ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/237482349

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

Article · March 2005

CITATIONS
81

READS
18,770

2 authors:

Wonseok Choi
Hanyang Women'd University
4 PUBLICATIONS **136** CITATIONS

SEE PROFILE

Nancy B. Powell
North Carolina State University
35 PUBLICATIONS **553** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Superhydrophobic superoleophobic surface materials' development View project

All content following this page was uploaded by Wonseok Choi on 19 July 2014.

The user has requested enhancement of the downloaded file.

Skechers EX1021
Skechers v Nike

NC STATE UNIVERSITY

JTATM

JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

Volume 4, Issue 3, Spring2005

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

Wonseok Choi, Ph. D. Student
Nancy B. Powell, Associate Professor
College of Textiles
North Carolina State University
2401 Research Drive
Raleigh, N.C. 27695-8301
(919) 515-6578

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.

Skechers EX1021
Skechers v Nike

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

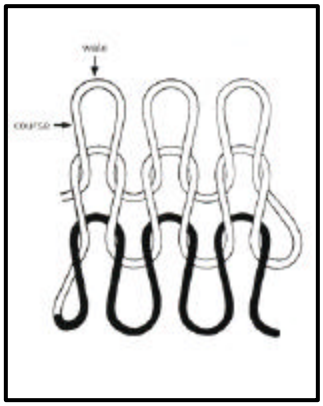


Figure1.1a. Weft knitting

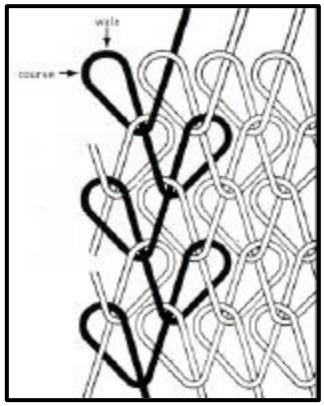


Figure 1.1b. Warp knitting (Black, 2002

Skechers EX1021
Skechers v Nike

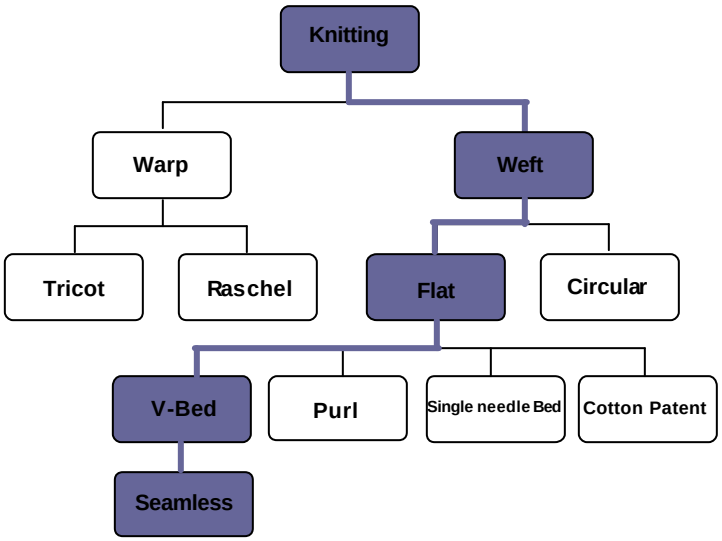


Figure 1.1c. Knitting Classification Diagram

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].

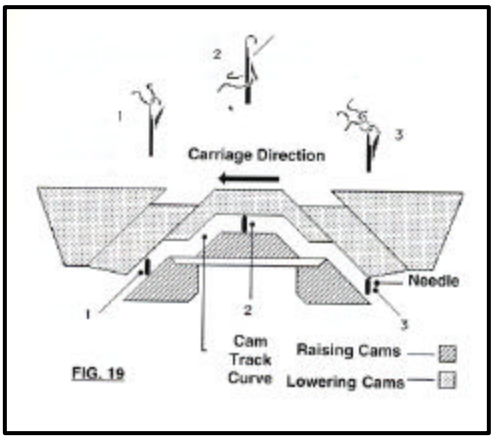


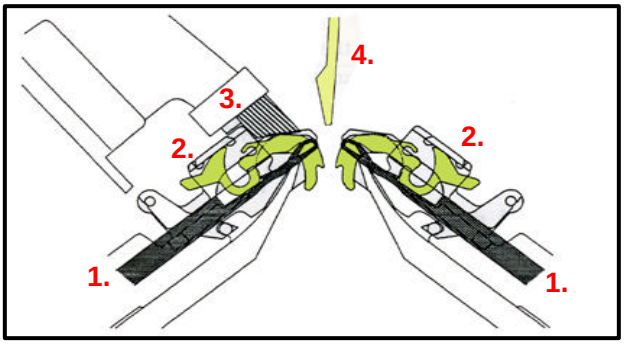
Figure 1.1d. Knitting action of latch needle though cam track
(Raz, 1991)

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].

J T A T M

Skechers EX1021
Skechers v Nike



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])

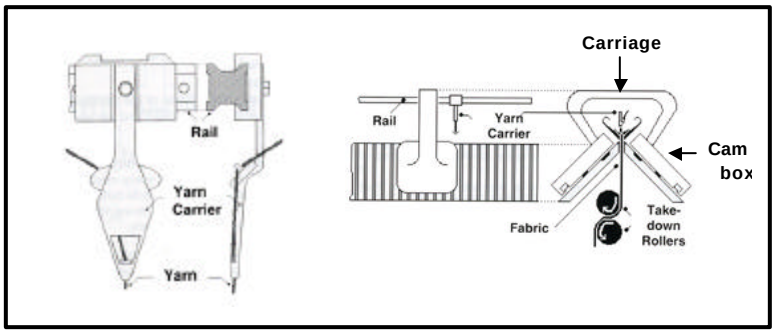


Figure 1.1f. Yarn Carriers, Carriage and Take-down Rollers (Raz, 1991)

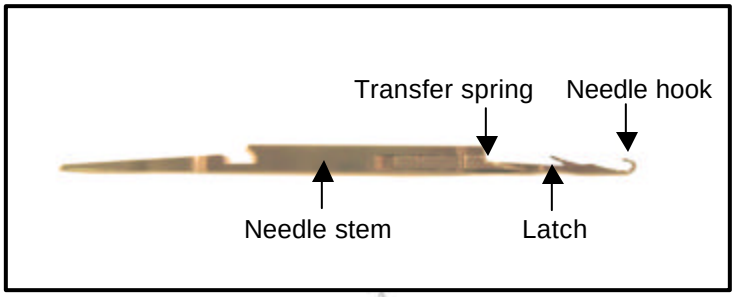


Figure 1.1g. Latch needle on Shima Seiki Machine

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

Skechers EX1021
Skechers v Nike

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.

Skechers EX1021
Skechers v Nike

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.

J T A T M

Skechers EX1021
Skechers v Nike

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

Skechers EX1021
Skechers v Nike

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*)

Skechers EX1021
Skechers v Nike

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

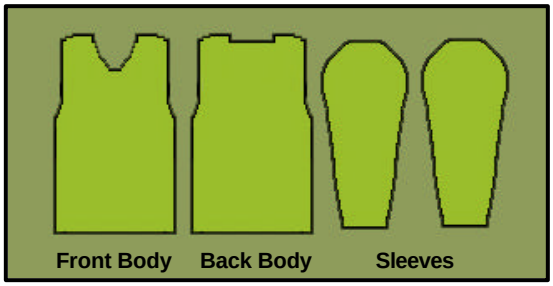


Figure 5.1. Cut and sew production
(Shaded area: Cutting Waste)

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

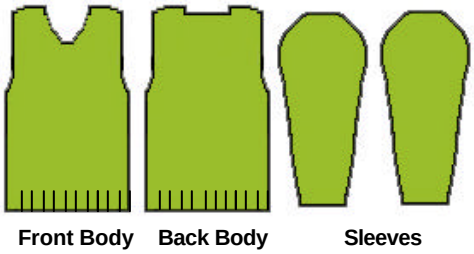


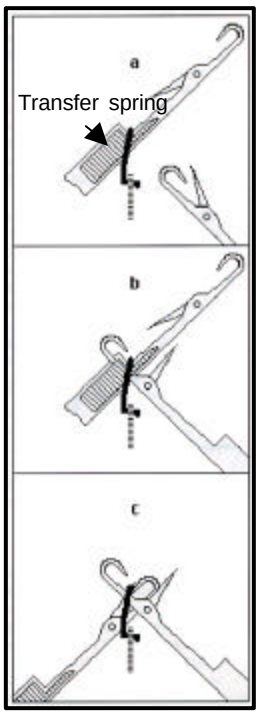
Figure 5.2. Fully-fashioning production

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].

J T A T M

Skechers EX1021
Skechers v Nike



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)

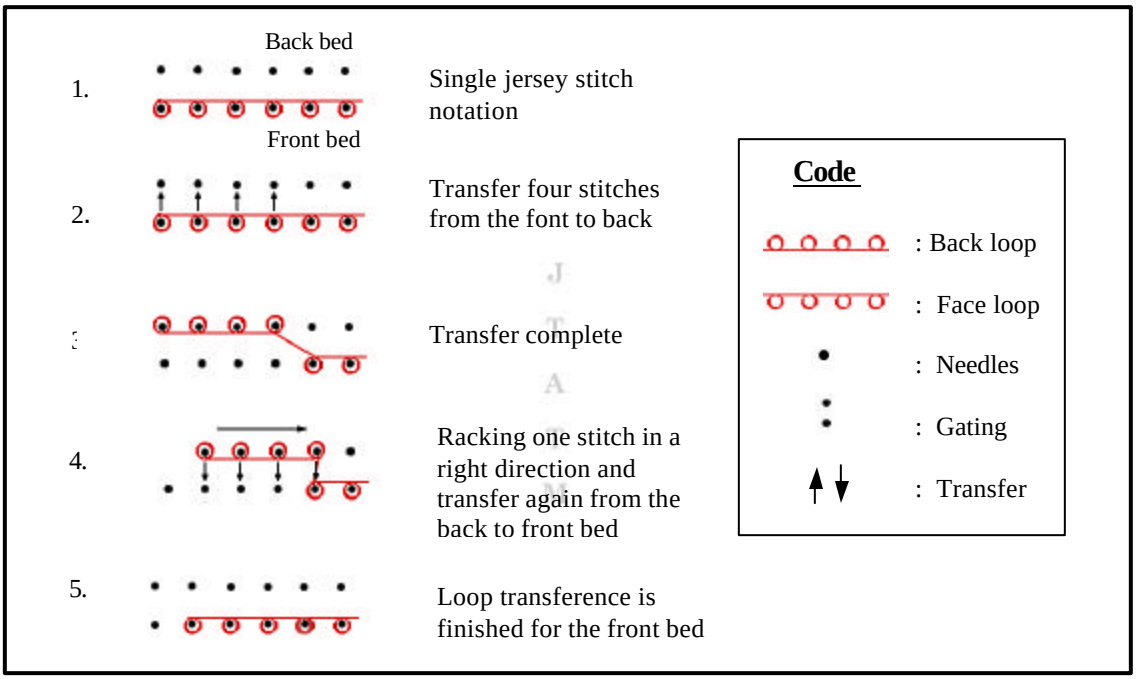


Figure 5.2.1. Narrowing process by loop transference on flat V-bed machine

Skechers EX1021
Skechers v Nike

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.

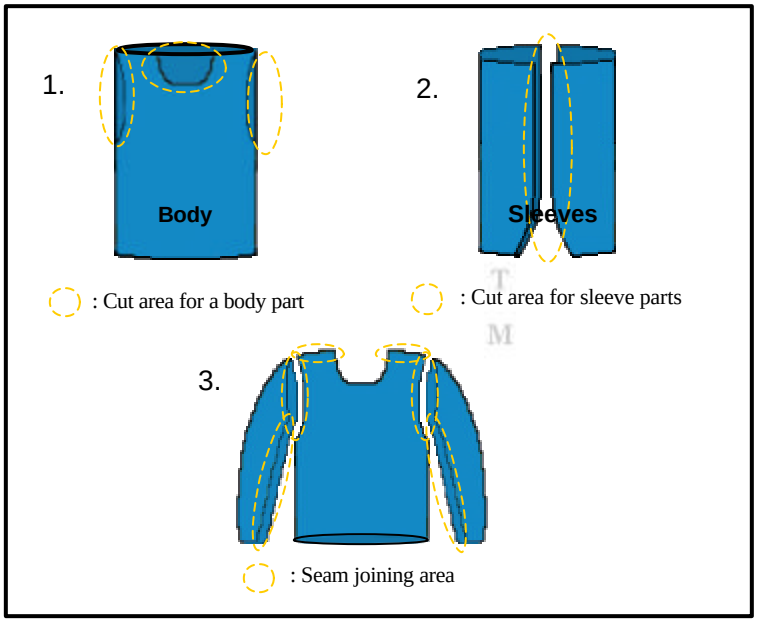


Figure 5.3a. *Complete garment production by a seamless circular knitting machine*

Skechers EX1021
Skechers v Nike

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.

J T A T M

Skechers EX1021
Skechers v Nike

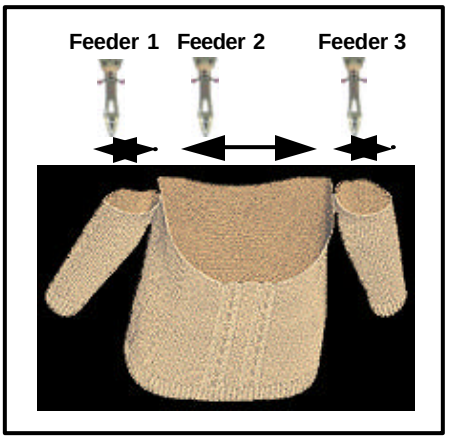


Figure 6.1. Three-dimensional complete garment knitting until underarm point (Shima Seiki)

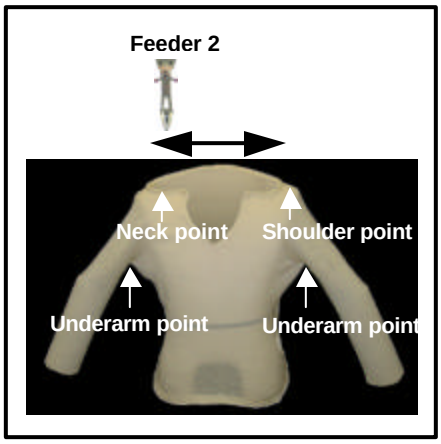


Figure 6.2. Three-dimensional complete garment knitting after underarm point

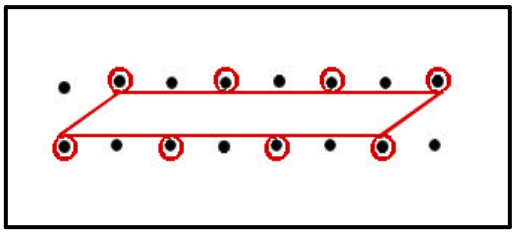


Figure 6.3. Alternate stitch notation on complete garment knitting

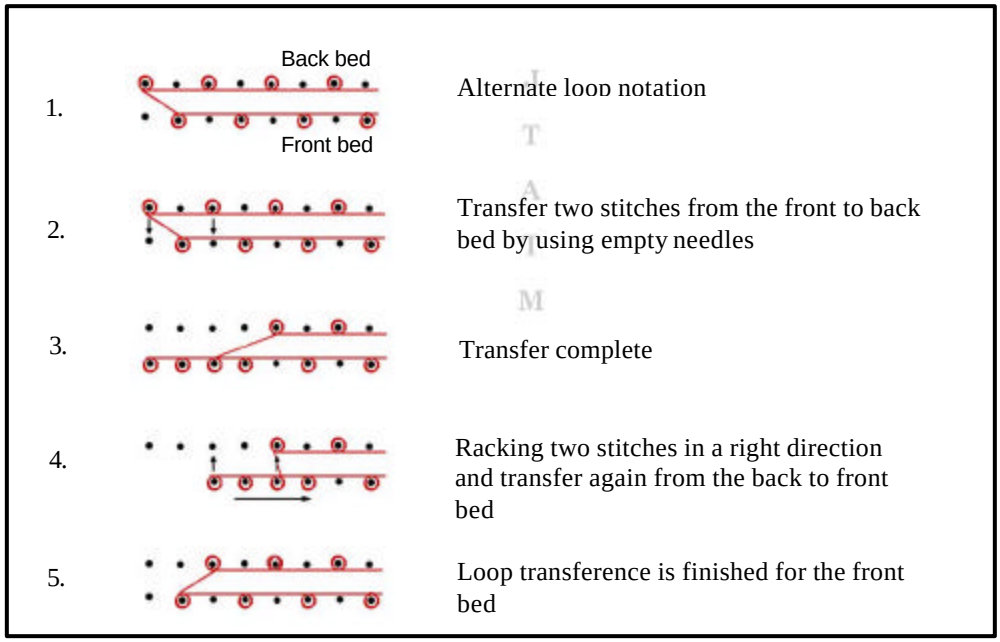
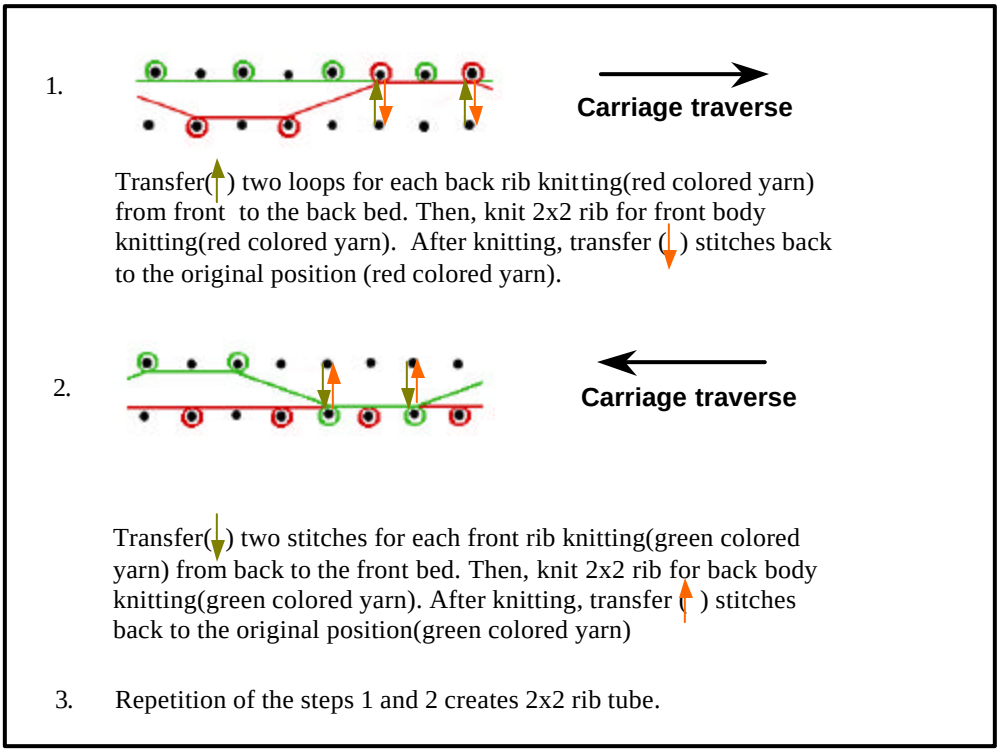


Figure 6.4. Loop transference on complete garment knitting

Skechers EX1021
Skechers v Nike



** 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.

J T A T M

Skechers EX1021
Skechers v Nike

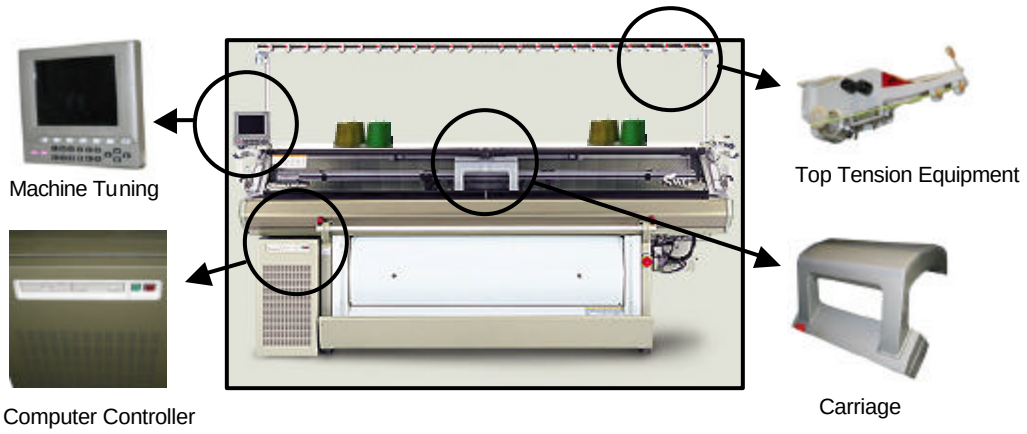


Figure 7.1. SWG-V® machine

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.

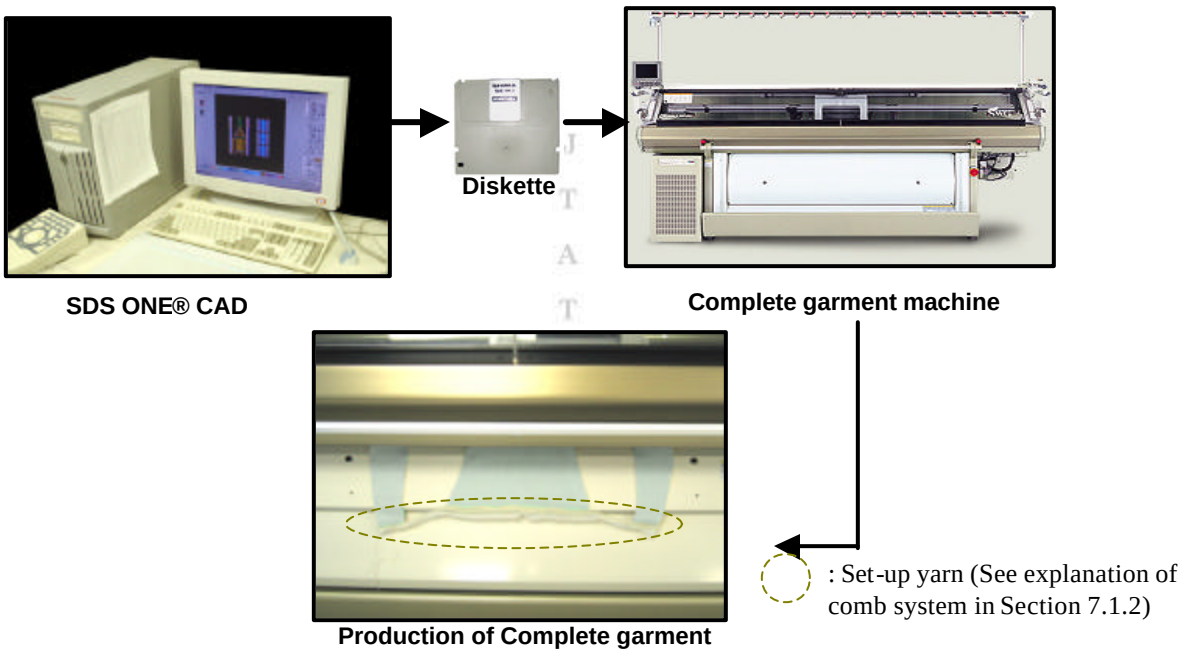
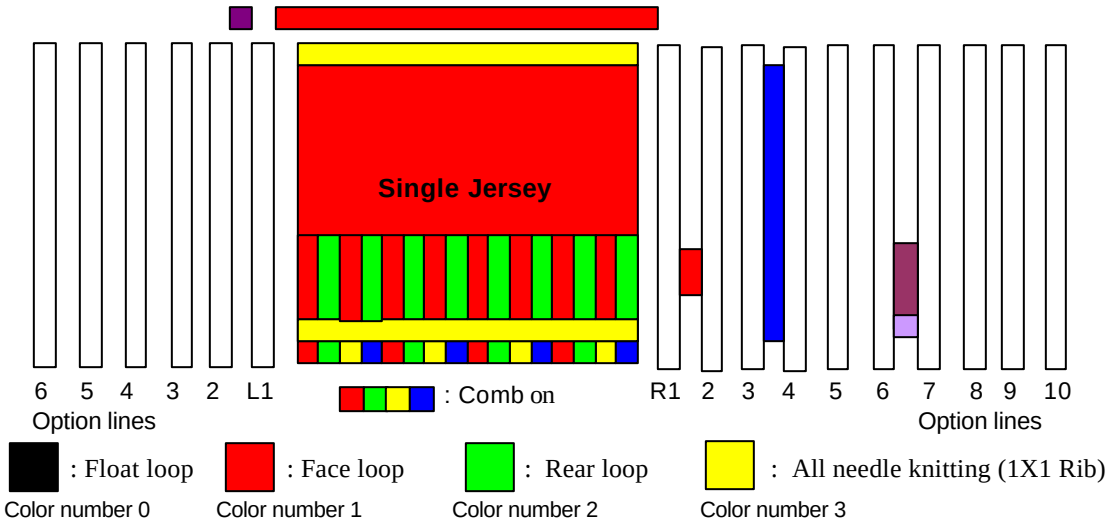


Figure 7.1.1. Shima Seiki Knitting machine system

Skechers EX1021
Skechers v Nike

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.

Skechers EX1021
Skechers v Nike

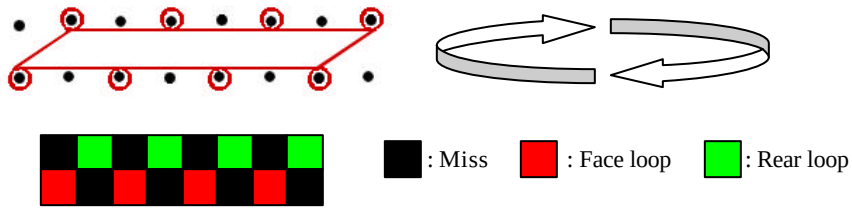


Figure 7.1.2b. Stitch notation for seamless knitting and CAD design on Shima Seiki CAD system

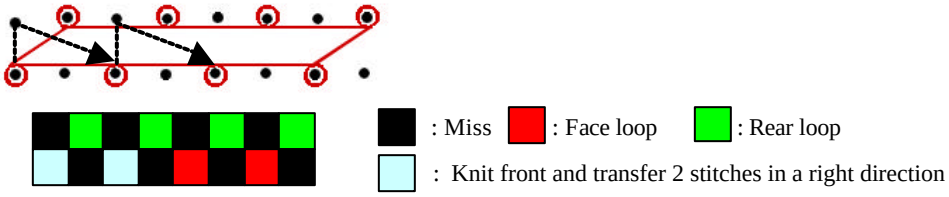


Figure 7.1.2c. Loop transference on front bed for seamless garment knitting

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.

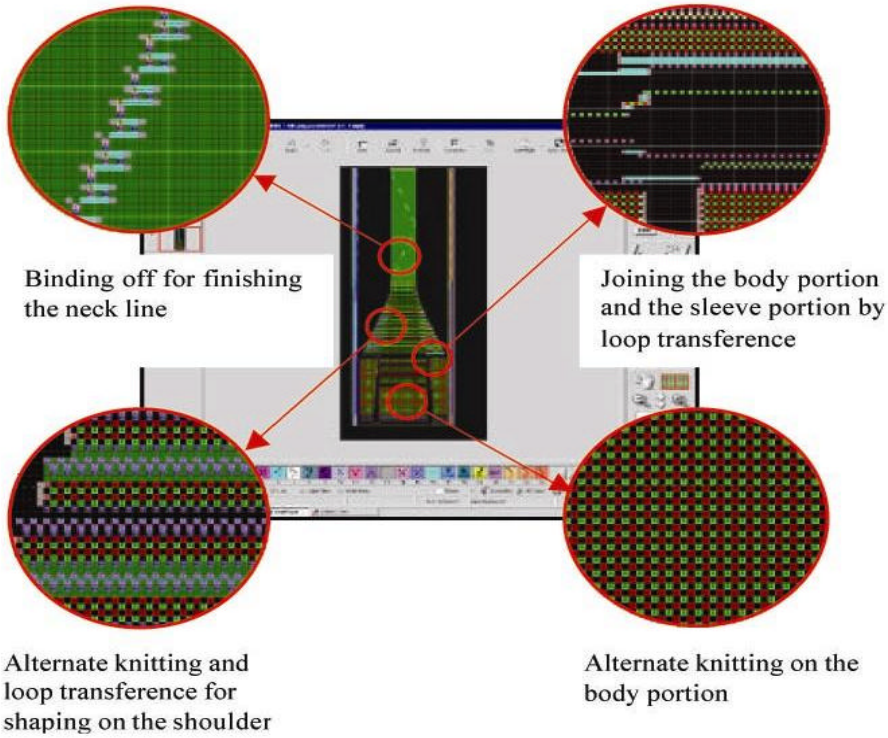


Figure 7.1.2d. Design for complete garment on Shima Seiki CAD system

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.

Skechers EX1021
Skechers v Nike

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.

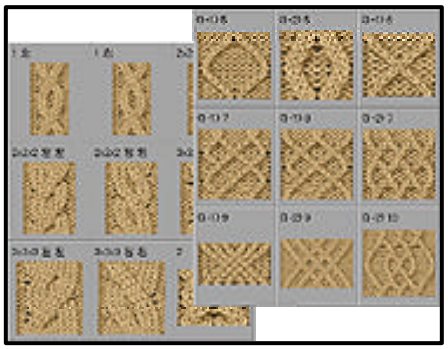


Figure 7.1.2e. Structure pattern database

Figure 7.1.2f Virtual sampling (Shima Seiki)

Skechers EX1021
Skechers v Nike

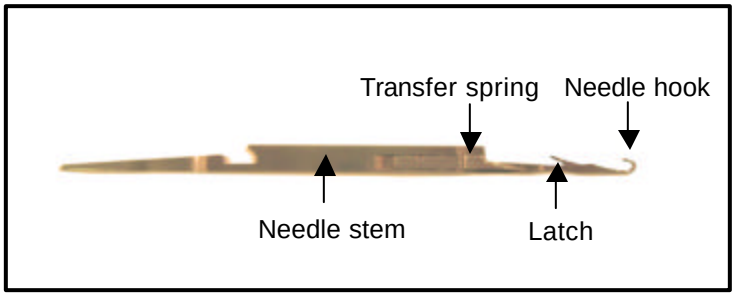


Figure 7.1.3.1a.
Latch needle on SWG-V® machine

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.

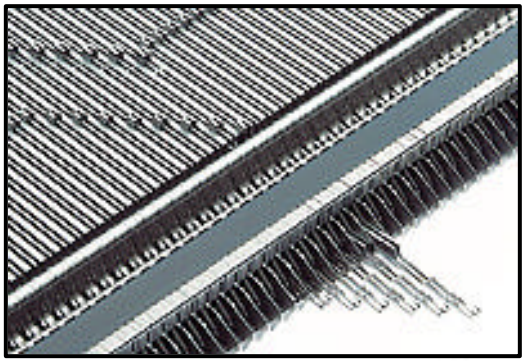


Figure 7.1.3.1b. twin gauge needles
(Shima Seiki)

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.

Skechers EX1021
Skechers v Nike

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).

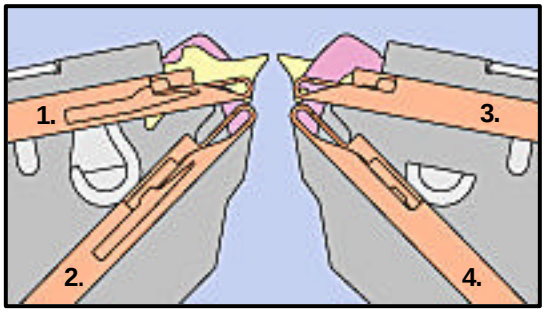


Figure 7.1.3.2. Cross section Diagram of the SWG-X® four-needle bed configuration (Shima Seiki)

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].

J T A T M

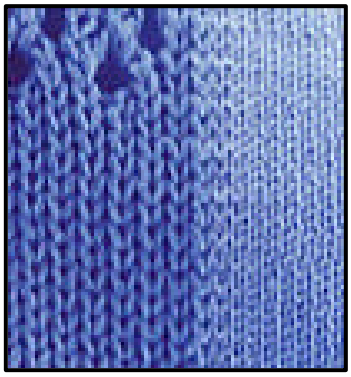


Figure 7.1.3.3. multiple-gauge knitting sample with 12G and 7G mixed side by side (Shima Seiki)

Skechers EX1021
Skechers v Nike

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.

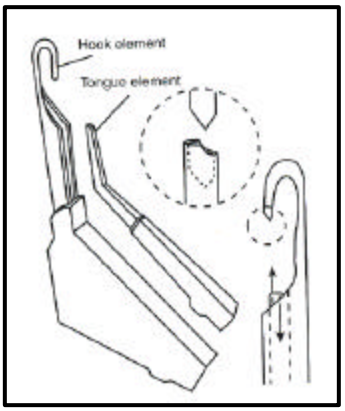


Figure 7.1.3.4a. Compound needle (Kadolph and Langford, 1998)

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).

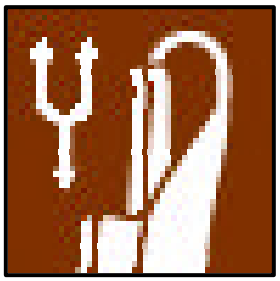


Fig 7.1.3.5a. Slide needle (Shima Seiki)

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

J T A T M

Skechers EX1021
Skechers v Nike

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.

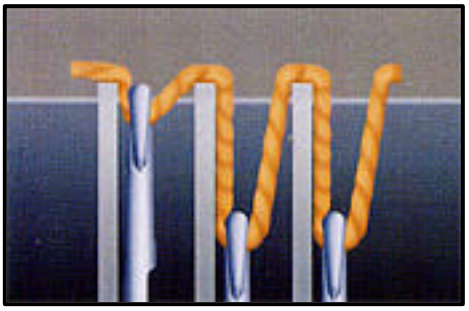


Fig 7.1.3.5b. Conventional latch needles offset slots (Shima Seiki)

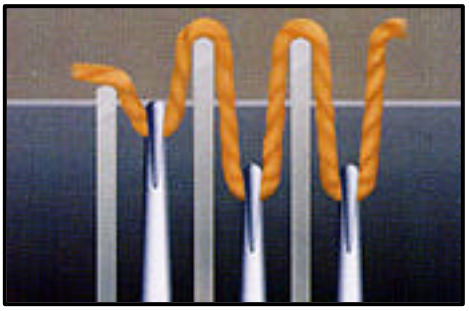


Fig 7.1.3.5c. Slide needles centered in slots

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.

J T A T M

Skechers EX1021
Skechers v Nike

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

Skechers EX1021
Skechers v Nike

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.

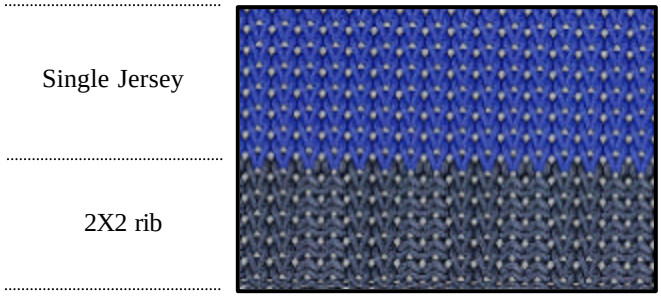


Figure 7.2.1. *2X2 Rib and single jersey displayed on the Stoll M1 CAD system*

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.

J T A T M

Skechers EX1021
Skechers v Nike

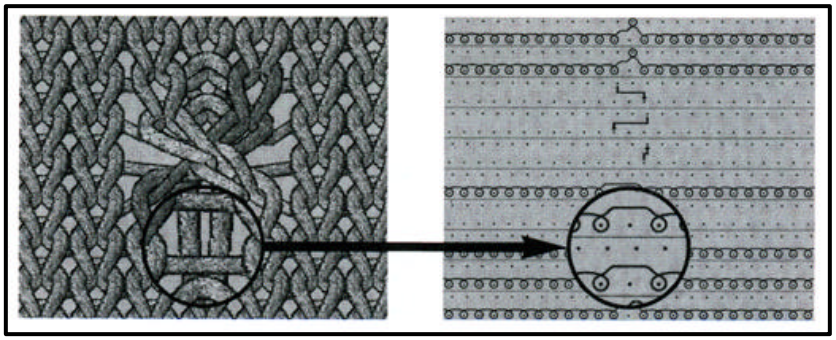


Figure 7.2.2. Linked windows options of fabric design view and technical view
(Spencer, 2001)

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,

J T A T M

Skechers EX1021
Skechers v Nike

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 T A T M

Skechers EX1021
Skechers v Nike

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

Skechers EX1021
Skechers v Nike

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

Skechers EX1021
Skechers v Nike

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

Skechers EX1021
Skechers v Nike

9. REFERENCES

1. Black, S. (2002). Knitwear in Fashion. *Thames & Hudson*, New York. p.174-175.
2. De Arajo M. D. (2002). Weft-Knitting Fabric Design for Technical Application. *Textile Asia*, *33(3).* p.23-27.
3. Denton, M J. & Daniels, P. N. (2002). Textile Terms and Definitions. *The Textile Institute*, Manchester, UK. *11*, p.383, p.65, p.138, p.308, p.176.
4. Groz-Beckert. (2004). Groz-Beckert Needles(Manual). p.120-121.
5. Hylton, E. G. (2005). Personal interview. Cotton Inc. February 28, 2005.
6. Hunter, B. (2004). Technology Transfer. *Knitting International, 111(1311).* p.35-39.
7. Hunter, B. (2004). Loop Tension and Fabric Quality. *Knitting International, 111(1312).* p.40.
8. Hunter, B. (2004). Is Knitwear Software too Rigid? *Knitting International, 111(1318).* p.19-20.
9. Hunter, B. (2004). Complete Garments - Evolution or Revolution?(Part I). *Knitting International, 111(1319).* p.18-21.
10. Hunter, B. (2004). Complete Garments-Evolution or Revolution?(Part II). *Knitting International, 111(1320).* p.22-23.
11. Hunter, B. (2004). Complete Garments-Evolution or Revolution?"(Part III). *Knitting International, 111(1321).* p.20-22.
12. Kadolph, S. J. & Langford, A. L. (1998). *Textiles, Merrill Prentice Hall,* New Jersey, *8*. p.217, p.219-220.
13. Knit Americas. (2001). Seamless Sweaters Here to Stay, Winter, p.22-23.
14. Knitting International. (2004). Lonati buys Sangiacomo, *111(1313).* p.19.
15. Knitting international. (2004). Technology Spurs Further Growth. 111(1318). p.59.
16. Knitting Together. (n.d.). Retrieved December 20, 2004, from http://www.knittingtogether.org.uk.
17. Kobata, et. al. (2001). Method of Knitting 3-D Shape Knit Fabric. *United States Patent: 6,318,131.*
18. Lehrich, R. (2004). Shima Seiki training. NCSU. From March 8, 2004 to March 12, 2004.
19. Linda, G. & Leggett, N. (1990). The Machine Knitter's Dictionary, *Batsford Ltd*, London, p.114.
20. Legner, M. (2003). 3D-Products for Fashion and Technical Textile Applications from Flat Knitting Machines. *Melliand International, 9(3).* p.238-241.
21. Maison, L. (1979). Flat knitting Machines. *ITF Maille*, France. p.B-4.
22. McIntyre J. E. & Daniels, P. L. (1997). Textile Terms and Definitions, *The Textile Institute, 10*. p.180, p.270, p.213, p.225, p.383.
23. Merle, M.L. (2003). Developments in Three-Dimensional Knitting for Preforms and Clothing, Proceedings: *International Textile Design and Engineering Conference*, Edinburgh, Scotland, Heriot-Watt University, Netherdale, Galashiels TD1 3HF, UK.
24. Millington, J. (1996). Knitting: a High Technology Industry. *Textile Outlook International*, p.98, p.105.
25. Mowbray, J. (2003). Oswal Shapes up to the Challenge. *Knitting International, 110(1307)*. p.28.
26. Mowbray, J. (2004). Complete Knitwear Solutions. *Knitting International, 111(1311).* p.42.
27. Mowbray, J. (2004). A New Spin on Knitwear. *Knitting International, 111(1312)*. p.34-36
28. NeutralPosture. (n.d.). Retrieved January 22, 2005, from http://www.neutralposture.com.
29. Onal, L. (2003). The Relation of Seam-free Garments and Mass Customization, *ITB International Textile Bulletin, 49(3).* p.44.
30. Powell, N.B. (2003). Italian Textile Technology. *Textile World, 153(6)*. p.40-41.
31. Powell, N.B. (2003). Mass Customization in Transportation Textiles through Shaped Three-Dimensional Knitting. Proceedings: *International Textile Design and Engineering Conference*, Edinburgh, Scotland, Heriot-Watt University, Netherdale, Galashiels TD1 3HF, UK.
32. Pratt, H. (1972). Knit Barre Cause and Cures. *AATCC Symposium.* New York. p.3.
33. Raul, J. (1998). Dictionary of Textiles. *Anmol Publications PVT.* India, p.84, p.24.

J T A T M

Skechers EX1021
Skechers v Nike

34. Raz, S. (1991). Flat Knitting : The New Generation. *Meisenbach Bamberg*, Meisenbach. p.34-37, p.14, p.62-63.
35. Santoni. (2004). Know-How : Santoni. *Gruppo Lonati, Brescia*, Italy, p.2-29.
36. Schlotterer, H. (1998). Stoll-Pattern Innovations from Pitti Imagine Filati. *Knitting Technology, 20(3).* p.97-99.
37. Shima Seiki. (2004). Shima Seiki Instruction Manual, *Shimatronic WholeGarment® Machine SWG-V*, Wakayama, Japan, p.1-4.
38. Shima Seiki. (2004). Creating Shaping Guide. *SDS-ONE Knit Paint(Shaping_HelpE)*, Version A-38.
39. Shima Seiki Mfg. (n.d.). Retrieved September 9, 2004, from http://www.shimaseiki.co.jp.
40. Sorge, M. (1994). A Stitch in Time: Inland Fisher Guide's Low-cost, High-tech Seat Covers. *Ward's Auto World*, p.52.
41. Spencer, D. (1983). Knitting Technology. *Pergamon Press*, New York. p.42.
42. Spencer, D. (1989). Knitting Technology, *Woodhead Publishing Limited*, Cambridge, England. 2. p.13-14, p.202, p.26, p.18, p.24, p.25, p.72-73
43. Spencer, D. (1996). Sitting Pretty, *knitting International, 103/1232-(32)*. p32
44. Spencer, D. (2001). Knitting Technology, a Comprehensive Handbook and Practical Guide. *Woodhead Publishing Limited*, Cambridge, England. 3. p.106, p.76, p.238, p.144, p.140, p.234, p.27
45. Stoll. (n.d.). Retrieved October 11, 2004, from http://www.stoll.de.
46. Stoll, H. (2001). New Approach to the Design Automobile Interiors using Three-dimensionally Knitted Fabrics. *Melliand International, 7(6).* p.127.
47. Teknit, (n.d.). Retrieved November 11, 2004, from http://www.teknit.com/Pages/summary.htm#ecol.
48. Tortora, G. P. & Robert, S. M. (1996). Fairchild's Dictionary of Textiles. *Fairchild Publication*, New York. 7. p.287.
49. Tubbs, M. C. & Daniels, P. N. (1991). Textile Terms and Definitions. *The Textile Institute*, Manchester, UK. 9. p.132-133, p.79, p.184.
50. Ward, J. (2004). Email interview. Shima Seiki USA Inc. November 29, 2004.
51. Ward, J. (2005). Email interview. Shima Seiki USA Inc. January 6, 2005.
52. Young, E. A. (1985). Knitwear Manufacturers' Use of Electronic V-bed Knitting Machines with Presser Foot. *A thesis submitted to the Graduate Faculty of North Carolina State University*, Raleigh. p.26.

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

Skechers EX1021
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.

J T A T M

Skechers EX1021
Skechers v Nike

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
T
A
T
M

Skechers EX1021
Skechers v Nike

View publication stats