fibre architecture. The event drew 41 speakers from the global industry and various academic bodies.

Mervyn Davies *(Fig. 1)*, Marks & Spencer (GB), said retail customers have never demanded more than they do today, and their requirements have never been so diverse. He listed present day requirements, together with recent innovations, as including: garments that keep you safe; products that make you feel better; products that are more comfortable, especially if you are particularly sensitive; garments that fit better (virtually bespoke clothing); garments that make you more comfortable by heating up or cooling down; products that ease communication, even incorporating mobile phones; more environmentally friendly garments in terms of manufacture and disposal; those meeting the demands of a specific use, such as travel; new fibres derived from corn starch or even wool; and wool reconstituted to produce microfibres or films possessing all the natural attributes of wool – such as antibacterial, flame resistant performance and breathability.

Mr Davies said new knitting machinery technology, and the resultant innovative structures made possible, also facilitate the development of an increasing number of products for use in the medical and industrial fields.

## Colour, weight, touch and handle

Other speakers covered more specific aspects of the contemporary knitting industry. Dr Massimiliano Zegna Barufa, of Zegna Barufa Borgosesia SpA (I), said colour, weight, touch and handle are the characteristic elements of a yarn, which itself constitutes the smallest yet most important component of knitwear. He described how research and development of the initial concept of a new yarn involves close contact with trade associations, trade fair organisations, boutiques de style, fibre supplier, boutiques and general markets to identify trends and to initiate new ideas.

He said: "Sensitivity, intuition, experience, creativity, and constant commitment are the main factors required for working in the spinning industry." He claimed these factors are the basis of a craft inherited from the culture and tradition of the Biella area of Italy. Giving two examples of the effect on knitwear design, he said "Cashwool", developed in the 1980's at a time when the market wanted something different from fluffy lambswool, offers almost limitless versatility. Available in mélange, solid and mouliné colours and machine-washable forms, "Cashwool" is used for men's and women's classic, performance knitwear and may even be used with other types of yarn. The second example given was Shamir ultrafine cashmere yarns. These were created in response to an almost niche market request and rescued the appeal of cashmere at a time when conventional yarns of this type appeared to be suffering a decline in quality.



*Fig. 1:* Mervyn Davies, Marks & Spencer: «The pace of change is increasing.»
Picture: DW

## Innovative, high performance, high tech

In a paper reviewing recent developments in yarn technology, Antonino Piccolini, Fil Man Made Group (I), suggested yarns may be classified into three groups: innovative, high performance, and high tech items. He said, however, these terms are often the cause of confusion and misunderstanding.
He summarised the many ways of developing innovative yarns basically into six routes, although combinations of the six routes can also be used.

- By using a fibre based on a new polymer
- or a fibre produced by chemical modification
- or a new fibre produced by cross-section modification
- or a fibre with modified physical and mechanical features
- or by blending two or more fibres
- or a yarn produced by new spinning techniques.



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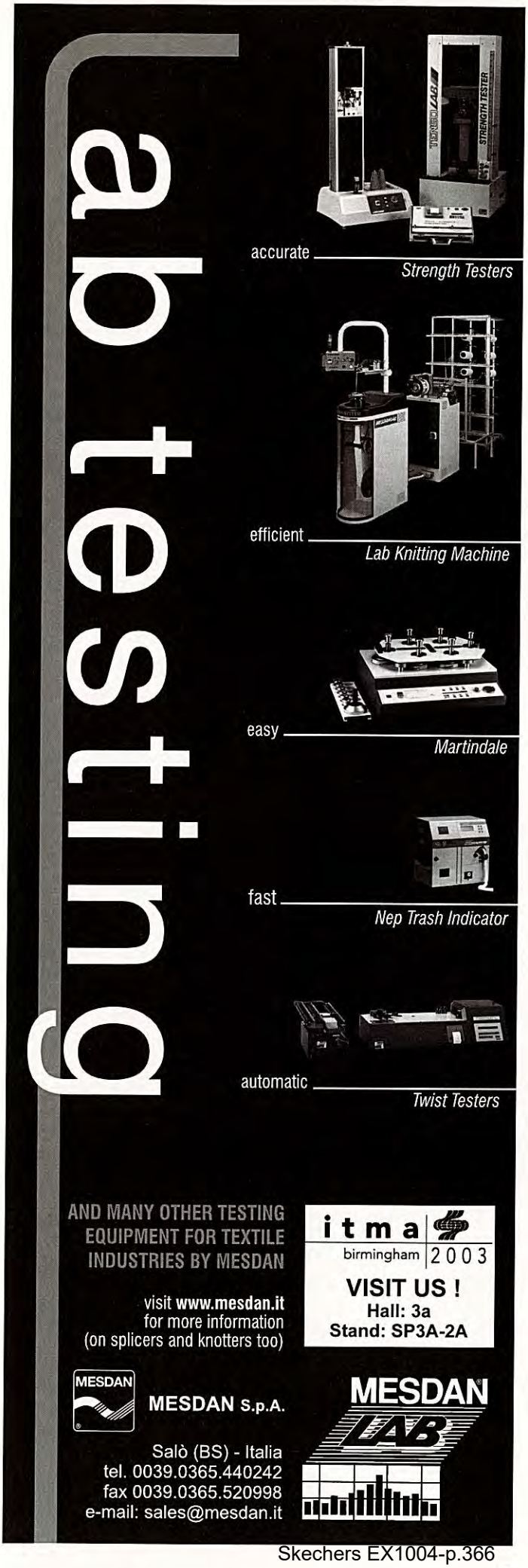
He defined a high performance yarn as being one with a "way of working or functioning clearly superior to the yarns normally intended for specific end-uses." This group included flame retardant yarns based on intrinsically flame retardant fibre, and anti-bacterial yarns based on anti-bacterial fibre.

High tech yarns were described as being usually based on "engineered organic synthetic polymers" such as para- and meta-aramids, although a number of fibres based on inorganic materials could be included. He mentioned how "Basofil" (melamine), "Zylon" (poly-phenylene-2,6benzobisoazole) and "Panox" and "Lastan" (both partially oxidized polyacrylonitrile) are already being evaluated for knitting applications although they are really still under development. Inorganic items such as carbon and various metallic fibres are also being used, alone or in blends. He noted that all the Formula-1 teams, pilots and mechanics, wear knitted underwear, socks and gloves made with high tech yarns. "The yarns are in continuous evolution, as are spun yarns based on meta- and para-arid microfibre"

In conclusion, Mr Piccolini said "Besides a marketing investigation aimed at identifying the requirements of the niche market at which the new yarn is aimed, the development of an innovative product requires expertise and, many times, significant financial effort, for the whole textile chain, including fibre producer, spinner, knitter, dyer and finisher, and manufacturer. The return on the investment is often long term."

### Whole garment knitting

A paper delivered by Hidekazu Masui, Shima Seiki Mfg Ltd (J), suggested how the concept of whole garment knitting as a means to boost productivity has become more attractive in high labour cost countries at a time of increasing competition in global markets. He explained how Shima Seiki has worked for many years to overcome





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the challenges involved in automating the process. Machine development progressed from simple chain-driven basic needle selection machines to the more sophisticated chain-driven jacquard selection stitch transfer units.

Although it had been possible for some time to produce basic shaped fully-fashioned panels, the restrictions imposed by slow production, lack of yarn control and take-down control, and the enormous amount of time needed to create the knitting machine programmes, severely hampered progress. However, in 1989, the

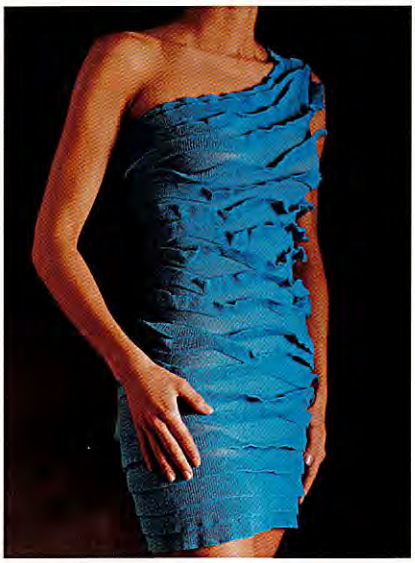


*Fig. 2:* High fashion style created on modern Stoll flat knitting machines. Picture: Stoll

introduction of the Shima Seiki SES122FF unit, a purpose-built V-bed, belt driven variable stroke knitting machine with individual electronic needle selection, comb set-up, digital stitch control, and many other innovations essential for the production of fully shaped panels, was a quantum leap forward.

More major progress followed with the introduction by the Japanese company of a new concept in machine programming software. This not only dramatically reduced programming times, but also offered greater versatility in patterning and shaping technologies.

In 1999, Shima Seiki launched what the speaker described as the world's first purpose-built range of whole garment knitting machines. These employed highly innovative compound slider needles, individually selectable take-down mechanism, additional auxiliary transfer, sinker and needle beds, plus a unique programming system. For the first time designers and technicians could create new types of whole garment knitted items sufficiently attractive to help revive jaded market sectors.

Collaboration between the European branch of the Japanese machinery builder and Davenport Knitwear (GB) has resulted in the latter's purchase of 48 SWGX 12 gauge units and three SDS design systems. This equipment permits the GB knitwear manufacturer to respond to customers' constantly changing requirements, caused by rapid changes in fashion trends or even weather. Deliveries in units of 50 dozen can be made within three days, thanks to the ease with which style changes can be made on the equipment.

In a second paper concerned with the commercial reality of whole garment knitting, Ali Aytemiz, Aytemizler Textile Industry & Trade Co. Ltd. (TR), reviewed the machinery available, the need for greater designer familiarity and expertise with the concept, and the marketing arguments for its use. He said targeted ideals of standardisation of fabric and garment weight control, uniformity of measurements, and finishing, have very nearly been achieved. The latest technology offers to the customer the promise of comfort, particularly in close fitting garments, children's wear and underwear tops. Mr Aytemiz said "in the near future, variable stitch density will permit garments to be knitted in more realistic body shapes. Already, the trials we have carried out have received a very good response. The excess material which occurs in traditional knitwear can be avoided, resulting in lighter garments." He said material consumption and make-up costs are significantly lower compared with those of panel knitting. The resultant cost advantage will become an important argument. High quality stitch construction combined with the use of high quality yarns will be available to customers at more affordable prices.

## Industrial textiles sector growing

A speaker from Clariant GmbH (D), in a presentation concerned with coating knitted goods for technical

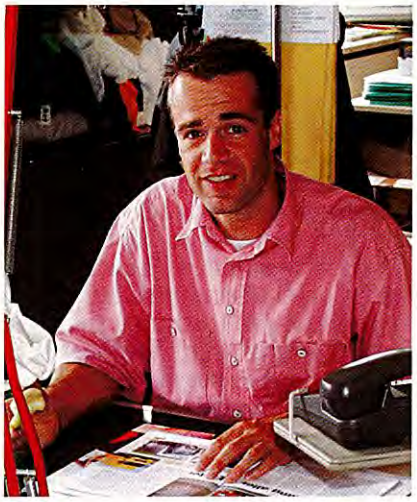


*Fig. 3:* Karl Mayer's Stephan Jung: "The possibilities of the "Rascheltronic" machine are now being appreciated beyond the underwear sector and into sportswear and upholstery sectors. Picture: Karl Mayer

applications, said the global market for technical textiles is estimated to be currently worth 42 billion USD. Beate Plückhan forecast that by 2005 this value will have increased by almost 50% to 61 billion USD.

In Western Europe, turnover is expected to increase in value from 11 billion USD last year (2002) to 12.9 billion USD in 2005. Technical textiles already account for 24% of the entire textile market in Western Europe and this percentage is rising strongly. However, the greatest growth potential is seen in Asian markets, followed by North America, and then Western Europe. The use of knitted construction in the technical textiles sector, already significant, is expected to increase by around 3% annually. She said their mass: performance ratio, and favourable cost in semi-finished


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state, means they can be used advantageously in composites. They are already used widely in medical and hygiene, apparel, protective, and automotive textiles, and in geotextiles.

The speaker discussed the types of textile auxiliaries used as binders, cross-linking and water/oil repellent agents and flame-retardants commonly used. These included polymer dispersions, melamine resins, fluorocarbons, and polyphosphates. She then outlined the application processes employed for different types of products.

In conclusion, she said the technical textiles market demands positive developments to improve the properties of existing fibres and new fibre developments, more cost favourable production technologies, and new product innovations "to reinforce and support the application possibilities of knitted materials in this high growth-potential market."

## Three-dimensional structures from flat knitting machines

According to Martin Legner, H. Stoll GmbH & Co (D) in contrast to that for most other types of textile machinery, the demand for modern flat knitting machines has grown immensely in recent years and a relatively high level of machines has been sold steadily *(Fig. 2)*.

In a paper dealing with the ability of modern flat knitting machines to manufacture three-dimensional structures for fashion and technical textile products, he suggested both economic and technical reasons underlie this apparent phenomenon. These reasons include knit-friendly fashion trends, high demand for modern machines from the Far East, growth of knitwear production in other regions such as China, Turkey, Arabian and Eastern European countries, globalisation of markets and increased prosperity in many countries, and the eagerness of established knitwear industries to adopt new design and production concepts.

He suggested flat knitting units, despite their relatively slow operation, offer "scope for design options which cannot be matched in terms of implementation simplicity as regards their styling and design versatility."

Fabric characteristics are also easily modified. Martin Legner described how, for example, a spherical shaped product can be generated by a three-dimensional knitting programme, without need of a special three-dimensional forming device. He emphasised that this is not the only form of innovative structures, which can be made. Others include voluminous knits, spacer fabrics, web or interface constructions, and tubular structures. He said all these possibilities can usually be created, even jointly applied, on the same machine.

Stoll knit-and-wear technology can be used to produce complete garments on a flat bed unit. The technology employs a three-dimensional knitting process. Using it to make a pullover, for example, three fashioned tubular pieces are joined by the use of knitting, transfer and linking actions to form a finished ready-to-wear garment. This technique is extremely versatile in that, in addition to the basic structure, simple jacquard and intarsia patterns, typical knitwear formations for shoulder, neck and collar, can be achieved.

Mr Legner said that, depending upon the required design of the knitted fabric, and by the possible use of machines with addition needle or transfer beds, such as the Stoll CMS 330 TC-4 and TC-R, complete outerwear garments can be made in finer gauges. He listed labour saving, optimised yarn consumption, minimised storage, logistic and reduced waste disposal costs as advantages associated with Stoll knit-and-wear manufacturing.

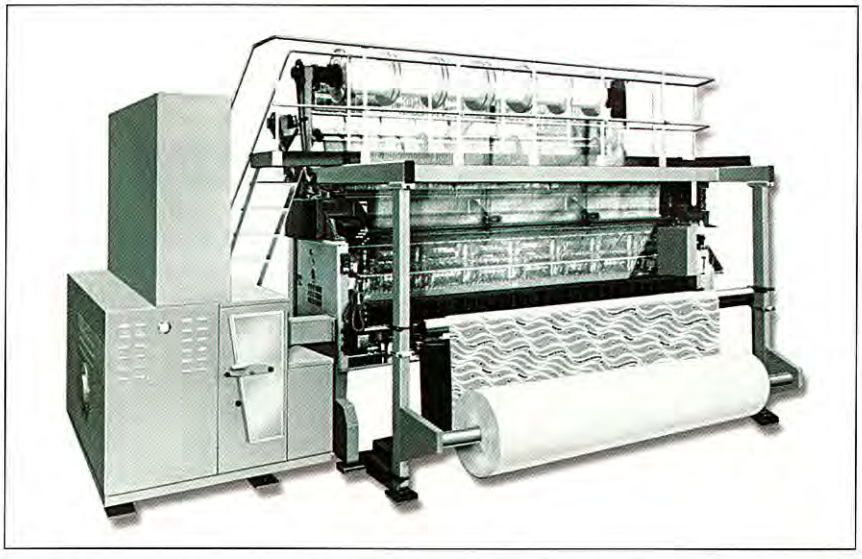


*Fig. 4:* Jacquard-patterned, elastic and rigid knitted constructions can be made on Karl Mayer's versatile "Cliptronic" units. Picture: Karl Mayer

## Impact of new machine concepts

Stephan Jung *(Fig. 3)*, Karl Mayer Textilmaschinenfabrik GmbH (D) outlined how recently introduced machine concepts are assisting the global knitting industries to meet increasingly complex demands, such as that for high and higher quality products, for greater individuality in different markets, for meeting a variety of different working methods, and for overcoming various technical problems, such as those associated with reference


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points for pattern centring and sample sizes.

Speaking about the Karl Mayer "Cliptronic" *(Fig. 4)* series of machines, for example, a variety of jacquard-patterned, elastic and rigid fabrics can be manufactured. Various machines from the range are being used primarily for making a wide variety of underwear and outerwear fabrics. "What they all have in common," he said, "is that the broché-knitted structures all have at their disposal relief-like pattern motifs which are not in any way restricted by repeats. These motifs can be specifically placed not only for design reasons but also from a functional point of view.

The fabric background can be designed independently from the patterning and can be formed by a complete jacquard bar." Detailing the wide versatility of the "Cliptronic" system, Mr Jung claimed that a manufacturer of ready-made garments is helped during further processing. Reference points for cutting and making-up can be established. "Stretching is increasingly function-oriented or limitable, more or fewer transparent zones can be created, and desired cooling functions can be introduced.

Further development of the company's "Rascheltronic" unit has added considerably to its patterning versatility when making fine jacquard-patterned, rigid and elastic fabrics. The advantages of this type of machine are now being appreciated beyond the underwear sector and into sportswear and the demanding upholstery sectors. Company logos can be incorporated, and function and design-oriented cooling openings (mesh inserts) can be included to achieve an optimum microclimate function while circumventing the necessity of expensive making-up operations.

## Hong Kong metamorphosis

The seesaw history of the Hong Kong knitting industry was outlined by Anthony Wan, senior R&D manager, Fountainset Holdings Ltd (HK). The Hong Kong textile industry was originally set up after the Second World by textile tycoons fleeing from Shanghai. By 1976 textile exports reached an all time high, accounting for 65% of Hong Kong's total exports, with 27% of the available workforce engaged.

However, booming land values in Hong Kong persuaded the tycoons to move their spinning mills to nearby Asian countries. Knitting, weaving, dyeing and garment making operations, occupying less space, remained. By 1980 the value of textile exports had slumped to 42%, although textiles remained the biggest industry. By the middle of that decade customers started demanding higher standards for their apparel.

From the early 1990's, competition from neighbouring regions, Thailand, Indonesia, Malaysia and the Philippines, and more recently Pakistan and India, became much stronger. The financial turmoil of 1997 was another blow, operating against the Hong Kong dollar, which was pegged to the USD. At the time, textile technology education was focused on production; little attention was paid to R&D. Mr Wan said product development in the knitting sector usually consisted of the "knock off" of a sample supplied by the customer. More recently, the shift towards functional and lifestyle garments has convinced Hong Kong knitters to start their own R&D programmes and work closely with yarn spinners and chemical suppliers.

Today's Hong Kong textile industry is vastly different. The association of the electronic and computer industries with the textile industry has presented both challenges and opportunities. In the knitting sector, R&D is now seen as the key to success, together with better supply chain management and production planning. "Without doubt, Hong Kong's knitting industry will remain a major player in the supply of knitted fabrics. But the industry will find it difficult to compete on the basic items, as part of this business will be dominated by those located in the developing countries." Speed, quality, price and innovation are now being considered the vital necessities for survival.

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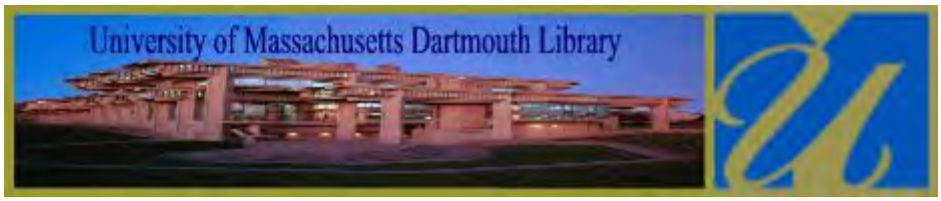
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285 Old Westport Rd.
North Dartmouth, MA 02747-2300
UMD Home

Phone: 508-999-8678
Contact:
Reference@umassd.edu

Last modified:
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cmcneil




***The University Library Catalog: a listing of books and materials***

**~ Check E-Resources below for searching journal indexes and other databases. ~**

Library Information | Patron Information | E-Resources | Interlibrary Loan | Other Libraries | FAQ | Library Home Page

| *Search Type* | | *Description* |
|---|---|---|
| Set Search Limits | | Set limits **BEFORE** searching to restrict results by date, language, location, etc. Limits **do not apply** to Author, Subject or Call Number searches. |
| Title/Author/Subject | | Search by title, journal title, author, subject heading or call number. |
| Basic Keyword | | Search by words in specific fields such as author, title, subject, and publisher, etc. Words can be combined with **AND**, **OR**, **NOT**. |
| Advanced Keyword | | For those who know the Boolean commands. Search by keyword and combine with **AND**, **OR**, **NOT**. |
| Ranked Keyword | | Search entire record by keyword. Results are ranked. |
| E-Reserves | | Electronic course reserves searchable by instructor's name, course, or department. |

| Library Info | Patron Info | E-Resources | Interlibrary Loan | Other Libraries | FAQ |
| Library Home Page | University Home Page |

# libraries.org

## A directory of libraries throughout the world



found **1** item where the item contains **University of Massachusetts Dartmouth**.

list search:

## Claire T. Carney Library

**University of Massachusetts - Dartmouth**

**Address:** 285 Old Westport Road
North Dartmouth, Massachusetts
02747-2300
United States

**County:** Bristol

**Phone:** 508-999-8750

**Connect to:** Library Web Site✔ Online Catalog

**Library details:** **Claire T. Carney Library** is an **Academic** library.
This library is affiliated with **University of Massachusetts** (view map) . The collection of the library contains **187,971** volumes. The library circulates **8,103** items per year. The library serves a population of **6,457** FTE Enrollment.

**Other Info:** Member of Boston Library Consortium

**Permalink:** https://librarytechnology.org/library/1242
(Use this link to refer back to this listing.)

**Administration:** The director of the library is **Judy Farrar, Interim Dean of Library Services** .

**Organizational structure:** The library is part of a **publicly-funded** organization. It operates on a **Non-profit** financial model.

**Academic Level:** The library Serves an educational institution at the **University** level. The Carnegie Foundation designates this institution as: **Doctoral Universities: High Research Activity** (level 16).

| Statistics Academic | | |
|---|---|---|
| **Enrollment** | 6,457 | **FTE Students** |
| **Collection size** | 187,971 | **volumes** |
| **Annual Circulation** | 8,103 | **transactions** |





Claire T. Carney Library




map location✔

### Related Libraries

- Other libraries with Carnegie class: **Doctoral Universities: High Research Activity**
- Libraries located in **North Dartmouth** (Massachusetts)
- Libraries located in **Bristol** county (Massachusetts)
- **View map of libraries in Bristol County**
- **all Academic libs in Massachusetts**

**About libraries.org**

View Detailed Statistics

**Wireless:** The library offers **wireless** access to the Internet.

| Technology Profile | | |
|---|---|---|
| | **Product Name** | **Year Contracted** |
| **Current Automation System** | **Alma** | **2012** |
| **Previous Automation System** | **Voyager** | 1999 |
| **Previous Automation System** | **MultiLIS** | 1991 |
| **Discovery Service (w/index)** | **Ex Libris CDI** | 2012 |
| **Discovery Interface** | **Primo VE** | **2020** |
| **Previous Discovery Interface** | Primo | 2012 |
| **Digital Collection Management** | **Alma Digital** | |
| **Electronic Resource Management** | **Alma** | |
| **Archives Management** | **ArchivesSpace** | |
| **Web Content Management** | **WordPress** | |
| **Item ID Type** | Barcode | |
| The library's automation system is hosted by the vendor through an **Software-as-a-Service** (**SaaS**) arrangement. | | |
| This library is responsible for the procurement of the library automation system. | | |

View Privacy and Security Report

| Identifiers | |
|---|---|
| **libraries.org ID** | 1242 |
| **OCLC Symbol** | SMU |
| **WorldCat Registry ID** | **1404** |
| **NCES LIBID** | 167987 |

**Record History:** This listing was created on Jun 16, 1997 and was last modified on Jan 19, 2024.

**Updates:** Corrections or Updates? Registered members of Library Technology Guides can submit updates to library listings in libraries.org. **Registration** is free and easy. Already registered? **login**. Or, you can report corrections just by sending a message to **Marshall Breeding**.

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This directory is a component of **Library Technology Guides**.

Please **contact Marshall Breeding** to report corrections about information listed for this library.

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