(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 December 2013 (27.12.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/188948 A1

(51) International Patent Classification:
*B27L 1/00* (2006.01) *G06T 7/40* (2006.01)

(21) International Application Number:
PCT/CA2013/000368

(22) International Filing Date:
17 April 2013 (17.04.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2,780,202 19 June 2012 (19.06.2012) CA
13/614,761 13 September 2012 (13.09.2012) US

(71) Applicant: **CENTRE DE RECHERCHE INDUSTRIELLE DU QUÉBEC** [CA/CA]; 333, rue Franquet, Québec, Québec G1P 4C7 (CA).

(72) Inventors: **GAGNON, Richard**; 2608, boul. Liégeois, Québec, Québec G1W 1Z6 (CA). **COUTURIER, Jean-Pierre**; 825, Beauregard, app. 502, Québec, Québec G1V 4L7 (CA). **GAGNÉ, Philippe**; 280, Monique-Corriveau, St-Nicolas, Québec G7A 4Z6 (CA). **DING, Feng**; 1701, de la Grésière, Québec, Québec G1W 2H1 (CA). **IBRAHIM, Fadi**; 7907, 109 Street, app. 104, Edmonton, Alberta T6G 1C7 (CA).

(74) Agent: **BOUDREAU, Jean-Claude**; 1201, Crémazie Est, bureau 1.210, Montréal, Québec H2M 0A6 (CA).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

*[Continued on next page]*

(54) Title: METHOD AND SYSTEM FOR DETECTING THE QUALITY OF DEBARKING AT THE SURFACE OF A WOODEN LOG

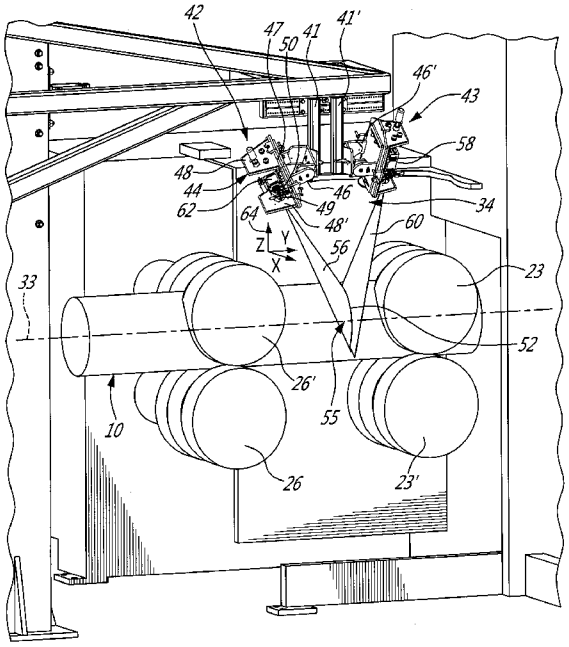



Fig. 3A

(57) Abstract: A method and system (22) for detecting and controlling the quality of debarking at the surface of a wooden log provide information on main parameters related to the debarking quality of the log surface, including fiber loss and residual bark. The debarking quality detecting method and system involve measurement of three-dimensional profile of at least a portion of the log surface to generate corresponding profile image data, which is processed to generate data indicative of the texture of the log surface. The texture data is then analyzed to generate resulting data on the debarking quality parameters. That quality indicative information can be generated on a continuous basis to provide an objective assessment of the quality performance in real-time in view of target productivity, and may then be used to perform optimal adjustments of the debarker operating parameters, either manually by the operator or automatically through feedback control.

WO 2013/188948 A1

GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published**:

— *with international search report (Art. 21(3))*

# METHOD AND SYSTEM FOR DETECTING THE QUALITY OF DEBARKING AT THE SURFACE OF A WOODEN LOG

## Field of the invention

[1] The present invention relates to the field of wood processing, and more particularly to methods and systems for detecting and controlling the quality of debarking performed on wooden logs in lumber mills.

## Background art

[2] The debarking process is a very important step for many industrial uses of wood from logs. Wood chips produced through the debarking process are the main raw materials of most pulp and paper, MDF and HDF boards industries. Bark has minimal value and may be associated with net financial loss incurred by the forest industry. Wood chips typically come from sawmills where they are produced from logs that have been debarked, and the debarking quality directly influences the chip quality and sawmill production yield. The debarking of wooden logs is an operation consisting of removing from the surface of each log a thin layer of material mainly containing bark (outer bark and inner bark) with some cambium, with the objective to preserve intact the fiber material under the cambium layer, so as to maximize economic yield obtained from lumber and wood chips. Typically, wood chips represent roughly 50% of the volume of material produced, within which a maximum of 1% (1.5 % in winter) of bark content is targeted, while aiming at preserving the full potential of lumber yield for each piece of timber. Since bark remaining on chips deteriorates the pulp being produced, it is within the industry practices that buyers of wood chips such as pulp producers and pressed board manufacturers, to impose economic penalties to chips providers or even refuse delivery in cases where bark content limit is exceeded. In the other hand, the compliance with that requirement may involve fiber loss from log surface as a result of debarking, causing a loss of income, due to fiber material loss in wood chips associated with residual fiber in bark, as well as to the lower value of lumber production attributed to a lower quality associated with surface and dimensional defects. In other words, residual bark on the debarked log surface increases the percentage of bark content in the wood chips which may thus be downgraded or refused by the mills, while excessive debarking

will result in fiber loss, thus decreasing sawmills revenues. The optimization of debarking process is very complex, mainly due to numerous variables to be considered in order to concurrently decrease fiber loss and residual bark on the debarked log surface. In practice, seeking to operate the debarking process at an optimal point is a difficult task. Generally, wood processing involves a large variation in raw material characteristics at the input end of the sawing process in contrast with upstream processes such as drying and planning. Therefore, debarking should be entirely efficient in terms of production capacity and debarked log quality while being fed in timber pieces of various diameters, moisture contents and wood species. The debarking equipment currently available includes the drum debarker, hydraulic debarker and rotary ring debarker, the two latter being used on sequential, respectively transverse and lengthwise, log processing lines, while the former is used for debarking logs in batches. During the past years, the rotary ring debarker has been the most used type of debarking equipment in sawmills. The rotary ring debarker makes use of spinning knifes mounted on a rotary ring as cutting tools, whose angular position as well as the magnitude of controlled pressure applied thereto are usually adjusted periodically to achieve an acceptable debarking quality taking into account a large variation at the input of the debarking process.

**[3]** The variations of log physical properties, environmental and storage conditions, as well as debarking operating conditions strongly influence the residual bark and fiber loss levels on the surface of debarked logs. The performance of a rotary ring debarker depends on log characteristics such as wood species, moisture content, freshness, mean diameter, and bark thickness. In particular, different wood species have their own characteristics that may affect the debarking process, for example black spruce is more easily debarked than balsam fir during winter. Moisture content is the most important factor in wood/bark adhesion strength. As to freshness, lowest bark/wood shear strengths can be observed with fresher logs as compared to aged logs. As to diameter, it is generally observed that amongst the debarked logs of a processed batch, those of small diameter are often poorly debarked. It is also well known that bark thickness varies between wood species, parts of the tree, as well as harvesting areas, and thus influences the choice of debarking operating parameters, especially pressure applied to the tools, as reported by Spurr, S.H, et al. in "Forest Inventory" The Ronald Press Company, NY. 1952, pp. 476; Philip, M. S. in "Measuring Trees and Forests", 2nd ed. CAB Inter., Wallingford, Oxforshire, UK. 1994, pp. 310; Wilhelmsson, L., et al. in "Models for predicting wood properties in stems of Picea abies and Pinus sylvestris in Sweden",

Scand. J. Forest Res. 17, 2002, pp.330-350; and Marshall, H. D., et al. in "Effects of bark thickness estimates on optimal log merchandiding", Forest Products Journal Vol. 56, No. 11/12, 2006. As to the effects of environmental and storage conditions on debarking quality, air temperature, which influences temperature state of log surface (i.e. frozen or non-frozen), has an effect on wood/bark adhesion strength when the log moisture content is greater than fiber saturation point, as reported by Baroth, R., in "Literature review of the latest development of wood debarking", Control Engineering Laboratory, University Oulu, Report A No. 27, August 2005, p. 4. The storage conditions such as storage time, ambient air conditions (temperature, relative humidity, velocity) also influence moisture content distribution in logs, which results in variation of wood/bark adhesion strength finally giving rise to debarking quality. Finally, the performance of a rotary ring debarker depends on its main operating parameters, namely pressure applied to the cutting tools, log feed speed, ring rotational speed, and cutting tool tip overlap. It is known that a poorly maintained or misadjusted debarker may cause log surface damages and well as sections of reduced diameter along the debarked log, which influences log classification and optimization by reducing available wood for lumber production. As to pressure radially applied to cutting tools, values for that parameter may be assigned according to log physical characteristics as well as environmental and storage conditions. At sawmill, pressure values are typically determined according to wood species, average log diameter and log surface log temperature state (frozen or non-frozen), and the radial pressure may be adjusted during debarking as the debarking log diameter is changed. When the radial pressure is set at low value to prevent fiber loss, more residual bark is thus observed on the debarked log surface. Log feed speed is considered as an important factor of debarking yield, and that parameter is usually kept at a high value at sawmill. As to ring rotational speed, a high value assigned to that parameter increases tool arms centrifugal forces and decreases tool reaction time, which factors are beneficial to debarking yield increases as reported by Laganière, B. et al. in "Effects of radial force and tip path overlap on the ring debarking efficiency of frozen balsam fir logs", Forest Products Journal, vol. 55, No. 3. 2005. As a result of combined effects of log feed and ring rotation, consecutive debarking tool tip path overlap occurs during debarking, and to ensure complete bark coverage by the tips, an overlap factor over 10% has been suggested by Lapointe, J. A. in "Optimizing the operation of ring debarkers. Research Memorandum", Project No. 76-0207-01. Domtar Research Center, Senneville, Qc, Canada. 1976, pp.45. For a given value of log feed or ring rotational

speed, the tool tip path overlap can be increased by decreasing the ring rotational or feed speed, respectively.

**[4]** Generally, operation of the rotary ring debarker is based on experience of sawmill operators, the operation parameters such as pressure applied to the cutting tools, log feed speed and ring rotational speed being set up for different wood species and log temperature states (frozen or non-frozen). For years, the quality control at the output end of known debarking equipment has been generally limited to visual control and classification by an operator, which is not precise and results in a relatively high classification error rate. In some lumber mills, samples are periodically selected in order to determine the amount of bark into wood chips or the amount of fiber present into bark. These procedures give merely rough indications of debarker performance that merely allow trend monitoring, without providing accurate quality control. For years, many automated system have been proposed to automate debarking quality detection generally based on sensors measuring surface reflectivity of the debarked logs or samples thereof, such as disclosed in the following patent publications: US 2,769,468; US 5,247,978; US 5,274,244; US 5,335,790; US 6,137,894; US 6,166,393; US 6,493,076; US 6,526,154 ; US 6,614,041; US 6,539,993; and US 2010/236664. However, surface reflectivity alone cannot discriminate all of the various characteristics associated with debarked surface quality to allow an accurate control thereof. More recently, the use of three-dimensional profile data for detecting surface defects on debarked logs has been proposed by L. Thomas in "Automated detection of surface defects on barked hardwood logs and stems using 3-D laser scanned data" Virginia Polytechnic Institute and State University, Virginia, U.S.A., September 2006. However, the contour-based detection approach as taught by Thomas is limited to the identification of defects characterized by significant height changes, such as defective knobs and depressions, the detection of which defects cannot allow an accurate control over the quality of debarking.

**Summary of the invention**

**[5]** The following presents a simplified summary in order to provide a basic understanding of one or more aspects of the invention. This summary is not an extensive overview of the invention, and is neither intended to identify key or critical elements of the invention, nor to delineate the scope thereof. Rather, the primary purpose of the

summary is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

**[6]** The object of the proposed invention is to obtain for each wooden log under or after debarking operation, information on main parameters related to the debarking quality of the log surface, including fiber loss and residual bark. That quality indicative information can be generated on a continuous basis at the output end of the debarker, providing an objective assessment of the quality performance in real-time in view of target productivity, and may then be used by the operator to perform optimal adjustments of the debarker operating parameters when necessary. Furthermore, knowing or measuring upstream the intrinsic characteristics of the each log entering the debarker such as diameter and wood species, its environmentally influenced characteristics such as temperature and moisture content, as well as debarker tool data such as angular position of cutting tools and wear level of tools, information on fiber loss and residual bark obtained while debarking or at the output of debarker may be used to automatically perform in feedback the required debarker adjustments, such as magnitude of controlled pressure applied to cutting tools, ring rotational speed and log feed speed, to provide optimal performance in real time.

**[7]** According to the above object, from a broad aspect of the invention, there is provided a method for detecting the quality of debarking at the surface of a wooden log, comprising the steps of: i) measuring a three-dimensional profile of at least a portion of the log surface to generate corresponding profile image data; ii) processing the profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of the wooden log to generate data indicative of the texture of the log surface; and iii)analyzing the texture data to generate resulting data on parameters related to the debarking quality of the log surface, said parameters including fiber loss and residual bark.

**[8]** According to the above object, from another broad aspect of the invention, there is provided a system for detecting the quality of debarking at the surface of a wooden log. The debarking quality detecting system comprises a three-dimensional profile measuring unit for scanning at least a portion of the log surface to generate corresponding profile image data; data processing means receiving the profile image data for detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of the wooden log to generate data indicative of the texture of the log surface; and data analyzing means receiving the texture data to

generate resulting data on parameters related to the debarking quality of the log surface, said parameters including fiber loss and residual bark.

**[9]** According to the above object, from a further broad aspect of the invention, there is provided a software product data recording media in which program code is stored, the program code will cause a computer to perform a method for detecting the quality of debarking at the surface of a wooden log, from three-dimensional profile data of at least of portion of a surface of the log, which method comprising the steps of: processing the profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of the wooden log to generate data indicative of the texture of the log surface; and analyzing the texture data to generate resulting data on parameters related to the debarking quality of the log surface, said parameters including fiber loss and residual bark.

**[10]** According to the above object, from another broad aspect of the invention, there is provided a method for detecting the quality of debarking at the surface of wooden logs and for controlling a debarking process applied to the wooden logs on the basis of said debarking quality, comprising the steps of: i) measuring a three-dimensional profile of at least a portion of the surface of one of the logs to generate corresponding profile image data; ii) processing the profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of the wooden log to generate data indicative of the texture of the log surface; iii) analyzing the texture data to generate resulting data on parameters related to the debarking quality of the log surface, said parameters including fiber loss and residual bark; and iv) controlling the debarking process applied to a next one of the logs using the resulting data.

**[11]** According to the above object, from a still further broad aspect of the invention, there is provided a system for detecting the quality of debarking at the surface of wooden logs and for controlling a debarking process applied to the wooden logs on the basis of said debarking quality, comprising a three-dimensional profile measuring unit for scanning at least a portion of the log surface to generate corresponding profile image data, data processing means receiving the profile image data for detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of the wooden log to generate data indicative of the texture of the log surface, data analyzing means receiving the texture data to generate resulting data on parameters related to the debarking quality of the log surface, said parameters including fiber loss

and residual bark, and means for controlling the debarking process applied to a next one of said logs using said resulting data.

**[12]** According to the above object, from still another broad aspect of the invention, there is provided a software product data recording media in which program code is stored, said program code will cause a computer to perform a method for detecting the quality of debarking at the surface of wooden logs and for controlling a debarking process applied to the wooden logs on the basis of said debarking quality, comprising the steps of: i) measuring a three-dimensional profile of at least a portion of the surface of one of the logs to generate corresponding profile image data; ii) processing the profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of the wooden log to generate data indicative of the texture of said log surface; iii) analyzing the texture data to generate resulting data on parameters related to the debarking quality of the log surface, said parameters including fiber loss and residual bark; and iv) controlling the debarking process applied to a next one of the logs using the resulting data.

**Brief description of the drawings**

**[13]** Some illustrative embodiments of the debarking quality detection and control method and system will now be described in view of the accompanying drawings in which:

**[14]** **Fig.1** represents a log being subjected to debarking through the action of cutting tools provided on a typical rotary ring debarker;

**[15]** **Fig. 2** represents a log to be debarked, showing its dimensional parameters;

**[16]** **Fig. 3** is an isometric view of a debarking line provided with a debarking quality detection and control system according to one embodiment as described in detail below;

**[17]** **Fig. 3A** is a partial isometric view of the debarking quality detection and control system of **Fig.3**, showing details of the profile measurement unit;

**[18]** **Fig. 4** is a top view of the debarking line and debarking quality detection and control system of **Fig. 3**;

**[19]** **Fig. 4A** represent a log feeding unit disposed upstream the debarker of **Fig. 4**;

**[20]** **Fig. 5** is a side view of the debarking line and debarking quality detection and control system of **Fig. 3**;

**[21]** **Fig. 6** is a cross-sectional end view of the debarking line and debarking quality detection and control system of **Fig. 3** according to section lines 6-6 shown in **Fig. 5**;

**[22]** **Fig. 7** is a schematic block diagram of the debarking quality detection and control system of **Fig 3**, representing its computer-based hardware and software components;

**[23]** **Figs. 8A** to **8D** are exemplary images respectively representing light intensity, laser line width, profile and transverse coordinate data associated with a scanned log;

**[24]** **Fig. 9** is an example of binary mask image as obtained by segmentation of the image data represented in **Figs. 8A** to **8D**;

**[25]** **Fig. 10A** and **10B** are images respectively representing the rotated profile image and a cleaned image obtained therefrom through pixel interpolation;

**[26]** **Figs. 11A** to **11C** are scaled images respectively derived from previously cleaned intensity, width and profile images of **Figs. 8A** to **8C**;

**[27]** **Fig. 12** is an image resulting of a flattening task as performed on the scaled profile image of **Fig. 11C**;

**[28]** **Fig. 13A** and **13B** are respectively horizontal and vertical edge detected images as obtained from the flattened profile image of **Fig. 12**;

**[29]** **Fig. 14** is a first example of a main screen showing a quality indicator as generated by the computer program;

**[30]** **Fig. 15** is a second example of a main screen showing fiber loss level as generated by the computer program;

**[31]** **Fig. 16** is a third example of a main screen showing residual bark level as generated by the computer program;

**[32]** **Fig. 17** is a fourth example of a main screen showing residual optimal debarked surface level as generated by the computer program;

**[33]** **Fig. 18** is a graph presenting the values of the debarking quality indicator experimentally obtained for a number logs, and of mean pressure values applied to the debarker tools, with respect to the corresponding log diameter ranges;

**[34]** **Fig. 19** is an image representing roughness areas on the log surface which can be obtained from the edge detected images of **Figs. 13A** and **13B**.

**[35]** **Fig. 20A** and **20B** are images respectively representing a mask indicating fiber tear areas and a mask indicating smooth areas of the log surface, as obtained from the roughness indicative image of **Fig. 19**;

**[36]** **Fig. 21A** and **Fig. 21B** are images respectively representing the scaled intensity image (**Fig. 11A**) and the corrected intensity image obtained by applying a ramp function;

**[37]** **Fig. 22** is a filtered image obtained by thresholding the corrected intensity image of **Fig. 19B**;

**[38]** **Figs. 23A** to **23C** are images respectively representing the mask indicating fiber tear areas on the log, the mask indicating enlarged bark areas on the log, and the resulting correction of the fiber tear indicating mask after removal of enlarged bark areas;

**[39]** **Fig. 24** is a combined image representation of the resulting quality-related parameter data;

**[40]** **Fig. 25** is a schematic block diagram of a model predictive control (MPC) structure adapted to carry out optimized control of the debarking process;

**[41]** **Fig. 26** is an example of predictive model based on a neural network structure; and

**[42]** **Fig. 27** are graphs showing the performance of debarking in terms of the quality-related parameters as simulated without and with the MPC structure and according to a control sequence based on various states of debarking operating parameters $P$, $V$ and $\omega$.

**Detailed description of the illustrative embodiments**

**[43]** Referring to **Fig. 1**, there is schematically represented a log 10 being subjected to debarking through the action of cutting tools 12 such as knifes mounted at working ends of arms 14 provided on a typical rotary ring debarker, and disposed in a circular arrangement defined by the ring. The log 10 is fed into the rotary ring debarker in a continuous mode of operation at a feed speed $V$ and as its ring rotates at a rotational ring speed $\omega$, the bark 16 of the log gets peeled down to the cambium layer, herein designated as the debarked surface 18, through the action pressure $P$ radially applied to tools 12. It can be seen that the log 10 is typically characterized by a length $L$, a minimum log diameter $D_{MIN}$ and a maximum log diameter $D_{MAX}$ as shown in **Fig. 2,** which parameters influence log taper shape, and may be considered by the predictive model of debarking process as will be explained below in detail.

**[44]** Referring now to **Fig. 3**, a typical debarking line generally designated at 20 is provided with a debarking quality detection and control system 22 aligned with the output end of a debarker 24 provided with a conveying system including infeed and outfeed devices 21 and 21' each using front and rear pairs of vertically aligned V-shaped press rolls 23, 23' and 26, 26' for transporting a log 10 along a travel path axis 33 while being processed by debarker 24, the debarked log being received on an exit conveyer 11

within a shielding tunnel 15. The debarker 24 may be a rotary ring debarker such as model A5 supplied by Nicholson Manufacturing Ltd (Sidney, BC, Canada), or any other appropriate debarker available in the marketplace. The detection system 22 includes a profile measuring unit 34 held above the travel path axis by a pivoting frame 28 mounted to a vertical stationary column 25 standing from the plant floor and rigidly secured thereto, and using a hinge assembly 27, enabling an operator to move the profile measuring unit between a working position as shown in **Fig. 3** and a withdrawal position allowing the operator an access to the outfeed device 21'. The pivoting frame 28 includes a post 29 to which are laterally secured upper and lower pairs of lugs 32, 32' provided with aligned bores adapted to receive upper and lower hinge-pins 35, 35', a respective end of which in turn engaging with lower and upper hub bracket 36, 36' secured to the column 25. The pivoting frame 28 further includes a boom 37 rigidly secured at a base end thereof to the post 29 with reinforcing members 38, 38', and having a free end to which is attached a subframe 39 having a bottom portion forming an adjustable support 40. The boom 37 can be firmly held to the working position using a locking device 54 secured to the column 25 as shown in **Fig. 4**.

**[45]** The support 40 is provided with a plurality of parallel elongated openings for adjustably receive and secure first and second holders 41, 41' to which are respectively attached a camera assembly 42 and a laser source assembly 43 as part of the profile measuring unit 34, as better shown in **Fig. 3A**. The three-dimensional profile measuring unit 34 is used for scanning at least a portion of the log surface to generate corresponding profile image data, to be analyzed in order to detect debarking quality of the log surface in terms of quality parameters including fiber loss and residual bark, as will be described later in more detail. The camera assembly 42 includes an enclosure 44, which is respectively shown in **Figs. 5** and **3A** with and without its cover 45, for containing and protecting from the log processing environment a digital 3D camera 62, which enclosure 44 is adapted to be secured to holder 41 through a mounting arrangement 46 allowing positional and angular adjustment of the optical sensing field 56 with respect to a scanning plane transverse (*i.e.* parallel to plane *X-Z* in reference system 64) to the travel path axis 33 as shown in **Fig. 6**. The camera enclosure 44 has a base wall 47, as well as a front and rear wall 48, 48' defining a peripheral edge, the front wall 48' having an opening 49 protected by an optical element made of light transparent material such as glass or plastic. The enclosure 44 further has a device 50 for mounting the camera 62 within the enclosure such that it has its optical sensing field 56 directed

toward opening 49 for passing therethrough. Power supply line, control and scanning output data lines as well as a vortex tube for cooling (not shown), can be introduced within enclosure 44 through appropriate apertures provided on rear end wall 48. Turning to **Fig. 5**, the enclosure 44 further includes an enclosure cover 45 having a closing edge adapted to mate with the peripheral edge defined by the enclosure walls to provide full closing of the camera mounting space, while allowing full access to this space when the cover 45 is brought to an open position after release of a clamp 51 provided on the enclosure 44. Conveniently, the laser source assembly 43 includes an enclosure 44' of a design similar to the camera enclosure 44 as described above, which enclosure 43 is respectively shown in **Figs. 5** and **3A** with and without its cover 45', for containing and protecting from the log processing environment a laser source 58. The enclosure 43 is adapted to be secured to holder 41' through a mounting arrangement 46' allowing positional and angular adjustment of the fan-shaped laser beam 60 defining the scanning plane, as better shown in **Fig. 6**.

**[46]** As better shown in **Fig. 3A**, the profile measuring unit 34 has its sensing field 56 transversely directed toward travel path axis 33 and defining a profile scanning zone 55 associated with the log surface as intersected by the optical sensing field 56, to generate profile image data related to the scanned log surface, in a direction along axis *Z* according to reference system 64, which direction *Z* being orthogonal to a reference plane *X-Y* parallel to the travel path axis. The profile sensor unit may conveniently use a same laser triangulation ranging approach as disclosed in U.S. Patent no. 7,429,999 issued to same assignee as of the present invention. In the presently described embodiment, the longitudinal axis generally defined by the log 10 is maintained substantially aligned or parallel to the travel path axis 33, which is collinear or at least parallel to Y axis of the reference system 64. In the present embodiment, while scanning along the log longitudinal axis is conveniently obtained as a result of a relative movement between the conveyed log and the stationary profile measuring unit 34, it is to be understood that longitudinal scanning could also be obtained by using a profile measuring unit capable of moving lengthwise with respect to a stationary log, for example in a case where a drum debarker is used for debarking logs in batches. The laser source 58 included in the profile measuring unit 34 is used to direct, at angle with the optical sensing field 56, the fan-shaped laser beam 60 toward profile scanning zone 55 to form a reflected laser line onto the log surface, corresponding to a scanned zone 52. The 3D camera 62 is used to capture an image of the reflected laser line or scanned

zone 52, the output of which camera 62 being fed through its processing unit and output line through link 57 as shown in **Fig. 3**, to an image acquisition unit as part of computer 66 which generates profile image data in a manner that will be described in detail below in view of **Fig. 7**. A digital 3D camera such as model C3-2350 from Automation Technology GmbH (Bad Oldesloe, Germany) integrating a processing module for profile-related output generation, may be used. A laser such as model ILS-670-500-A-20°, 500 *mW* – 670 *nm*, from Osela Inc. (Pointe-Claire, Quebec, Canada) may be used, with a transverse fan angle of about $30^0$. It is to be understood that any other appropriate camera of laser available in the marketplace can be used. The image acquisition unit may be based on hardware available on the marketplace, such as model Odyssey PCI e-x4ecl data acquisition boards from Matrox (Dorval, Quebec, Canada). An electrical supply unit for the profile measuring unit 34 can be contained in a cabinet 68 secured to the column 25 by frame member 53. Although the scanning plane is defined by the fan-shaped laser beam 60 in the embodiment shown in **Fig. 3**, it is to be understood that in another embodiment, the scanning plane could be defined by the optical sensing field of the camera, provided the fan-shaped laser beam is still directed at angle with the optical sensing field to allow triangulation. Moreover, while a fan-shaped laser beam is conveniently used in the shown embodiment to form a reflected laser line, a plurality punctual laser beams directed to corresponding points of the log surface may also be used to generate profile image data.

**[47]** It can be appreciated from **Fig. 3A** that log 10 moving along the travel path axis 33 in a direction indicated by arrow 41 parallel to axis *Y* of reference system 64, has its surface intersecting the sensing field 56 at a surface zone onto which laser beam 60 reflects light toward camera 62. The portion of the scanned surface for which three-dimensional profile is measured can be comprised of several scanned zones 52 transversely extending along the circumference the log, at several corresponding locations along the travel path axis 33. Experiences have shown that reliable measurements can be obtained with a scan zone representing about 15% of the log circumference, applied at least every 2.5 *mm* along the travel path axis 33. This result is based on the fact that for logs processed with a typical rotary ring debarker, debarking quality characteristics are substantially uniform along the log circumference at any given scanning position, so that the detection obtained with a limited scan zone is substantially representative of the entire log circumference. It is to be understood that a higher scan zone ratio could be used for debarked logs showing significant variations of debarking

quality characteristics along their circumference. While only a portion of the log surface is conveniently scanned in order to optimize processing and analyzing time, full surface (full circumference) of a log could also be scanned if necessary. It is also to be understood that even a single three-dimensional profile measuring unit 34 is involved in the embodiment shown in **Fig. 3**, a plurality of such units may be integrated to simultaneously scan several sets of zones of the log surface distributed along the circumference the log, by adapting the pivoting frame accordingly, or by providing a separate supporting structure. Furthermore, while the conveying stability of each log is usually maintained by the feeding device 21 provided on the debarker 24 to prevent vibration causing log translation and rotation under the impact of the rotary cutting tools, a small residual translation or rotation of the log along or about its longitudinal axis would not adversely affect the three-dimensional profile measurement of the scanned surface portion. The function of the processing unit integrated in the camera 62 consists of deriving the profile-related output data from two-dimensional images captured by the camera, involving calculation of the centers of gravity (centroids) of the laser beam image, or any other appropriate algorithm. The processing module can be wholly or partially integrated into the camera 62, or be part of a separate data processing unit interfaced with the camera to receive and process two-dimensional image data therefrom.

**[48]** As will be explained below, to provide a further indication of the residual bark, the debarking quality detection and control system 22 may include means for measuring light reflection from the inspected log surface portion to generate corresponding reflected light intensity image data. Conveniently, the same camera 62 may be used to obtain such intensity image data, wherein each pixel value represents the intensity value measured at a given position along the laser line, which intensity value is obtained through integration in the direction transverse to the laser line, *i.e.* along its width extending parallel to the direction of axis *X* in the reference system 64. Optionally, the same camera 62 may be used to obtain further image data wherein each pixel value represent the width of the laser line at the given position, on the basis of which further image analysis may be performed to detect debarking quality. As an alternative, a separate image sensor unit (not shown) could be provided for measuring light reflection from the inspected log surface portion, which separate unit would include a 2D digital camera having its output being fed to the image acquisition unit, generating a two-dimensional intensity image of the laser line, or having its own illumination source such

as set of fluorescent tubes. Although a monochrome camera could be used to obtain the required intensity image data, an equivalent intensity image signal such as luminance could also be obtained from a color camera, and the color signal components may provide additional information about other characteristics of the log surface. The debarking quality detection and control system 22 also includes profile image data processing and analyzing means in the form of a programmed computer 66, which may be installed in a control room remote from the debarking line, by using an appropriate link between the output of camera 62 and the input of computer 66. From the profile image data, the data processing means generates data indicative of the texture of the log surface, which data is then sent to the data analyzing means which generates resulting data on main parameters related to the debarking quality of the log surface, in terms of detected fiber tear and residual bark, which data can be displayed to the operator.

**[49]** As will be explained later in more detail, the computer 66 can be connected to the controller (PLC) 67 of the debarker 24 using link 70 to receive information on debarker operating parameters that could be used by the programmed computer 66 or displayed to the operator. It has been observed that for a same wood species and when debarking operation parameters are kept constant, some physical characteristics such as log diameter, taper shape and environmental conditions such as log temperature state (frozen or non-frozen) have significant influence over debarking quality. Optionally, and as will be explained below in more detail in view of **Figs. 25** to **27**, the computer software may include a control module using information on fiber loss and residual bark as measured, to provide commands enabling the controller 67 to send through link 72 feedback control signals for the required debarker adjustments providing optimal performance in real time, on the basis of input data related to intrinsic characteristics of each log entering the debarker such as wood species information, mean log diameter, taper shape indicator, and environmentally influenced characteristics such as log surface temperature and moisture content, coming from other sensors or data entry means through link 83. For that purposes, as shown in **Fig. 4A** in view of **Fig. 4**, the debarking line 20 may be provided with a log conveyer 13 located upstream the debarker 24, and having an outfeed end 106 aligned with the travel path axis 33, so that a next log 10' to be debarked is transported toward the front V-shaped press rolls 23, 23' at the infeed end of the debarker 24. Located adjacent the conveyer 13 is a log diameter and length measurement device 17 having its output operatively connected to the controller 67

shown in **Fig. 3** for sending thereto signals indicative of the diameter and length of the log 10' as it is moved past the measuring device 17. Any appropriate non-contact sensor may be used as diameter and log length measurement device 17, such as laser light curtain sensor of type P, 600 mm, supplied from ScanMeg Inc. (Boisbriand, Quebec, Canada), which includes a laser emitter module 19 facing a first side of conveyer 13 so as to direct laser beams toward the travel path axis as intersected by log 10', and a laser detecting module 19' facing the other side of conveyer 13 so as to capture laser light unobstructed by log 10' along its radial dimension. Conveniently, a mean diameter can be derived from measurements of minimum log diameter $D_{MIN}$ and a maximum log diameter $D_{MAX}$ as shown in **Fig. 2,** or can be derived from a plurality of measured diameter values obtained along the log 10' from its leading end to its trailing end. Knowing the preset feed speed of conveyer 13, the log length $L$ may be easily derived from the output signals of detecting module 19', based on detection of the abrupt signal intensity decrease associated with entry of the log leading end through the sensing field of the device 17, and the abrupt signal intensity increase associated with exit of log trailing end out of the device sensing field. Moreover, the spacing between consecutive logs can be measured in a similar way, which spacing measurement may be used by the computer for synchronization purposes. Conveniently, log taper shape indicator may be derived as follows:

$$T = \frac{(D_{MAX} - D_{MIN})}{L} \qquad (1)$$

It should be understood that the log taper shape indicator may also be derived from a plurality of measured diameter values obtained along the log from its leading end to its trailing end. Furthermore, for improving the debarking control as will be explained below in detail, there may be provided a non-contact temperature sensor 63 conveniently located adjacent the conveyer 13 for measuring the temperature at the surface of the next log 10' to be debarked, to send a temperature indicative signal to the controller 67 shown in **Fig. 3**. Any appropriate non-contact temperature sensor such as model MI-D-10-LT-CB3 supplied from Raytek Corp. (Santa Cruz, CA, USA) may be used. The location of conveyer 13 with log diameter and length measuring device 17 and temperature sensor 63 is determined so as to allow sufficient processing time to the computer 66 to perform signal processing and analyzing tasks of a currently debarked log 10, as well as to allow some computation for debarking control purposes as will be explained later in detail. Fiber loss and residual bark levels can be estimated by

comparing log surface areas respectively characterized by fiber loss and residual bark with the log surface considered, by calculating a ratio (or percentage) of the log surface where each of these characteristics has been detected, to the corresponding surface of the log or log section considered. Debarking quality is differently affected at leading and trailing ends of a log as compared with its middle, body section, due to the cutting tool attack under pressure that occurs against the log leading end, and the cutting tool retracting that occurs at the log trailing end. Therefore, according to preset limits defining leading end, trailing end and body sections of the log, a representative portion of the log surface for each of these three log sections can be scanned, to provide corresponding three sets of quality parameter data, from which fiber loss level and residual bark level are estimated for one or more of said sections, or for the whole log surface. For example, for a 4,88 *m* (16 ft) log, both the leading end and trailing end limits can typically be of 0.6 *m* (2 ft), leaving 3.66 *m* (12 ft) for the log body section. Furthermore, a ratio of the optimally debarked surface, *i.e* unaffected by fiber loss or residual bark, to the log surface considered can be easily calculated (optimal debarked surface level in %). Optionally, predetermined weighting factors can be assigned to the sections on the basis of their relative importance in debarking quality detection, which factors are applied to estimate fiber loss level and residual bark level data.

**[50]** Furthermore, fiber tear and residual bark can be visually represented in the form of an image generated from the resulting data, which represents areas of the log or log section surface considered, where fiber loss and residual bark have been respectively detected, as will be explained below in more detail in view of examples.

**[51]** As another alternative, a knowledge-based system such as an expert system fed by detected quality data may be provided in the computer software to assist the operator to make decisions so as to perform a more efficient control of the debarking process.

**[52]** Referring now to **Fig. 7**, the debarking quality detection system 22 is schematically represented with its computer-based hardware and software components. The image acquisition unit is connected to the camera processing unit 59 to receive 3D information and to generate corresponding profile image data, in correspondence with physical sensed location on the inspected log surface. For so doing, the image acquisition unit 65 includes a frame grabber 74 programmed to integrate all necessary functions to associate 3D information with sensed location data for each scanned surface portion as well as all processing functions aiming at standardization of image

specifications. As to the sensed location along *Y* axis on the inspected log surface, although the operation of debarking line 20 is less complex when each log is fed by conveyor 26 to the system 22 at a predetermined, substantially uniform speed along travel path axis 33 which may typically reach 140 linear *m/min*, a varying speed or position/time profile could also be used. The speed or position/time profile operation of the system according to actual speed conditions can be performed by providing means for measuring the actual speed or position/time profile of the moving log, such as a rotary encoder (not shown), or any appropriate non-contact detector (photocell array, laser velocimeter) disposed at a proper location along the travel path axis 33, coupled to conveyer 26 and sending its output through link 69 to the data acquisition unit 65. Alternatively, the data acquisition unit may use the time synchronization approach, as disclosed in co-pending U.S. patent applicant no. 12/693,693 as published under no. US 2010/0188500A1, wherein updating time data is used to perform sensor output data assembling with corresponding sensed location data related to log surface. The image resolution along *X* axis is intrinsic to pixel density of the CCD array provided on the digital camera 62 and to any sub-pixelation algorithm used by the processing unit 59, which resolution along *X* is typically of 0.33 *mm/pixel* with *j*=1280 pixels for a C3-2350 camera according to the settings used. The scanned log being displaced perpendicularly with respect to the CCD array of camera 62 to form a two-dimensional image, the resolution along *Y* axis is determined by the relative distance traversed by the log between two successive image acquisition steps, which resolution along *Y* is typically from about 2 to 2.5 *mm/pixel*. Hence, image resolution along *X* axis can be typically up to six times resolution along *Y* axis, with a number of lines *i* depending on the actual length of the scanned log as well camera settings used. For example, $i \approx 1400$ for a log length of about 2.44 *m*. For image displaying and interpretation purposes, such resolution difference may be compensated by scaling, as will be explained later in view of an example.

**[53]** Prior to its operation, the camera 62 must be optically calibrated according to the supplier specifications to ensure image sensing accuracy, using any appropriate procedure involving reference charts of predetermined image intensity levels, such as a black-white-grey chart. Furthermore, the frame grabber is programmed to apply spatial calibration of the measured 3D information in order to make accurate correspondence between the measured coordinates with respect to the camera reference system (*i.e.* in pixels), and the "world" coordinates (*e.g.* in *mm*) with respect to the physical reference

system 64. For so doing, a calibration approach such as disclosed in U.S. Patent no. 7,429,999 issued to same assignee as of the present invention, or any other appropriate calibration technique, may be programmed in the frame grabber including a proper interface for the operator to carry out calibration tasks. As a convention, a point (*i, j*) in a profile image is associated with a corresponding *z* profile coordinate along *Z* axis, wherein each line *i* of the image represents a *y* coordinate along *Y* axis which is parallel to travel path axis 33, and wherein each column *j* of that same image is associated with a CCD array column at a *x* coordinate along *X* axis.

**[54]** As a result of applying spatial calibration, the measured centroid position coordinates (in pixel) for each column *j* of the camera CCD array is converted into "world" reference coordinates. Conveniently, the *z* coordinates are defined with respect to the central point of the calibration target that has been used in the calibration procedure that preceded operation of the system. Since initially, each coordinate *j* does not correspond to a constant, actual distance on the log surface with respect to *x* axis, image data as expressed with respect to the camera reference system are corrected by converting each *j* coordinate with respect to a physical reference, and each *i* within the same image data is associated to a constant physical distance in transverse direction along *x* axis. Conveniently, the results of spatial calibration may be generated in the form of image data complementary to profile image data and light intensity image data, so that three images associated with the scanned surface are basically created, the first representing *z* coordinate (profile) values of the detected centroids along *Z* axis, the second representing reflected light intensity values corresponding to the centroids, and the third representing *x* transverse coordinate values of the centroids along *X* axis. As mentioned above, a fourth image may be optionally created, representing laser line width at corresponding centroids. The frame grabber is programmed to apply predetermined thresholds for assigning a preset value to pixels generated by the CCD array, which physically cannot correspond to a point of log surface, such as points associated with conveyer parts, and thrown or hanging bark fragments. The preset value, such as 0 or 9999, is chosen to be far from the valid pixel range, extending typically from a positive minimum value to a value between 100 and 1500 for example, to clearly discriminate valid pixels from invalid pixels. It is to be understood that the valid pixel range is influenced by many factors depending from the camera settings and calibration, as well as from the characteristics of the logs under inspection, such as wood species, diameters and lengths.

**[55]** Exemplary resulting images as generated by the frame grabber 74 after scanning of a log are shown in **Figs. 8A** to **8D** with respect to *X* and *Y* axis of the chosen reference system, respectively representing distance unit (*e.g. mm*) and pixel unit, each image containing typically 179.2 x $10^3$ pixels (1280 x 1400). In **Fig. 8A**, light intensity image data are represented, wherein the values of intensity are conveniently indicated through various grey levels extending within the range of measured values. In **Figs. 8B**, **8C** and **8D** respectively, laser line width, profile image and transverse coordinate data are represented according to a same grey level-based format.

**[56]** All said image data as generated by frame grabber 74 are available at an output of the image acquisition unit 65 to be communicated through link 71 to the input of a detection module 76, whose ultimate function consists of generating specific information related to the debarking quality of the surface of the inspected log, namely fiber loss and residual bark, to generate corresponding output data through link 73 to a database 78. First, the profile image data is processed to generate data indicative of the texture of the log surface, and then, the texture data is analyzed to generate the resulting debarking quality data. For so doing, the detection may call for appropriate processing and analyzing subroutines respectively identified at 84 and 86 in **Fig.7**, which subroutines may be in the form of DLL files containing appropriate code for performing the desired functions, which will be described below in detail in view of an example. Although a DLL architecture may be conveniently used as a basis for modules and other components of the computer program, any other architecture such as COM architecture may also be used for a same purpose. All data communication links described above may be implemented into a data communication network to provide data exchange between the database 78, the various modules and components of the detection system 22, as well as the debarker and other sensors/data entry means through controller 67. Such a communication network can further be connected to a plant control computer linked to the controller 67 and allowing an operator to make input parameter settings for the detection module 76.

**[57]** An exemplary implementation of processing and analyzing techniques capable of generating texture data will now be explained in detail. However, it is to be understood that any other appropriate processing and analyzing techniques can be used by the person skilled in the art of image data processing for the same purpose.

**[58]** As a first processing task, a segmentation subroutine is called for performing morphological segmentation of the image data, in order to produce a binary mask image

(referred to below as *"mask_valid"*) wherein a valid pixel is assigned a value of "1", while any invalid pixel value is assigned a null value "0". For so doing, any of the intensity, laser line width, profile image or transverse coordinate image data can be used as starting data, since all of them have been assigned the same preset value for invalid pixels. The resulting binary image is then further processed by erosion using an appropriate structuring element of a few tens of lines by a few columns (*e.g.* matrix of 41 x 1 pixel) to move away from the edges inward, and outside pixels are cleaned to remove noise by applying an appropriate closing structural element of a few lines by a few columns (e.g. matrix of 5 x 5 pixel), to retain in the data only pixel values likely to be associated with a surface within the perimeter defined by the scanned log. Finally, the segmentation is completed by applying a structural element defining a threshold pixel area (*e.g.* 5000 pixel$^2$) to eliminate from the binary image very small blobs of pixels associated with noise, and preserve the larger blobs of valid pixels into the mask. An example of the resulting binary mask image as obtained by segmentation of the image data represented in **Figs. 8A** to **8D** is shown in **Fig. 9**, and its utility for image data analysis will be explained below in detail.

**[59]** Referring again to the resulting image data represented in **Figs. 8A** to **8D**, it can be appreciated that some islands of invalid pixels appear to be surrounded by valid pixels, which islands must be also considered as noise deserving cleaning. Referring now to **Fig. 10A** which is a rotated and enlarged view of the profile image of **Fig. 8C**, some islands of invalid pixels are designated at 88, which could be wrongly detected as texture areas associated with a quality parameter such as fiber loss. Therefore, a second processing task aims at identifying the invalid pixel islands to then perform substitution by estimated valid pixel values through interpolation. For the purpose of this estimation, mean values derived from valid pixels surrounding invalid pixels of interest can be used. For so doing, an appropriate subroutine such as provided in libraries available on the marketplace such as *"imfill"* function of Matlab™ from Mathworks (Natick, MA), or "*MblobReconstruct*" function of MIL 9.0 from Matrox Electronics Systems (Dorval, Canada) can be used. The result of pixel interpolation task as performed on the profile image of **Fig. 10A** is shown in the cleaned image of **Fig. 10B**, wherein values of invalid pixel islands have been substituted by valid pixel values.

**[60]** It can be appreciated from **Figs. 8A** to **8D**, **9** and **10A** and **10B**, that at the represented stages of processing, image data do not reflect the actual proportion of an inspected log 10 as shown in **Fig. 3**. As mentioned above, such image deformation is the

result of higher image resolution along *X* axis as compared with image resolution along *Y* axis. From the resulting data, it is desirable to generate an image representing areas of the log surface respectively characterized by the detected fiber loss and residual bark. As mentioned above, image data measurement is performed with respect to orthogonal reference axis *X* and *Y* characterized by different resolution levels, which can be compensated by proper scaling of the resulting data, to provide a more realistic image displaying and to facilitate image interpretation by the operator. The scaling task may be performed by interpolation, whereby both scales along *X* and *Y* axis are modified according to a desired ratio, substantially without significant data alteration. For so doing, bicubic, nearest-neighbor or bilinear interpolation may be applied by calling an appropriate subroutine such as "*imresize*" function of Matlab™.

**[61]** The more realistic result of scaling task as performed on the cleaned profile image of **Fig. 10B** using calling factors of 0.56 and 4 respectively for *X* axis and *Y* axis can be seen in the processed image of **Fig. 11C.** Properly scaled images derived from previously cleaned intensity and line width image data as referred to above in view of **Figs. 8A** and **8B** are shown in **Figs. 11A** and **11B**. Although image scaling is performed following the cleaning task in the present exemplary implementation, it could be performed either at an earlier or later stage of processing.

**[62]** A next processing task aims at flattening the profile image data to compensate for the generally curved shape of the log surface, which could otherwise adversely affect the measurement accuracy of the quality parameters to be detected. More specifically, flattening has the effect of assigning a substantially same weight to all surface areas covered by the sensing field of the profile measurement unit, regardless of their orientation within the scanning plane. The flattened profile image data (*ima_Z_f*) can be performed by applying to the scaled profile image data (*ima_Z*) a high-pass spatial frequency filter, conveniently obtained with subtraction of low-frequency data content, by calling an appropriate subroutine such as "*imfilter*" function of Matlab™ making use of a Gaussian-type convoluting kernel of 32 pixel dimension with 6 as standard deviation, according to the following command:

$$Ima_Z_f = imaZ - imfilter\ (ima_Z, fspecial\ ('gaussian',\ 32,\ 6)) \qquad (2)$$

**[63]** The result of the flattening task as performed on the scaled profile image of **Fig. 11C** can be seen in the processed image of **Fig. 12.** It can be seen that profile data

associated with the log surface as generally indicated at 90 has a collateral effect of bringing out side pixels as generally designated at 92, associated with high frequency transition out of the log perimeter. These outside pixels will be discarded for analysis purposes using the binary mask image *"mask_valid"* referred to above, as will be explained below in more detail. As an alternative, the profile image data flattening can be performed by applying to the scaled profile image any appropriate curve-fitting algorithm known by the person skilled in the art of image data processing.

**[64]** A next processing step aims at extracting the texture characterizing the profile image data. For so doing, a technique of edge detection can been applied, which consists of detecting vertical and horizontal edges of the profile image data with respect to the substantially longitudinal axis of the log to obtain texture data. According to the convention used hereinabove using reference system 64, horizontal and vertical edges may be respectively associated with axis *Y* and axis *X* shown in **Fig. 12**. The detected horizontal and vertical edge are generated into the form of respective images (*zhe* and *zve*) on the basis of a Sobel convolution kernel, while reducing the dimension of the flattened image (*ima_Z_f*) by a predetermined factor (e.g. 0.5) to improve processing speed and reduce sensibility to noise, by calling an appropriate subroutine such as *"resize"* function of Matlab™ according to the following command:

$$zve = resize(ima_Z_f;\ 0{,}5) \circledast \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & 0-2 \\ 1 & 0 & -1 \end{bmatrix} \tag{3}$$

$$zhe = resize(ima_Z_f;\ 0{,}5) \circledast \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{4}$$

**[65]** The result of the edge detection task as performed on the flattened profile image of **Fig. 12** for horizontal and vertical directions can be seen in the edge detected images shown in **Fig. 13A** and **13B**.

**[66]** According to a first texture analysis approach, the detected vertical and horizontal edges as part of texture data are directly compared to provide an indication of the relative ratio of fiber loss to residual bark. As a result of that direct comparative approach, a quality indicator may be obtained. For example, a useful quality indicator $q$ can be obtained from the following image:

$$Q = arctan\frac{zhe}{zve} \quad (5)$$

**[67]** For example, a mean value of image Q for the whole log surface or for a section thereof may be assigned to the debarking quality indicator *q* for each log scanned, to produce historical quality data, the utility of which will now be explained in the context of an example in view of **Figs. 14** and **18**.

**[68]** Referring to **Fig. 14**, there is shown a first example of a main screen as generated by the computer program, so that the resulting data regarding debarker performance may be directly viewed by the operator on display 80 of **Fig. 7**. According to this exemplary implementation, the detection results are made available to the operator through several displaying means, namely a first graph designated at 85 showing evolution of quality indicator *q* as the selected debarking quality parameter, with respect to the last period of production time (3 hours) as also selected by the operator, and a first analog dial 87 showing the current quality indicator value in real time. A second graph 89 is displayed for presenting evolution of a selected operating parameter, which is the mean pressure (*kPa* or *psi*) applied to the cutting tools with respect to time in the shown computer screen. A second analog dial 91 for displaying the current tool pressure value in real time is also provided, which ranges from 172 to 379 *kPa* (25 to 55 psi) in the example shown. Other operating parameters such as mean log surface temperature, log conveying speed, mean log diameter or log moisture content could also be displayed. Four scrolling lists at 93, 95, 97 and 99 enable the operator to select displaying criteria, namely log diameter range, species under production, log section and time period. On the first graph 85, in addition to the quality indicator curve 101, three lines are displayed designated at 103, 105 and 107. The central line 103 corresponds to the target for the desired quality parameter value as predetermined and entered by the operator, which has been set at *q*=58.4 in the example shown. It is desirable to assign a value to the target according to known log characteristics, and especially in consideration to the diameter range of the logs to be debarked. In practice, an optimal debarking quality implies a compromise between fiber loss and residual bark at the debarked surface of the log, and the operating conditions at which said compromise may be reached are dependent on the characteristics of the logs fed to the debarker, such as species and dryness state (moisture content). Generally, an increase of fiber loss caused by a more aggressive angle for the cutting tools may be compensated by a corresponding

decrease in pressure applied to the tools. However, for a given small diameter range, *e.g.* < 7.62 *cm (3 in)*, logs may exhibit such a variation of dryness state so that some debarked logs present preponderant fiber loss while some others present preponderant residual bark, which result could be observed on the basis of standard deviation computing. Moreover, for a same debarking quality as qualitatively observed by the operator for two batches of logs characterized by distinct diameter ranges, the corresponding detected quality indicator values may be different, and therefore, the respective target values assigned by the operator could also be different. The lines 105 and 107 respectively correspond to predetermined upper and lower limits for the quality indicator, which may be entered by the operator in the form of a maximum deviation below and above the preset target, defining a range of acceptable debarking quality, which maximum deviation has been given a value of 1.2 in the example shown. Generally, the upper limit for the quality indicator $q$ can be interpreted as a debarking state where an unacceptable level of residual bark onto the considered log surface is likely to be observed, while the lower limit for the quality indicator $q$ can be interpreted as a debarking state where an unacceptable level of fiber loss onto the considered log surface is likely to be observed. Generally, the maximum deviation value is chosen by the operator on the basis of detection results corresponding to the body section of the logs, to provide a better fit with observations that can be made by the operator upon operation of the debarker. In practice, a variation in a characteristic of the logs fed to the debarking line, such as dryness state (*e.g.* fresh green log versus dry log) may cause a corresponding fluctuation of the quality indicator $q$. In cases where the current quality indicator value falls outside the preset range of acceptable debarking quality, or a trend toward such eventuality is observed, the operator may perform adjustment of a selected debarker operation parameter, such as mean pressure (*kPa* or *psi*) applied to the cutting tools, in order to have the current quality indicator value be maintained within the acceptable range as debarking is going on. Optionally, the acceptable range may be segmented in sub-ranges indicated on the scale of the first analog dial, wherein an optimal sub-range 109 extends from $q$=57.8 to $q$=59, below and above which extend lower quality (though still acceptable) sub-ranges 102 and 102' respectively from $q$=57.2 to 57.8 and from $q$=59.0 to 59.6 in example shown, and the inacceptable quality ranges beyond the sub-ranges 102 and 102' are indicated at 104 (excessive fiber loss) and 104' (excessive residual bark). Apart from the option of selecting the log section or sections to be considered for result displaying purposes, the operator may also determine the

number of logs (log population, typically between 50 to 300 logs) involved in the calculation of the mean quality indicator *q*, conveniently based on a moving average relative to the specific time considered. A practical example making use of the debarking quality parameter monitoring will now be discussed in view of the graph shown in **Fig. 18**, which presents the values of debarking quality indicator experimentally obtained for 75,000 logs with respect to their corresponding log diameter ranges with percentage, as well as to mean pressure values (*psi*) applied to the debarker tools as set by the operator upon monitoring of debarking quality indicator values. Generally, logs of relatively small diameter may be harder to debark, as can be seen from the relatively high value of quality indicator obtained for the smallest diameter range between 2.54 to 7.62 *cm* (1.0 to 3.0 *in*), which reflects preponderance of residual bark, even though the operator have adjusted the debarker accordingly by settling a more aggressive angle for the cutting tools, while choosing to apply a relatively low pressure on the debarking tools to compensate for fiber loss caused by the more aggressive angle used. However, the observed quality indicator may still be within the acceptable quality indicator range centered to the target value as set by the operator for the log diameter range being processed. For the two following diameter ranges extending respectfully between 7.62 to 8.89 *cm* (3.0 to 3.5 *in*) and 8.89 to 10.16 *cm* (3.5 to 4 *in*), in consideration of less residual bark on the logs, the operator may have reduced the tool angle toward less aggressive values, while keeping the increase of pressure on the debarking tools, in such a manner that debarking quality indicator observed for these log diameter ranges decreases, while remaining within an acceptable quality indicator range centered to the corresponding target value as set by the operator. For the following log diameter ranges, it can be appreciated that the values of debarking quality indicator increases with log diameter range values, as the operator applies increasing pressure on the debarking tools, in order to maintain the quality indicator value within the acceptable range as set for the diameter range being processed, considering that the tool angle is still adjusted toward less aggressive values.

**[69]** For the purpose of an alternate texture analysis approach, the detected vertical and horizontal edges may be further processed to obtain texture data as an indication of log surface roughness, by extracting through comparison of the detected edge images, the maximum absolute values to form a single image (*ima_rug*) representing roughness of the log surface. Such an image can be obtained using the following Matlab™ command:

$$ima_rug = max(|zhe|, |zve|) \quad (6)$$

**[70]** A roughness indicative image that can be obtained from the edge detected images or **Fig. 13A** and **13B** is shown in **Fig. 19**.

**[71]** A first series of image analysis tasks according to the present implementation will now be described, whereby the parameters related to the debarking quality of the log surface can be derived from the texture data. In order to provide some immunity to local discontinuity of texture, image analysis is preceded by averaging the texture using a filter of an appropriate dimension (*e.g. k = [11,11]*) such as provided by the "*imfilter*" function of Matlab™ according to the following command:

$$Ima_rug_f = imfilter\ (ima_rug,\ ones(k)/(k(1)*k(2)));\quad (7)$$

**[72]** A first image analysis task aims at identifying the portion of the filtered texture data which can be associated with fiber loss at the surface of the log to generate a corresponding mask (*mask_loss*) using predetermined thresholds depending upon the relative importance of fiber loss characterizing the surface of the scanned log, the resulting range texture data values as a result of measurement and processing, and the chosen computation mode (floating point or integer). It is to be understood that the thresholds can be readily selected though preliminary measurements with log samples presenting various debarking states, for example in view of predetermined standard quality grades for the debarked logs. In the present implementation, high and low fiber loss minimum threshold have been considered to derive a combined detection, wherein the presence of at least one high pixel value within an area generally characterized by low fiber loss will favor high fiber loss detection, using the *"imreconstruct"* function of Matlab™ according to the following test:

$$mask_loss = imreconstruct\ (mask_high_loss,\ mask_low_loss);\quad (8)$$

wherein: $mask_high_loss = ima_rough_f > T_h;$

$mask_low_loss = ima_rough_f > T_l;$

**[73]** As a result of preliminary measurement with log samples, values of $T_h$=3 *and* $T_l$ =1.5 have been found appropriate.

**[74]** Moreover, a further roughness threshold has been considered in the generation of a further mask aimed at excluding from fiber loss detection surface areas

characterized by relatively smooth log surface such as oxidized or burned areas which can be considered like well debarked wood surface, which surface areas may also include dark areas that could otherwise be mistaken with bark, as will be explained later in more detail. Conveniently, the excluded surface areas are those whose detected roughness value is lower than a predetermined roughness threshold. In the present implementation, a corresponding mask (*mask_smooth*) may be obtained using an appropriate opening structural element of square dimension (*e.g.* 11x11) by calling the *"imopen"* function of Matlab™ according to the following test:

$$mask_smooth = imopen(ima_rough, strel('square', 11)) < 0.1 \ \& \ mask_valid; \quad (9)$$

wherein the outside pixels are excluded from analysis with the use of the predetermined *mask_valid* mask. In the latter test, *ima_rough_f* could also be used in replacement of *ima_rough*. It is to be understood that the exclusion task could be performed later, in a same manner as explained below in the case of fiber loss detection.

**[75]** The resulting *mask_loss* and *mask_smooth* masks obtained from the roughness indicative image of **Fig. 19** are shown in **Fig. 20A** and **20B**.

**[76]** As mentioned above, the reflected light intensity image data can be considered through a further analysis, by comparing with a predetermined intensity threshold the reflected light intensity data, to provide a further indication of the residual bark in addition to the resulting quality indicative information based on texture data as described above. For the purpose of this further residual bark detection task, it can be appropriate to first apply a correction to the intensity of image pixels corresponding to the lateral portions of the scanned log, which appear darker as compared with image pixels corresponding to central areas of the log, due to log curvature effect on lighting which is more marked at image edges.

**[77]** A convenient way to perform that correction consists of using a ramp function applying a factor of a first value (*e.g.* $f_1=1$) to the pixels of the central areas, and a factor of a greater value (*e.g.* $f_2=2$) to the pixels of the image edges. In the present implementation, a corresponding corrected intensity image (*ima_int_c*) may be obtained from the scaled intensity image *(ima_int)* using an appropriate ramp (*calibre*) in integer 16 bit mode by calling the *"uint16"* function of Matlab™ according to the following command:

$$ima_int_c = uint16(double(ima_int) .* calibre); \quad (10)$$

**[78]** The result of this correction task as performed on the scaled intensity image of **Fig. 11A** which is reproduced in **Fig. 21A**, can be appreciated by comparison with corrected image shown in **Fig. 21B.** According to an alternate but more complex approach, it would be possible to obtain a better fitting correction by calculating correction factors specific to each pixel or small pixel area using related angular information that could be derived from profile image data. Then, the further task of residual bark detection aims at identifying the portion of the corrected intensity image data which can be associated with bark at the surface of the log to generate a corresponding mask (*mask_bark*) using a predetermined threshold, depending upon the wood species involved, the resulting intensity image data values as a result of measurement and processing, and the chosen computation mode (floating point or integer). Here again, it is to be understood that the thresholds can be readily selected though preliminary measurements with log samples presenting various debarking states, for example in view of predetermined standard quality grades for the debarked logs. The corresponding mask (*mask_bark*) based on the predetermined threshold (*thresh_int*) may be obtained with appropriate filtering, such as the median filter (*medfilt2*) along with appropriate opening structural element of square dimension (*e.g.* 5x5) used in the present implementation by calling the *"imopen"* function of Matlab™ according to the following test:

$$mask_bark = imopen(ima_int_f<thresh_int \;\&\; mask_valid, strel('square', 5)); \quad (11)$$

wherein: $ima_int_f = medfilt2(ima_int_c,[3,3]);$

**[79]** and wherein the outside pixels are excluded from analysis with the use of the predetermined *mask_valid* mask. The result of thresholding as performed on the corrected intensity image of **Fig. 21B** can be appreciated in the filtered image shown in **Fig. 22.**

**[80]** Experiences based on preliminary measurements with log samples presenting various debarking states have shown that fiber loss can be detected with the *mask_loss* mask on areas surrounding bark zones, where no fiber loss is actually present, due to the surface irregularities characterizing transitions between bark and surrounding, well debarked surface. In order to prevent or at least limit such adverse effect, it is desirable

to enlarge to some extent the detected bark zones by appropriate image filtering, such as through the application of structural elements for performing, from the *mask_bark* mask, closing (*imclose*), opening (*bwareaopen*) and dilation (*imdilate*) operations of appropriate dimension as used in the present implementation by calling from Matlab™ the following command:

$$mask_bark_enl = imdilate\ (bark_enl_seed,\ strel('square',\ 25)); \qquad (12)$$

wherein: $bark_enl_seed = bwareaopen(mask_bark_c,\ 40*40);$ and

$$mask_bark_c = imclose(mask_bark,\ strel('square',\ 15));$$

**[81]** As will be described below in more detail, the obtained *mask_bark_enl* mask indicating enlarged bark areas can then be subtracted from the *mask_loss* mask to remove the corresponding detected fiber loss areas, as illustrated with reference to the example of **Figs. 23A** to **23C**, the enlarged bark areas 94 as indicated by the *mask_bark_enl* mask of **Fig. 23B** have been removed from *mask_loss* mask of **Fig. 23A** to obtain the corrected image of **Fig. 23C** showing corresponding corrected areas 94'.

**[82]** Then, the resulting quality-related parameter data in terms of fiber loss, bark as well as smooth areas obtained from the analysis tasks as described above can be combined on the basis of a given detection priority order, so that any area of the scanned log surface is assigned a single parameter quality information, especially for displaying purpose in the form of a combined image. Conveniently, an identification code from a list of possible codes shown in Table 1 is assigned to the various areas associated with the resulting detection.

TABLE 1

| Parameter/Characteristic | Code |
|---|---|
| 1. outside log | 0 |
| 2. well debarked | 1 |
| 3. smooth | 2 |
| 4. bark | 3 |
| 5. fiber loss | 4 |

**[83]** In the present implementation, smooth areas where neither fiber loss nor bark should be detected are considered first, to assign a corresponding identification code

"2", while excluding outside pixels as previously identified (mask_valid) and with an appropriate conversion in integer 8 bit mode, according to the following Matlab™ command:

$$detect(detect==1 \ \& \ mask_smooth) = 2; \quad (13)$$

wherein: $detect = uint8(mask_valid);$

**[84]** Then, priority is given to fiber loss detection unless enlarged bark areas are involved, to assign a corresponding identification code "4", according to the following Matlab™ command:

$$detect(detect==1 \ \& \ mask_loss \ \& \sim mask_bark_enl) = 4; \quad (14)$$

followed by bark code assignment "3" performed according to the following Matlab™ command:

$$detect(mask_bark_c ==1 \ \& \sim mask_smooth) = 3; \quad (15)$$

**[85]** In the latter command, *mask_bark* could also be used in replacement of *mask_bark_c*. Finally, the pixels outside log surface are given the corresponding "*0*" code on the basis of the binary mask image *"mask_valid"* referred to above, according to the following Matlab™ command:

$$detect(\sim stat_mask) = 0 \quad (16)$$

**[86]** An example of resulting quality-related parameter data that have been combined in a single image is given in **Fig. 24**, wherein fiber loss, bark and smooth areas are indicated at 96, 98 and 100, respectively, for example though different visual texture or colors.

**[87]** Turning back to **Fig.7**, the resulting data may be directly viewed by the operator on display 80, in the form of images representing areas of the log surface characterized by the detected parameters, and the operator can enter displaying commands to the detection module through keyboard 81 or any other appropriate data entry means. Optionally, information stored in the database 78 can be read out through link 75 by a control module 79 programmed to allow the operator to have access to historical quality data in the form of report 82, either for each log or for any group of logs corresponding to one or more selected criteria such as diameter range, wood species, scanned log

section (leading end, body, trailing end), and trend calculations for a selected period of operation time can be performed by the control module 79. Here again, apart from the option of selecting the log section or sections to be considered for result displaying purposes, the operator may also determine the number of logs (log population, typically between 50 to 300 logs) involved in the calculation of mean values for each quality-related parameter, conveniently based on a moving average relative to the specific time considered. Turning to **Fig. 15,** there is represented a second example of main screen generated by the computer program, in which the first graph 85 shows evolution of fiber loss level (%) as the selected debarking quality parameter, with respect to the whole period of production time (4 days) as also selected by the operator. According to this second example, the second graph 89 is displayed for presenting evolution of mean log surface temperature as the selected operating parameter, with respect to time.

**[88]** Turning to **Fig. 16**, there is represented a third example of main screen showing generated by the computer program, in which the first graph 85 shows evolution of residual bark level (%) as the selected debarking quality parameter, with respect to the whole period of production time (4 days) as also selected by the operator. As in the second example, the second graph 89 is displayed for presenting evolution of mean log surface temperature as the selected operating parameter, with respect to time. Turning to **Fig. 17**, there is represented a fourth example of main screen as generated by the computer program, in which the first graph 85 shows evolution of optimal debarked surface level (%) as the selected debarking quality parameter, with respect to the whole period of production time (4 days) as also selected by the operator. As in the second and third examples, the second graph 89 is displayed for presenting evolution of mean log surface temperature as the selected operating parameter, with respect to time.

**[89]** Turning back to **Fig. 7**, warning/alarm signals according to operator's settings can be generated by the control module 79 whenever the value of any quality parameter exceeds preset thresholds. Furthermore, from the controller 67 and through link 70, the detection module 76 may cause the database 78 to automatically store debarker input parameter data including assigned log identification number, log length, selected log debarking diameter range, mean log diameter (unbarked), log surface temperature, as well as debarker operation parameters such as mean pressure applied to the cutting tools, angular position of cutting tools, ring rotational speed and log feed speed, for reporting purposes to the operator. The log identification number being associated with profile image data, texture indicative data, quality parameter data and other information

corresponding to each scanned log, it allows the operator to retrieve from the database 78 any desired data related to a specific one or a set of scanned logs, such as fiber loss level, residual bark level and optimal debarked surface level, for whole log or section thereof.

**[90]** All useful parameters can be made accessible for monitoring and editing by the operator through display 80 and keyboard 81 while the debarking line is in operation, via dialog boxes provided by a proper interface as part of detection module 76. The logs to be inspected can be fed to the detection system 22 in a synchronous mode, so that camera output data related to a predetermined number of scanned logs are stored in the acquisition unit memory until processing of these data by frame grabber 74 is completed. It should be understood that an asynchronous mode of operation could also be applied. Also, the debarking quality data may be used by the control module 79 to assign a quality grade to each debarked log, on the basis of predetermined classification thresholds for the debarking quality parameters that can be established in view of the characteristics of the logs entering the debarker such as diameter, wood species, temperature and moisture content. Furthermore, a marking station (not shown) connected to controller 67 may be provided to apply log identification number and/or quality grade information onto each log.

**[91]** Optionally, on the basis of input and quality output parameter data, the control module may integrate a mathematical model enabling a real-time optimization of the debarking process, allowing the operator to make fast decisions in view of one or more events such as: debarker failure detection due to mechanical break; premature or misadjustment of a component; resulting effect on debarking quality of a modification or adjustment made to a debarker component related to an operating parameter; detection of raw material variation influencing the debarking quality; or any other change of equipment maintenance monitoring parameter. The mathematical model could be knowledge-based such as an expert system model, fed by the output parameter quality data as generated by detection module, as well as statistical analysis, mathematical modelization and other useful complementary analysis results, which expert system model would establish and apply rules for processing subjective and objective events to make predictive quality assessment and recommend a solution to the operator. Furthermore, the control module 79 optionally makes use of debarking quality information on fiber loss and residual bark as measured to send through link 77 commands enabling the controller 67 to send through link 72 feedback control signals for

the required debarker adjustments providing optimal performance in real time. For so doing, in the same manner as explained above, the profile image data is processed to generate data indicative of the surface texture of a debarked log, which data is analyzed to generate resulting data on the debarking quality-related parameters characterizing the debarked surface, i. e. fiber loss and residual bark. Then, the resulting data is used to control the debarking process applied to a further log, by generating control data related to a plurality of input operating parameters of the debarking process, on the basis of predetermined control setpoint data associated with the quality-related parameters. In the example of rotary ring debarker as described above, the input operating parameters may be the mean pressure applied to cutting tools, log feed speed, ring rotational speed, or any combination thereof. A same control strategy adapted to other type of debarker may be implemented by selecting appropriate input operating parameters.

**[92]** In order to experimentally verify the reliability of debarking quality indicative information provided by the method and system as described above, three trials were performed using a ring debarker operating in a sawmill respectively according to three distinct debarking states characterizing respective samples of processed logs, namely: optimal debarking, with remaining bark, and with fiber loss. Each trial was to check the consistency of the debarking quality-related parameter data resulting from the log surface texture analysis with respect to actual debarking quality that may be appraised through visual inspection by a skilled operator. To avoid any bias due to log diameter variations, the logs of 2.745 *m* (9 feet) long subjected to the trials were selected from a typical diameter range of 17.8 to 20.3 *cm* (7 to 8 *in*), and only data associated to the body section, *i.e.* central 1.525 *m* (5 feet), of each debarked log were considered, to avoid debarking quality disturbances due to different cutting tool attack conditions that prevail at log leading and trailing ends. A log population of at least 300 logs of a common species such as black spruce was considered for the calculation (moving average) of mean values for each quality-related parameter.

**[93]** For each debarking state, a sample of logs was visually inspected by the skilled operator in order to adjust the operation parameters of the ring debarker, especially pressure applied to the cutting tool, according to the desired debarking quality level, while directing a particular attention to distinguish inner bark characterized by pinkish white color, from black spruce sapwood characterized by yellowish color. For the purpose of classification in the first, optimal debarking state, few mils (0.0254 *mm*) of sapwood fiber loss in rare places on the log body section with a very small level of bark

on less than 5-10% of the surface was tolerated. For the purpose of classification in the second state characterized by remaining bark, the pressure on cutting tools were gradually decreased, and the level where a positive pressure adjustment would be required to restore acceptable debarking quality was used as the decision criterion by the classification operator. Roughly, 5-10% of the log body surface covered by inner bark while presenting very small bark spots in rare places, was tolerated. As to the third, fiber loss state of debarking, the pressure on cutting tools were gradually increased in order to eliminate all bark from the log body surface, and the level where a negative pressure adjustment would be required to restore acceptable debarking quality was used a the decision criterion by the classification operator. Then, from the sampled logs, those belonging to the chosen diameter range were identified and subjected to the proposed debarking quality measurement method using the system as described above. Table 2 presents results of the trials in terms of remaining bark and fiber loss according to the three debarking states considered.

TABLE 2

| | | DEBARKING STATE | | | NUMBER OF LOGS INSPECTED |
|---|---|---|---|---|---|
| | | Remaining bark | Optimal debarking | Fiber loss | |
| Remaining bark (%) | Mean (%) | 16.9 | 6.1 | 1.5 | 640 |
| | Standard deviation (%) | 14.3 | 7.8 | 2.9 | |
| | 1% LSD factor (%) (highly significant) | 01.1 | | | |
| | 5% LSD factor (%) (significant) | 0.9 | | | |
| | Standard error | 1 | 0.6 | 0.2 | |
| Fiber loss (%) | Mean (%) | 4.6 | 5 | 6.1 | 640 |
| | Standard deviation (%) | 4.3 | 4.9 | 5.3 | |
| | 1% LSD factor (%) (highly significant) | 0.5 | | | |
| | 5 % LSD factor (%) (highly significant) | 0.4 | | | |
| | Standard error | 0.3 | 0.3 | 0.4 | |

**[94]** According to the results of the trials, the estimated mean remaining bark was 16.9 % for the remaining bark state, 6.1 % for the optimal debarking state and 1.5 % for the fiber loss state. The estimated mean fiber loss was 4.6 % for the remaining bark state, 5 % for the optimal debarking state and 6.1 % for the fiber loss state. Therefore, the estimated mean remaining bark has varied from 1 to 20 %, while the estimated mean fiber loss has varied from 4 to 7 %. Table 1 also presents the results of an analysis of variance performed on the data associated with the debarking states, with calculated *F* values of 8.1 for fiber loss and 334.8 for remaining bark, indicating significant differences between the various trials. In order to identify which trials are different one another, the

Least Significant Difference (LSD) was used. For a highly significant trial, LSD is 01.1 % for the remaining bark remaining trials, while LSD is 0.9 % for a significant trial. The difference between the estimated mean values having largely exceeded 01.1 %, the differences between the trials are thus highly significant, and therefore, it is clear that the remaining bark detection is correctly performed. For a highly significant trial, LSD is 0.5 % for the fiber loss trials, while LSD is 0.4 % for a significant trial. The remaining bark-optimal debarking trial is borderline for being highly significant, whereas the optimal debarking-fiber loss is highly significantly different. A significant difference between the remaining bark-optimal debarking trials was confirmed through visual inspection by the classification operator on a higher number of logs. To observe the difference between the trials and corroborate the results, the standard error was added and subtracted from the estimated mean values to test for overlapping (If an overlap between trials is observed, no difference can be inferred). As observed through LSD analysis, a difference was found between some of the trials, but not for all of them. Therefore, one can conclude that, although the weak difference observed between the remaining bark-optimal debarking trials, there is clearly a significant difference between the trials as a whole, which means that the proposed method is capable of differentiate the fiber loss between the remaining bark and optimal debarking states, and the same method is generally capable of providing a reliable indication of remaining bark and fiber loss in the context of all debarking states considered in the trials. In view of the results of statistical analysis, the proposed method has proved to be useful for detecting the quality of debarking at the surface of wooden logs.

**[95]** Referring now to **Fig. 25**, there is shown a schematic block diagram of a model predictive control (MPC) structure of control module 79 as programmed in the computer, which module 79 is adapted to carry out an optimized control of the debarking process using the proposed strategy. The MPC structure of control module 79 may use a predictive model 110 of the debarking process based on relations involving the input operating parameters (*e.g.* mean pressure applied to cutting tools, log feed speed, ring rotational speed) and the resulting data on quality-related parameters (*i.e.* fiber loss and residual bark) for generating, at a first model output 112 shown in **Fig. 25**, predicted data on the debarking quality-related parameters, which data are represented by the output quality vector $\tilde{Y}(k+1)$ associated with the further log to be debarked as designated $k+1$. The predicted data is then compared at 111 with the control setpoint data $Y_{sp}$ to estimate predicted-setpoint error data represented by error vector $\hat{e}_{sp}$. The MPC structure of

control module 79 further makes use of an optimizer 114 programmed for generating, at optimizer output 116, the control data represented by current control vector *u(k)* associated with the currently debarked log as designated *k,* which control data minimize predicted-setpoint error data $\hat{e}_{sp}$ in accordance with a debarking performance criterion, such as debarking yield maximization, represented as $J_0$ in **Fig. 25**, and predetermined debarking process constraints imposed on one or more of the refining process input operating parameters. The control data *u(k)* is fed through link 77 to the controller 67, causing the latter to send through link 72 feedback control signals for the required debarking process adjustments providing optimal performance in real time. The control data is concurrently fed via line 116' at an input of the predictive model 110 for updating thereof. According to the example shown in **Fig. 25**, from the relations on which model 110 is based, the latter is capable of generating at second output 113 thereof an estimation of prior resulting data on the quality-related parameters, which data are represented by the output quality vector $\tilde{Y}(k-1)$ associated with a prior debarked log as designated *k-1*. The estimation vector $\tilde{Y}(k-1)$ is then compared at 115 with the resulting data *Y(k-1)* coming via link 75 from database 78 as generated by the detection module 76 in the manner described above in view of **Fig. 7**, to obtain estimated-resulting error data represented by error vector $\hat{e}$. The predictive model 110 may be built with any appropriate modeling platform such as a neural network, a multivariate linear model, a static gain matrix or a fuzzy logic model. An example of predictive model based on a feed-forward neural network structure is represented in **Fig. 26**, which model has 1 hidden layer with 12 nodes, 5 operating parameter inputs as defined above (*P*, *V*, $\omega$, *D*, *T*) and 2 quality-related parameter outputs (*F*, *B*) in the example shown. The first step of modeling consisted of performing mill trials to establish a model training file on the basis of the well known design of experiments theory, according to the various debarking operation parameters. Using full factorial designs, 25 tests were performed, involving log dimensional (*i.e.* log mean diameter *D*) and temperature measurements before debarking and log inspection after debarking using the three-dimensional profile measuring unit to generate profile image data and reflected light intensity image data from which the quality-related parameters, *i.e.* fiber loss *F* (%) and residual bark *B (%)*, were estimated. The model was trained using the fast training function "*trainlm*" of Matlab™, which function updates weight and bias using the Levenberg-Marquardt back-propagation training algorithm.

**[96]** Optionally, a plurality of models respectively adapted to a plurality of input parameter ranges may be built, allowing a selection of the most appropriate model according to actual measurements made on logs to be debarked. For example, the predictive model may be selected according to a mean log diameter measurement, from a plurality of models adapted to respective ranges of log diameter. According to an improvement of this approach, for each range of log diameter, there may be a plurality of models further adapted to respective ranges of log surface temperature (*e.g.* frozen and non-frozen), so that the predictive model may be selected according to a log surface temperature measurement. Another approach would consist of selecting the predictive model according to the log surface temperature measurement only, from a plurality of models adapted to respective ranges of log surface temperature, regardless log diameter.

**[97]** The predictive model being initially built on actual experimental debarking results, the continuous operation of the debarking process is influenced by disturbances designated by *d* in **Fig. 25**, such as cutting tool tip wear, log shape and dimension variations from one log to another, variations of environmental and storage conditions etc., which may cause some model degradation. For this reason, online identification of model may improve its accuracy. For that purpose, the MPC structure of control module 79 further makes use of an online identificator 118 receiving estimated-resulting error data $\hat{e}$ via line 117 and programmed for adjusting the relations of the predictive model to minimize error data $\hat{e}$, as indicated by output line 120 linked to model 110. Although it may be sufficient to perform the adjustment on an intermittent basis as schematically represented by switching operation 122, a continuous online identification may also be implemented. For a given online identification horizon $H_I$, $n_I$ points are used to minimize the error $\hat{e}$ between the model output quality vector $\tilde{Y}(k-1)$ and resulting data $Y(k-1)$ on the quality-related parameters obtained by online measurements, by adjusting the coefficients $K_I$, which are obtained by minimizing the following performance index:

$$J_I = \min_K \sum_{j=1}^{n_I} \hat{e}^2 = \min_K \sum_{j=1}^{n_I} (y - \hat{y})^2 \tag{17}$$

and the constraints on coefficients $K_I$ can be expressed as:

$$\forall_I \in \{1,2,\cdots m\}, \quad K_I \min < K_I < K_I \max \tag{18}$$

wherein $m$ is the number of coefficients in the model matrix. The Sequential Quadratic Programming (SQP) algorithm can be used for identifying the new coefficients of parameters (variables), as part of a weighting matrix of the model, in order to minimize the error $\hat{e}$. The model coefficients $K_l$ are updated in each horizon of online identification.

**[98]** According to the present example, the relations of the predictive model further involves at least one log dimensional parameter, such as mean log diameter and/or log taper shape indicator that have been described above with reference to **Figs. 2** and **4A**, measured with respect to a further log 10' to be debarked, at la location upstream of the debarker along the log conveying path as shown in **Fig. 4A**, the measured value being fed to the model 110 through the controller 67 via links 83, 70, 73 and 75' in the example shown in **Fig. 25**. The proposed MPC structure as described above, involving dimensional measurement before debarking, online quality measurement after debarking as well as control optimization, aims at improving debarked log quality by defining control data related to the chosen input operating parameter(s), in order to comply with the predefined performance criterion, e.g. debarking yield ($D_r$ =100-(B+F)%) maximization, while approaching respective setpoints of fiber loss and residual bark on the debarked log surface. In the example of **Fig. 25**, for a prediction horizon $H_P$ chosen as the time taken for debarking a log, $n_P$ points are considered, and the performance index $J_O$ is defined to find the optimal debarking parameters, $P$, $V$ and $\omega$ which minimize error $\hat{e}_{sp}$, and at the same time to keep a maximum high debarking yield $D_r$:

$$J_O = \max_R D_r + \min_R \sum_{j=1}^{n_P} \hat{e}_{SP}{}^2 = \max_R D_r + \min_R \sum_{j=1}^{n_P} (y_{SP} - \hat{y})^2 \qquad (19)$$

and the constraints on debarking parameters $R_r$ can be expressed as:

$$\forall_r \in \{1,2,\cdots q\}, \quad R_r \min < R_r < R_r \max \qquad (20)$$

wherein $q$ is the number of parameters (variables), the constraints on $R_r$ ensure the optimization results are within available control ranges. Besides the constraints imposed on $P$, $V$ or $\omega$, the optimization may consider constraints on other parameters such as tip tool path overlap which is a function of $V$, $\omega$, number of tips and tip width. The tip tool path overlap $O$ may be obtained from the following known relation:

$$O = \left(1 - \frac{fV}{\omega N l}\right) \times 100 \qquad (21)$$

wherein : $l$ is tool tip width;

$N$ is the number of tool tips on the ring;

$f$ is a unit convertion factor (metric system: 1000; English system:12).

The optimizer 114 uses the output quality vector $\tilde{Y}(k+1)$ as generated by the model updated through online identification to calculate debarker control data $u(k)$, complying with the performance index $J_O$. Here again, the SQP algorithm can be been used for performing the optimization.

**[99]** In some cases, abnormal disturbances affecting operating conditions, such as severe tool tip wear, or significant variation of moisture content (without use of an appropriate moisture sensor) characterizing the batch of logs under debarking cannot be handled by the MPC to achieve the desired performance. Reliability and robustness of the optimized control may be improved by considering an allowability range to predicted-setpoint error $\hat{e}_{sp}$ beyond which further adjustment of one or more selected input operating parameters should be provided. For so doing, a convenient approach consists of programming the optimizer (114) to adjust (either increase or decrease as appropriate) the control data $u(k)$ related to a selected input operating parameter, such as mean pressure applied to the cutting tools and/or cutting tool tip overlap, whenever the predicted-setpoint error data exceed first predetermined threshold data, in order to bring back the predicted data on the debarking quality-related parameters, *i.e.* output quality vector $\tilde{Y}(k+1)$, closer to the setpoint data, while still complying with the performance index $J_O$. Optionnaly, reliability and robustness of the optimized control may be further improved by also considering an allowability range to resulting-setpoint error data beyond which further adjustment of one or more selected input operating parameters should also be provided. For so doing, a convenient approach consists of programming the optimizer 114 to compare prior resulting data $Y(k-1)$ on the debarking quality-related parameters as received through optional line 75'' shown in **Fig. 25**, with the setpoint data to obtain resulting-setpoint error data. The optimizer 114 is also caused to further adjust (either increase or decrease as appropriate) from their current values the control data $u(k)$ related to a selected input operating parameter, such as mean pressure applied to the cutting tools and/or cutting tool tip overlap, whenever the resulting-setpoint error data exceed second predetermined threshold data, in order to reduce the resulting-setpoint error data for current process control without making use of the predictive model 110, while still complying with the performance index $J_O$. That

optional adjustment approach involving prior resulting data *Y(k-1)* may be represented by the following modified performance index $J_O$:

$$J_O = \max_R D_r + \min_R \sum_{j=1}^{n_P} \hat{e}_{SP}{}^2 = \max_R D_r + \min_R \sum_{j=1}^{n_P} (y_{SP} - \hat{y})^2 + \min_R \sum_{j=1}^{n_P} (y_{SP} - y)^2 \quad (22)$$

**[100]** On the basis of actual measurements on logs subjected to debarking at a mill, the performance of debarking in terms of the quality-related parameters as simulated without and with the MPC structure described above, and according to a control sequence based on various states of debarking operating parameters *P*, *V* and $\omega$ defined in Table 3, is illustrated by the graphs of **Fig. 27**, for the given control setpoints ($Y_{sp}$) of $B_{SP}$ = 10.0% and $F_{SP}$ = 5.0%.

**TABLE 3**

| | Phase **1** | Phase **2** | Phase **3** | Phase **4** | Phase 5 |
|---|---|---|---|---|---|
| ***P*** | Constant | Varied | Varied | Varied | Varied |
| ***V*** | Constant | Const. | Varied | Varied | Varied |
| | Constant | Const. | Const. | Varied | Varied |

**[101]** Phase 1 involves states of debarking operating parameters which are typical to prior debarking operation at sawmills. The control states are defined according to operator's experience and then generally kept constant, and may sometimes be adjusted according to debarked log qualities that are visible to the operator. As a result of such open loop control, it can be seen from **Figs. 27a** and **27B** that the estimation of quality-related parameters residual bark *B* and fiber loss *F* are far from their respective setpoints. The observed variations of these parameters may be due to changes in log diameter, taper shape and surface temperature characterizing the debarked logs. Phase 2 involves a state of debarking where the control data for the pressure *P* applied to cutting tools is varied through optimization using the MPC structure, and some performance improvement can observed when comparing with the performance obtained in phase 1, as shown in **Figs. 27A** and **27B**, especially regarding fiber loss *F*. Phase 3 involves a state of debarking where both pressure *P* and log feed speed *V* are varied

through optimization using the MPC structure, and performance improvement can still be observed when comparing with the performance obtained in phases 1 and 2, as shown in **Figs. 27A** and **27B**, especially regarding residual bark *B*. Phase 4 involves a state of debarking where ring rotational speed ω is varied in addition to pressure *P* and log feed speed *V* through optimization using the MPC structure, and it can be seen from **Figs. 27A** and **27B** that residual bark *B* and fiber loss *F* are closer to their respective setpoints as compared to preceding phases. Phase 5, which still involves variation of pressure *P,* log feed speed *V* and ring rotational speed ω, further involves subjecting the performance index $J_O$ to a condition of debarking yield maximization. It can be seen from **Fig. 27C** that the during phases 2 to 5 where the pressure *P* was varied, the constraints $R_{MIN}$ and $R_{MAX}$ as applied on *P* was always complied with. Similarly, It can be seen from **Fig. 27D** that during phases 3 to 5 where the log feed speed *V* was varied, the constraints $R_{MIN}$ and $R_{MAX}$ as applied on *V* have always been complied with. Furthermore, It can be seen from **Fig. 27E** that the during phases 4 and 5 where the ring rotational speed $\omega$ was varied, the constraints $R_{MIN}$ and $R_{MAX}$ as applied on $\omega$ have always been complied with. As to the performance of debarking obtained in terms of the quality-related parameters, it can be appreciated from Fig. 27B in view of Fig. 27A, that the performance index $J_O$ for phases 3 to 5 tends to minimize fiber loss *F* while complying with the residual bark setpoint $B_{SP}$, the debarking yield being maximized during phase 5. Referring to **Fig. 27F**, a gradual improvement of debarking quality performance can be observed from the evolution of mean square error MSE through phases 2 to 5.

**[102]** In order to experimentally verify the performance of the control of a debarking process on the basis of quality indicative information provided by the method and system as described above, further trials were performed using the same ring debarker used in the trials referred to above that confirmed the reliability of the debarking quality indicative information for detection purposes, and the results of the further trials were compared with those obtained using the same ring debarker operating under manual control. For that purposes, a population of more than 5000 logs was processed during a production period shared between the two modes of operation. Remaining bark and fiber loss estimated in terms of mean and standard deviation values were used as reference quality indicators. Table 4 presents results of the trials in terms of remaining bark and fiber loss according to the detection-based control and manual control modes of debarking operation.

**TABLE 4**

| | | DEBARKING OPERATION MODE | | NUMBER OF LOGS INSPECTED |
|---|---|---|---|---|
| | | Detection-based | Manual | |
| Remaining bark (%) | Mean (%) | 5.1 | 3.5 | 1812 |
| | Standard deviation (%) | 7 | 6 | |
| | 1% LSD factor (%) (highly significant) | 0.78 | | |
| | 5% LSD factor (%) (significant) | 0.6 | | |
| | Standard error | 0.133 | 0.144 | |
| Fiber loss (%) | Mean (%) | 8.1 | 10.3 | 1812 |
| | Standard deviation (%) | 4.9 | 5.9 | |
| | 1% LSD factor (%) (highly significant) | 0.96 | | |
| | 5% LSD factor (%) (highly significant) | 0.73 | | |
| | Standard error | 0.09 | 0.11 | |

**[103]** Table 4 also presents the results of an analysis of variance performed on the data associated with both debarking operation modes, with calculated *F* values of 29.5 for fiber loss and 22.8 for remaining bark, indicating significant differences between the various trials. Here again, in order to verify if the trials are different one another, the Least Significant Difference (LSD) was used. For a highly significant trial, LSD is 0.78 % for the remaining bark remaining trials, while LSD is 0.6 % for a significant trial. The difference between the estimated mean values having largely exceeded 0.78 %, the

differences between the trials are thus highly significant, and therefore, it is clear that the remaining bark control is correctly performed. For a highly significant trial, LSD is 0.96 % for the fiber loss trials, while LSD is 0.73 % for a significant trial, thus giving highly significant differences between the trials. Therefore, the control mode of debarking operation has provided a highly significant reduction of fiber loss as compared to the normal operation mode, thus contributing to significantly increase available wood for lumber production. To observe the difference between the trials and corroborate the results, the standard error was added and subtracted from the estimated mean values to test for overlapping (If an overlap between trials is observed, no difference can be inferred). As observed through LSD analysis, a difference was found between all trials. Therefore, one can conclude that there is clearly a significant difference between the trials, thus indicating that the detection-based mode of debarking operation is capable of efficiently controlling the quality debarking parameters in order to limit wood losses and thus improve profitability of the sawmill.

1. A method for detecting the quality of debarking at the surface of a wooden log, comprising the steps of:

i) measuring a three-dimensional profile of at least a portion of the log surface to generate corresponding profile image data;

ii) processing said profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of said wooden log to generate data indicative of the texture of said log surface; and

iii) analyzing said texture data to generate resulting data on parameters related to the debarking quality of said log surface, said parameters including fiber loss and residual bark.

2. The debarking quality detecting method of claim 1, further comprising the step of:

iv) comparing log surface areas respectively characterized by said fiber loss and residual bark with said log surface to estimate fiber loss level and residual bark level.

3. The debarking quality detecting method of claim 2, further comprising before step iv) the step of defining a plurality of surface sections of said log surface including a leading end section, a body section and a trailing end section, wherein said fiber loss level and residual bark level are estimated for one or more of said sections.

4. The debarking quality detecting method of claim 3, wherein said fiber loss level and residual bark level are estimated for at least two of said sections using predetermined weighting factors assigned thereto on the basis of their relative importance in debarking quality detection.

5. The debarking quality detecting method of claim 1, further comprising the step of:

iv) generating from the resulting data an image representing areas of said log surface respectively characterized by said detected fiber loss and detected residual bark.

6. The debarking quality detecting method of claim 5, wherein said measurement of the three-dimensional profile is performed with respect to a pair of orthogonal reference axis characterized by different resolution levels, said image generating step iv) includes scaling the resulting data to compensate for the resolution difference.

7. The debarking quality detecting method of claim 1, wherein said analyzing step iii) includes comparing said detected vertical and horizontal edges as part of said texture data to provide an indication of the ratio of said fiber loss with respect to said residual bark.

8. The debarking quality detecting method of claim 1, wherein said processing step ii) further includes processing said detected vertical and horizontal edges to obtain said texture data as an indication of roughness of said log surface.

9. The debarking quality detecting method of claim 1, wherein said processing step ii) includes flattening said profile image data to compensate for the generally curved shape of said log surface.

10. The debarking quality detecting method of claim 9, wherein said profile image data flattening is performed by applying thereto a high-pass spatial frequency filter.

11. The debarking quality detecting method of claim 9, wherein said profile image data flattening is performed by applying thereto a curve-fitting algorithm.

12. The debarking quality detecting method of claim 8, further comprising the step of:

iv) measuring light reflection from said log surface portion to generate corresponding reflected light intensity image data; and

v) comparing with a predetermined intensity threshold the reflected light intensity data to provide a further indication of the residual bark in addition to said resulting data.

13. The debarking quality detecting method of claim 12, wherein said measuring step iv) includes correcting said light intensity image data to compensate for the generally curved shape of said log surface.

14. The debarking quality detecting method of claim 12, further comprising the step of:

vi) generating from the resulting data an image representing areas of said log surface respectively characterized by said detected fiber loss, said detected residual bark , and a detected roughness value lower than a predetermined roughness threshold.

15. A system (22) for detecting the quality of debarking at the surface of a wooden log, comprising:

a three-dimensional profile measuring unit (34) for scanning at least a portion of the log surface to generate corresponding profile image data;

data processing means (66,84) receiving said profile image data for detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of said wooden log to generate data indicative of the texture of said log surface; and

data analyzing means (66,86) receiving said texture data to generate resulting data on parameters related to the debarking quality of said log surface, said parameters including fiber loss and residual bark.

16. The debarking quality detecting system of claim 15, wherein said data processing means (66,84) perform processing of said detected vertical and horizontal edges to obtain said texture data as an indication of roughness of said log surface, said system further comprising:

means (62) for measuring light reflection from said log surface portion to generate corresponding reflected light intensity image data; and

further data analyzing means (66,86) for comparing with a predetermined intensity threshold the reflected light intensity data to provide a further indication of the residual bark in addition to said resulting data.

17. A software product data recording media in which program code is stored, said program code will cause a computer to perform a method for detecting the quality of debarking at the surface of a wooden log, from three-dimensional profile data of at least of portion of a surface of said log, said method comprising the steps of:

i) processing said profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of said wooden log to generate data indicative of the texture of said log surface; and

ii) analyzing said texture data to generate resulting data on parameters related to the debarking quality of said log surface, said parameters including fiber loss and residual bark.

18. The software product data recording media of claim 17, wherein said method further comprising the step of:

iii) comparing log surface areas respectively characterized by said fiber loss and residual bark with said log surface to estimate fiber loss level and residual bark level.

19. The software product data recording media of claim 18, wherein said method further comprising before step iii) the step of defining a plurality of surface sections of said log surface including a leading end section, a body section and a trailing end section, wherein said fiber loss level and residual bark level are estimated for one or more of said sections.

20. The software product data recording media of claim 19, wherein said fiber loss level and residual bark level are estimated for at least two of said sections using predetermined weighting factors assigned thereto on the basis of their relative importance in debarking quality detection.

21. The software product data recording media of claim 19, wherein said method further comprising the step of:

iii) generating from the resulting data an image representing areas of said log surface respectively characterized by said detected fiber loss and detected residual bark.

22. The software product data recording media of claim 21, wherein said measurement of the three-dimensional profile is performed with respect to a pair of orthogonal reference axis characterized by different resolution levels, said image generating step iii) includes scaling the resulting data to compensate for the resolution difference.

23. The software product data recording media of claim 17, wherein said analyzing step ii) includes comparing said detected vertical and horizontal edges as part of said texture data to provide an indication of the ratio of said fiber loss with respect to said residual bark.

24. The software product data recording media of claim 23, wherein said processing step i) further includes processing said detected vertical and horizontal edges to obtain said texture data as an indication of roughness of said log surface.

25. The software product data recording media of claim 17, wherein said processing step i) includes flattening said profile image data to compensate for the generally curved shape of said log surface.

26. The software product data recording media of claim 25, wherein said profile image data flattening is performed by applying thereto a high-pass spatial frequency filter.

27. The software product data recording media of claim, 25 wherein said profile image data flattening is performed by applying thereto a curve-fitting algorithm.

28. The software product data recording media of claim 24, further comprising the step of:

iii) measuring light reflection from said log surface portion to generate corresponding reflected light intensity image data; and

iv) comparing with a predetermined intensity threshold the reflected light intensity data to provide a further indication of the residual bark in addition to said resulting data.

29. The software product data recording media of claim 28, wherein said measuring step iii) includes flattening said light intensity image data to compensate for the generally curved shape of said log surface.

30. The software product data recording media of claim 28, further comprising the step of:

v) generating from the resulting data an image representing areas of said log surface respectively characterized by said detected fiber loss, said detected residual bark , and a detected roughness value lower than a predetermined roughness threshold.

31. A method for detecting the quality of debarking at the surface of wooden logs and for controlling a debarking process applied to the wooden logs on the basis of said debarking quality, comprising the steps of:

i) measuring a three-dimensional profile of at least a portion of the surface of one of said logs to generate corresponding profile image data;

ii) processing said profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of said wooden log to generate data indicative of the texture of said log surface;

iii) analyzing said texture data to generate resulting data on parameters related to the debarking quality of said log surface, said parameters including fiber loss and residual bark; and

iv) controlling the debarking process applied to a next one of said logs using said resulting data.

32. The method of claim 31, wherein said controlling step iv) includes generating control data related to a plurality of input operating parameters of said debarking

process, on the basis of predetermined control setpoint data associated with said quality-related parameters.

33. The method of claim 32, wherein said debarking process uses a rotary ring debarker (24) provided with cutting tools (12), said input operating parameters are selected from the group consisting of mean pressure applied to the cutting tools, log feed speed, ring rotational speed and cutting tool tip overlap.

34. The method of claim 32, wherein said controlling step iv) includes the steps of:

a) providing a predictive model (110) of said debarking process based on relations involving said input operating parameters and said resulting data on quality-related parameters, for generating predicted data on said quality-related parameters;

b) comparing said predicted data with said control setpoint data to obtain predicted-setpoint error data;

c) providing an optimizer (114) for generating said control data which minimize said predicted-setpoint error data in accordance with at least one debarking performance criterion and predetermined debarking process constraints imposed on one or more of said refining process input operating parameters, said control data being fed to said predictive model.

35. The method of claim 34, wherein said debarking performance criterion is debarking yield maximization.

36. The method of claim 34, wherein said debarking process uses a rotary ring debarker (24) provided with cutting tools (12), said input operating parameters are selected from the group consisting of mean pressure applied to the cutting tools, log feed speed, ring rotational speed and cutting tool tip overlap.

37. The method of claim 36, wherein said optimizer (114) adjusts said control data related to one of said mean pressure applied to the cutting tools and cutting tool tip overlap whenever said predicted-setpoint error data exceed first predetermined threshold data.

38. The method of claim 37, wherein said controlling step iv) further includes the steps of:

d) comparing prior resulting data generated at said step iii) with said setpoint data to obtain resulting-setpoint error data;

e) further adjusting said control data related to one of said mean pressure applied to the cutting tools and cutting tool tip overlap whenever said resulting-setpoint error data exceed second predetermined threshold data.

39. The method of claim 38, wherein said comparing step d) and adjusting step e) are performed by said optimizer (114).

40. The method of claim 34, wherein said predictive model (110) is capable of generating from said relations an estimation of prior resulting data on said quality-related parameters, said controlling step iv) further includes the steps of:

d) comparing said estimation with said resulting data generated at said step iii) to obtain estimation-resulting error data;

e) providing an online identificator (118) for adjusting the relations of said predictive model to minimize said estimation-resulting error data.

41. The method of claim 34, wherein said relations further involves at least one log dimensional parameter, said method further comprising before said step iv) the step of:

a') measuring the dimensional parameter of said next log, the resulting dimensional measurement being fed to said predictive model.

42. The method of claim 41, wherein said at least one dimensional parameter is one of mean log diameter and log taper shape indicator.

43. The method of claim 42, wherein said log taper shape indicator is derived from at least two log diameter measurements respectively at a log leading end and a log trailing end, and a log length measurement.

44. The method of claim 41, wherein said at least one dimensional parameter is mean log diameter, said predictive model (110) is selected according to the mean log diameter measurement from a plurality of models adapted to respective ranges of log diameter.

45. The method of claim 44, further comprising before said step iv) the step of:

b') measuring the temperature at the surface of said next log, the resulting log surface temperature measurement being fed to said predictive model;

wherein for each one of said ranges of log diameter, there is a plurality of models further adapted to respective ranges of log surface temperature, said predictive model being further selected according to the log surface temperature measurement.

46. The method of claim 34, further comprising before said step iv) the step of:

a') measuring the temperature at the surface of said next log;

wherein said predictive model (110) is selected according to the log surface temperature measurement from a plurality of models adapted to respective ranges of log surface temperature.

47. The method of claim 34, wherein said predictive model (110) is built with a modeling platform selected from the group consisting of a neural network, a multivariate linear model, a static gain matrix and a fuzzy logic model.

48. A system (22) for detecting the quality of debarking at the surface of wooden logs and for controlling a debarking process applied to the wooden logs on the basis of said debarking quality, comprising:

a three-dimensional profile measuring unit (34) for scanning at least a portion of the log surface to generate corresponding profile image data;

data processing means (66,84) receiving said profile image data for detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of said wooden log to generate data indicative of the texture of said log surface;

data analyzing means (66,86) receiving said texture data to generate resulting data on parameters related to the debarking quality of said log surface, said parameters including fiber loss and residual bark;

means for controlling the debarking process applied to a next one of said logs using said resulting data.

49. The system of claim 48, wherein said debarking process uses a log debarker (24), said controlling means include a controller (67) operatively connected to said debarker (24) and a computer (66) programmed to generate control data related to a plurality of input operating parameters of said debarking process, on the basis of predetermined control setpoint data associated with said quality-related parameters.

50. The system of claim 49, wherein said log debarker (24) is a rotary ring debarker provided with cutting tools (12), said input operating parameters are selected from the

group consisting of mean pressure applied to the cutting tools, log feed speed, ring rotational speed and cutting tool tip overlap.

51. The system of claim 48, wherein a control module (79) is programmed on said computer and includes a predictive model (110) of said debarking process based on relations involving said input operating parameters, said input operating parameters and said resulting data on quality-related parameters, for generating predicted data on said quality-related parameters, said control module being further programmed for comparing said predicted data with said control setpoint data to obtain predicted-setpoint error data, said control module further including an optimizer (114) for generating said control data which minimize said predicted-setpoint error data in accordance with at least one debarking performance criterion and predetermined debarking process constraints imposed on one or more of said refining process input operating parameters, said control data being fed to said predictive model.

52. The system of claim 51, wherein said debarking performance criterion is debarking yield maximization.

53. The system of claim 51, wherein said debarking process uses a rorary ring debarker (24) provided with cutting tools (12), said input operating parameters are selected from the group consisting of mean pressure applied to the cutting tools, log feed speed, ring rotational speed and cutting tool tip overlap.

54. The system of claim 53, wherein said optimizer (114) adjusts said control data related to one of said mean pressure applied to the cutting tools and cutting tool tip overlap whenever said predicted-setpoint error data exceed first predetermined threshold data.

55. The system of claim 54, wherein said optimizer (114) compares prior said resulting data with said setpoint data to obtain resulting-setpoint error data, and further adjusts said control data related to one of said mean pressure applied to the cutting tools and cutting tool tip overlap whenever said resulting-setpoint error data exceed second predetermined threshold data.

56. The system of claim 51, wherein said predictive model (110) is capable of generating from said relations an estimation of prior resulting data on said quality-related parameters, said control module being further programmed for comparing said estimation data with said resulting data generated by said data analyzing means (66,86) to obtain estimation-resulting error data, said control module further including an online identificator (118) for adjusting the relations of said predictive model (110) to minimize said estimation-resulting error data.

57. The system of claim 51, wherein said relations further involves at least one log dimensional parameter, said system further comprising means for measuring the dimensional parameter of said next log, the resulting dimensional measurement being fed to said predictive model (110).

58. The system of claim 57, wherein said at least one dimensional parameter is one of mean log diameter and log taper shape indicator.

59. The system of claim 58, wherein said log taper shape indicator is derived from at least two log diameter measurements respectively at a log leading end and a log trailing end, and a log length measurement.

60. The system of claim 57, wherein said at least one dimensional parameter is mean log diameter, said predictive model (110) is selected according to the mean log

diameter measurement from a plurality of models adapted to respective ranges of log diameter.

61. The system of claim 60, further comprising means (63) for measuring the temperature at the surface of said next log, the resulting log surface temperature measurement being fed to said predictive model (110), wherein for each one of said ranges of log diameter, there is a plurality of models further adapted to respective ranges of log surface temperature, said predictive model being further selected according to the log surface temperature measurement.

62. The system of claim 51, further comprising means (63) for measuring the temperature at the surface of said next log, wherein said predictive model (110) is selected according to the log surface temperature measurement from a plurality of models adapted to respective ranges of log surface temperature.

63. The system of claim 51, wherein said predictive model (110) is built with a modeling platform selected from the group consisting of a neural network, a multivariate linear model, a static gain matrix and a fuzzy logic model.

64. A software product data recording media in which program code is stored, said program code will cause a computer to perform a method for detecting the quality of debarking at the surface of wooden logs and for controlling a debarking process applied to the wooden logs on the basis of said debarking quality, comprising the steps of:

i) measuring a three-dimensional profile of at least a portion of the surface of one of said logs to generate corresponding profile image data;

ii) processing said profile image data by detecting vertical and horizontal edges of said profile image data with respect to a substantially longitudinal axis of said wooden log to generate data indicative of the texture of said log surface;

iii) analyzing said texture data to generate resulting data on parameters related to the debarking quality of said log surface, said parameters including fiber loss and residual bark; and

iv) controlling the debarking process applied to a next one of said logs using said resulting data.

65. The software product data recording media of claim 64, wherein said controlling step iv) includes generating control data related to a plurality of input operating parameters of said debarking process, on the basis of predetermined control setpoint data associated with said quality-related parameters.

66. The software product data recording media of claim 65, wherein said debarking process uses a rotary ring debarker (24) provided with cutting tools (12), said input operating parameters are selected from the group consisting of mean pressure applied to the cutting tools, log feed speed, ring rotational speed and cutting tool tip overlap.

67. The software product data recording media of claim 64, wherein said controlling step iv) includes the steps of:

a) providing a predictive model (110) of said debarking process based on relations involving said input operating parameters, said input operating parameters and said resulting data on quality-related parameters, for generating predicted data on said quality-related parameters;

b) comparing said predicted data with said control setpoint data to obtain predicted-setpoint error data;

c) providing an optimizer (114) for generating said control data which minimize said predicted-setpoint error data in accordance with at least one debarking performance criterion and predetermined debarking process constraints imposed on one or more of said refining process input operating parameters, said control data being fed to said predictive model.

68. The software product data recording media of claim 67, wherein said debarking performance criterion is debarking yield maximization.

69. The software product data recording media of claim 67, wherein said debarking process uses a rotary ring debarker (24) provided with cutting tools (12), said input

operating parameters are selected from the group consisting of mean pressure applied to the cutting tools, log feed speed, ring rotational speed and cutting tool tip overlap.

70. The software product data recording media of claim 69, wherein said optimizer (114) adjusts said control data related to one of said mean pressure applied to the cutting tools and cutting tool tip overlap, whenever said predicted-setpoint error data exceed first predetermined threshold data.

71. The software product data recording media of claim 70, wherein said controlling step iv) further includes the steps of:

d) comparing prior resulting data generated at said step iii) with said setpoint data to obtain resulting-setpoint error data;

e) further adjusting said control data related to one of said mean pressure applied to the cutting tools and cutting tool tip overlap, whenever said resulting-setpoint error data exceed second predetermined threshold data.

72. The software product data recording media of claim 71, wherein said comparing step d) and adjusting step e) are performed by said optimizer (114).

73. The software product data recording media of claim 67, wherein said predictive model (110) is capable of generating from said relations an estimation of prior resulting data on said quality-related parameters, said controlling step iv) further includes the steps of:

d) comparing said estimation with said resulting data generated at said step iii) to obtain estimation-resulting error data;

e) providing an online identificator (118) for adjusting the relations of said predictive model to minimize said estimation-resulting error data.

74. The software product data recording media of claim 67, wherein said relations further involves at least one log dimensional parameter, said method further comprising before said step iv) the step of:

a') measuring the dimensional parameter of said next log, the resulting dimensional measurement being fed to said predictive model (110).

75. The software product data recording media of claim 74, wherein said at least one dimensional parameter is one of mean log diameter and log taper shape indicator.

76. The software product data recording media of claim 75, wherein said log taper shape indicator is derived from at least two log diameter measurements respectively at a log leading end and a log trailing end, and a log length measurement.

77. The software product data recording media of claim 74, wherein said at least one dimensional parameter is mean log diameter, said predictive model (110) is selected according to the mean log diameter measurement from a plurality of models adapted to respective ranges of log diameter.

78. The software product data recording media of claim 77, further comprising before said step iv) the step of:

b') measuring the temperature at the surface of said next log, the resulting log surface temperature measurement being fed to said predictive model (110);

wherein for each one of said ranges of log diameter, there is a plurality of models further adapted to respective ranges of log surface temperature, said predictive model being further selected according to the log surface temperature measurement.

79. The software product data recording media of claim 67, further comprising before said step iv) the step of:

a') measuring the temperature at the surface of said next log;

wherein said predictive model (110) is selected according to the log surface temperature measurement from a plurality of models adapted to respective ranges of log surface temperature.

80. The software product data recording media of claim 67, wherein said predictive model (110) is built with a modeling platform selected from the group consisting of a neural network, a multivariate linear model, a static gain matrix and a fuzzy logic model.

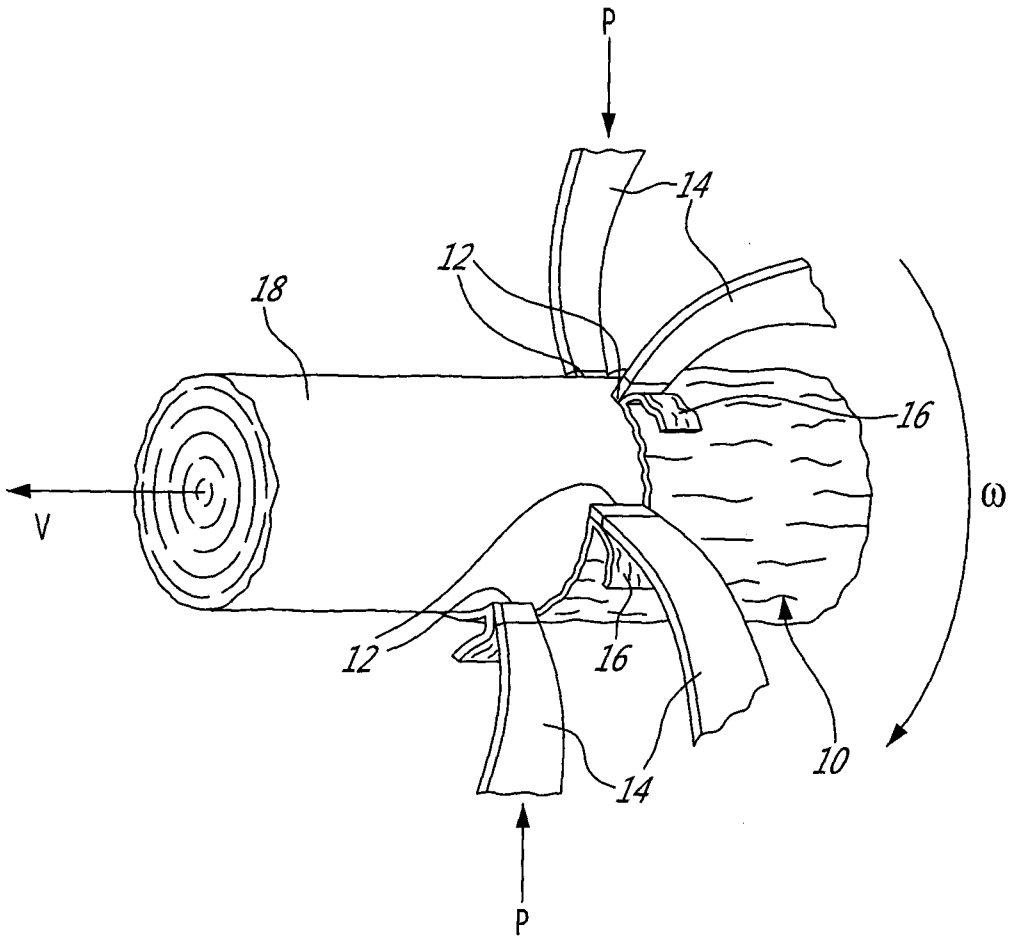



Fig. 1

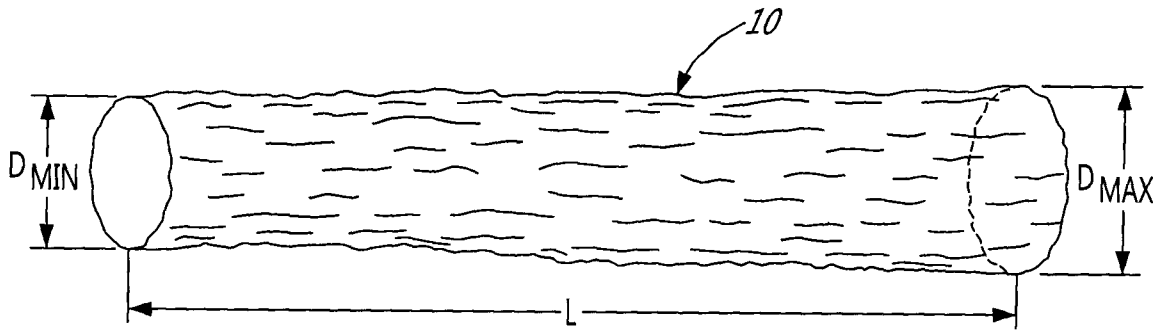



Fig. 2

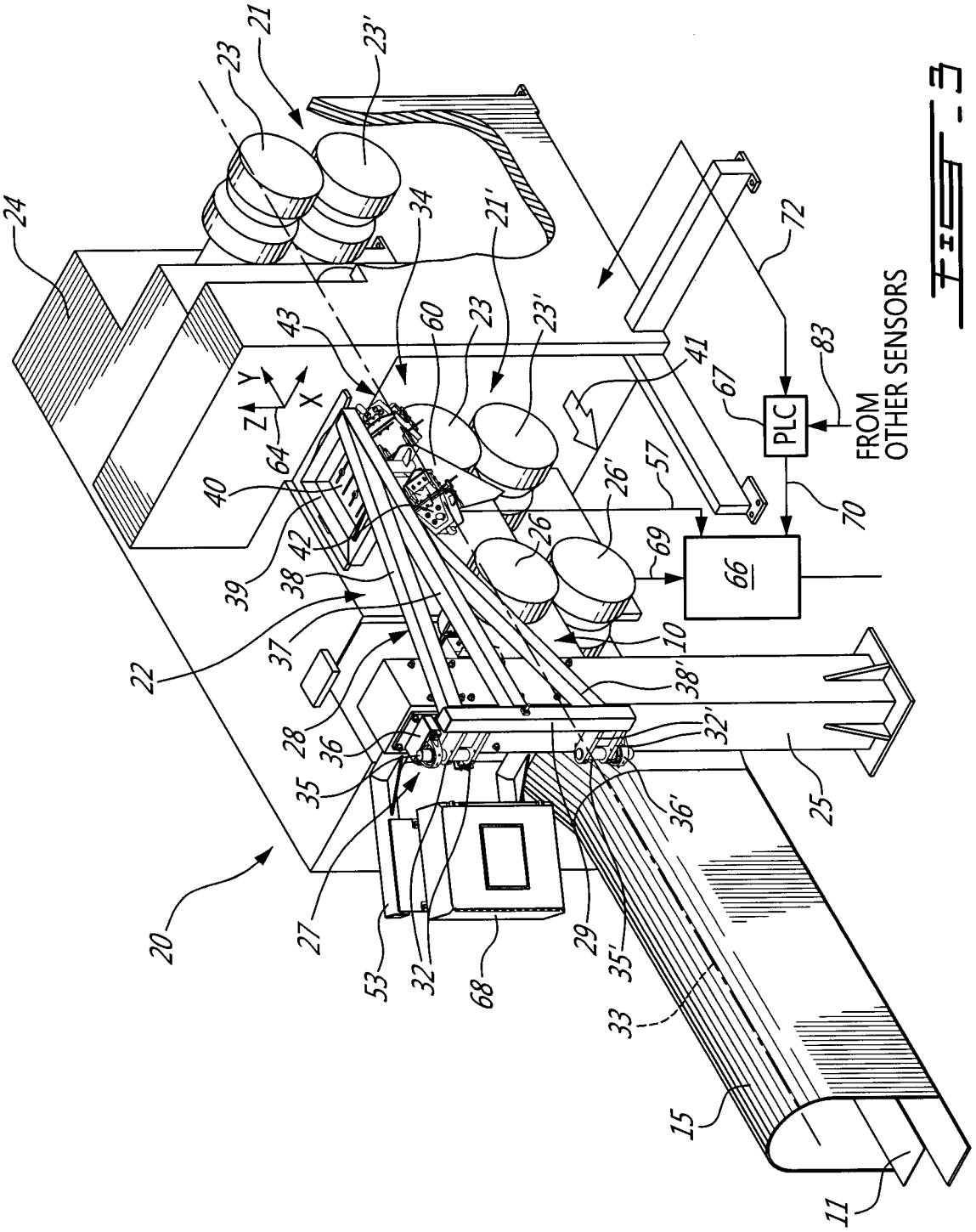



Fig - 3

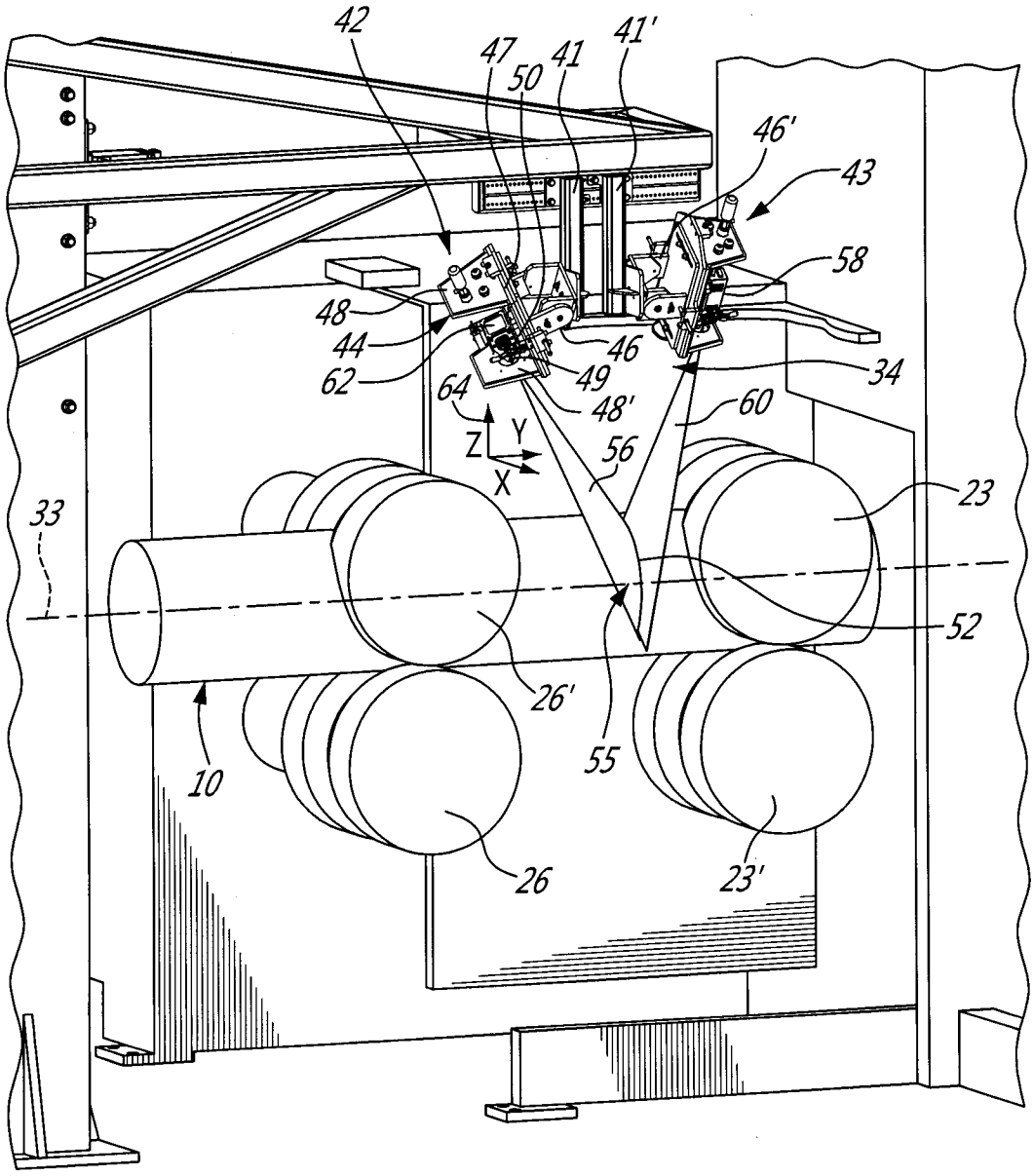

42
47
50
41
41'
46'
43
58
48
44
62
64
49
46
48'
34
60
Z
Y
X
56
33
23
52
26'
10
55
26
23'

Fig. 3A

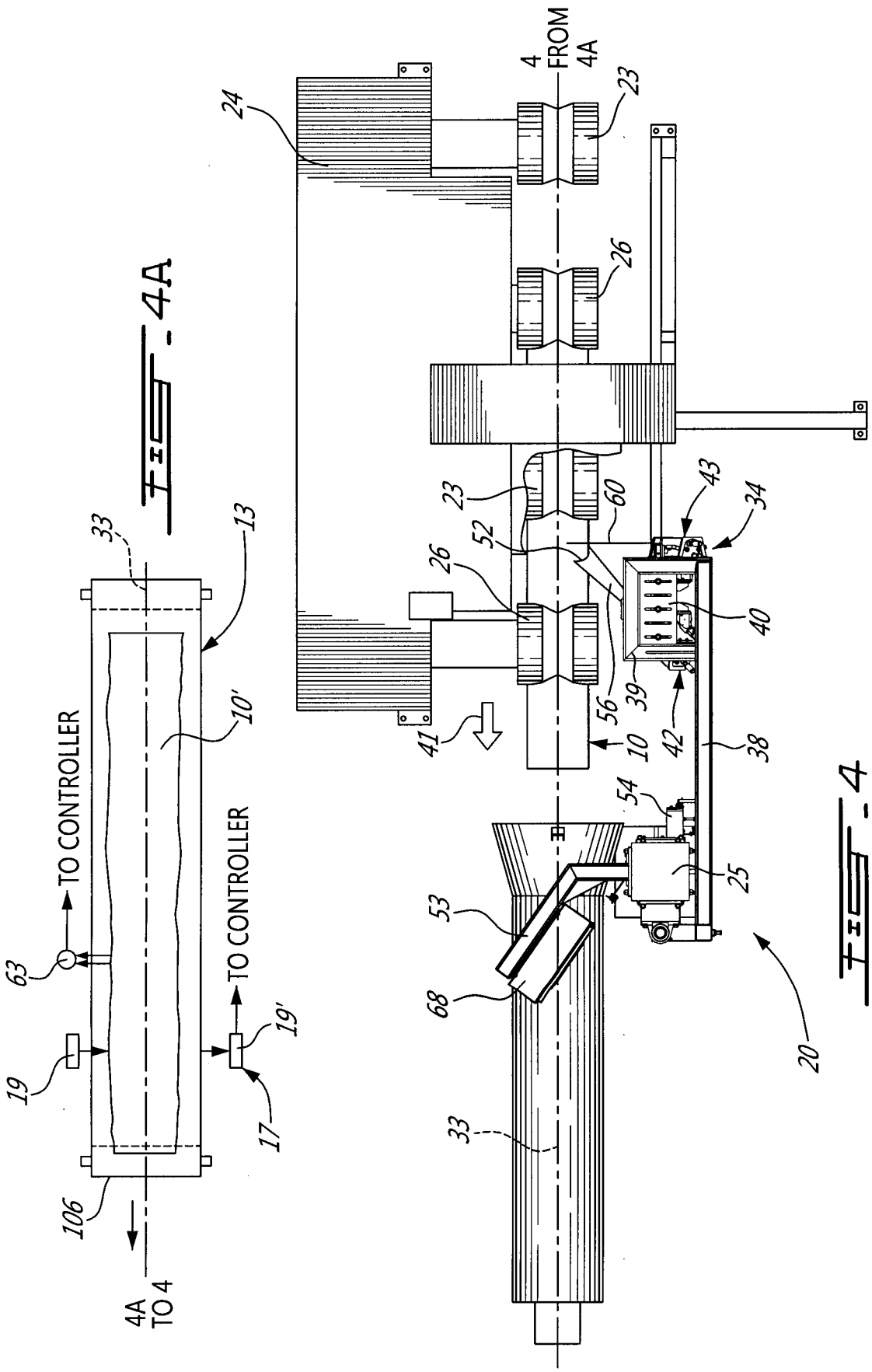

4
FROM
4A
24
23
26
23
60
43
34
52
26
40
39
56
10
42
38
41
54
25
53
68
33
20
33
13
10'
TO CONTROLLER
TO CONTROLLER
63
19
19'
17
106
4A
TO 4

FIG - 4A

FIG - 4

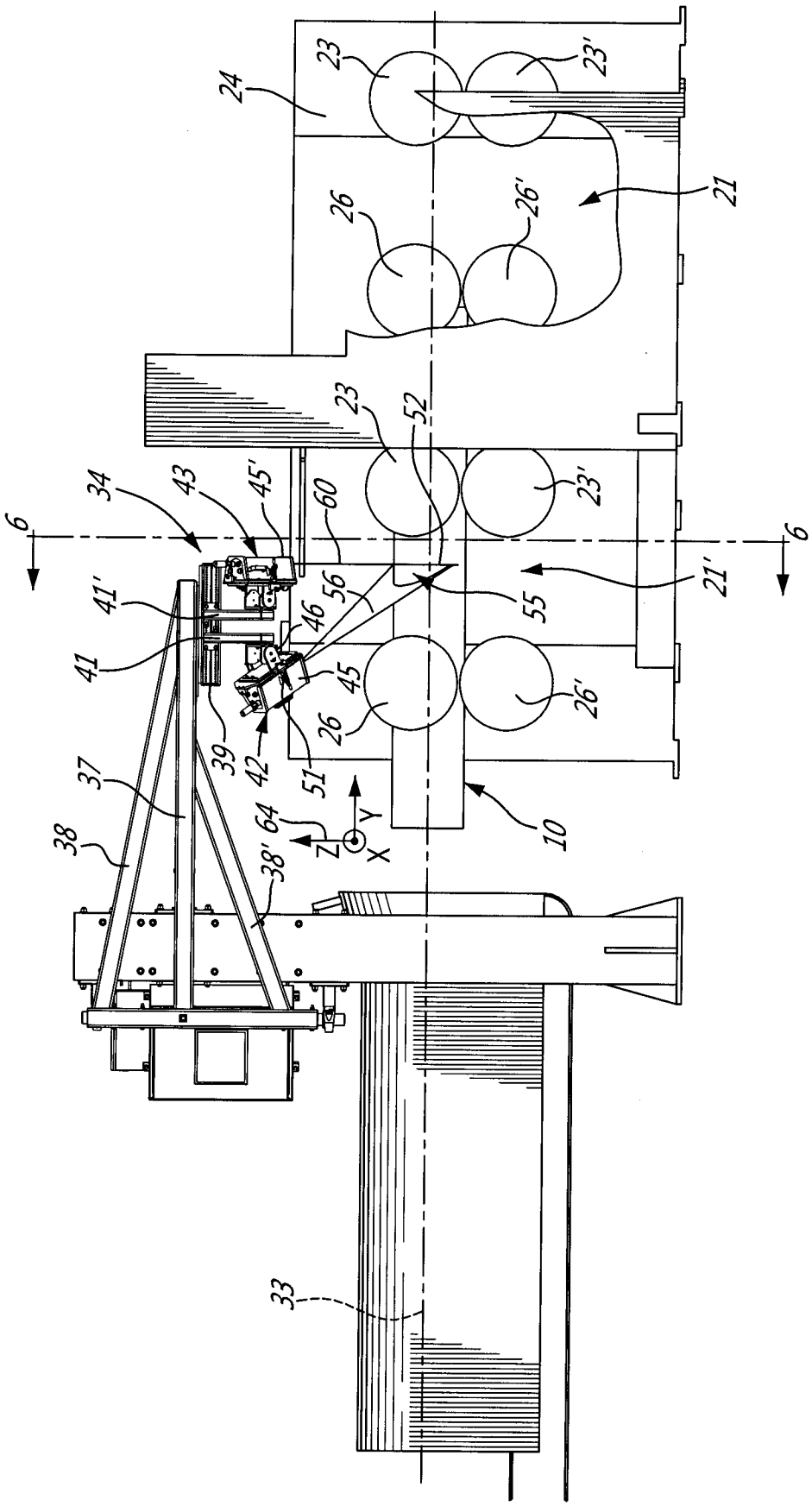

24
23
23'
21
26
26'
23
52
23'
34
43
45'
60
6
6
41'
56
55
21'
46
41
45
26'
26
39
42
51
37
64
Y
Z
X
10
38
38'
33

Fig-5

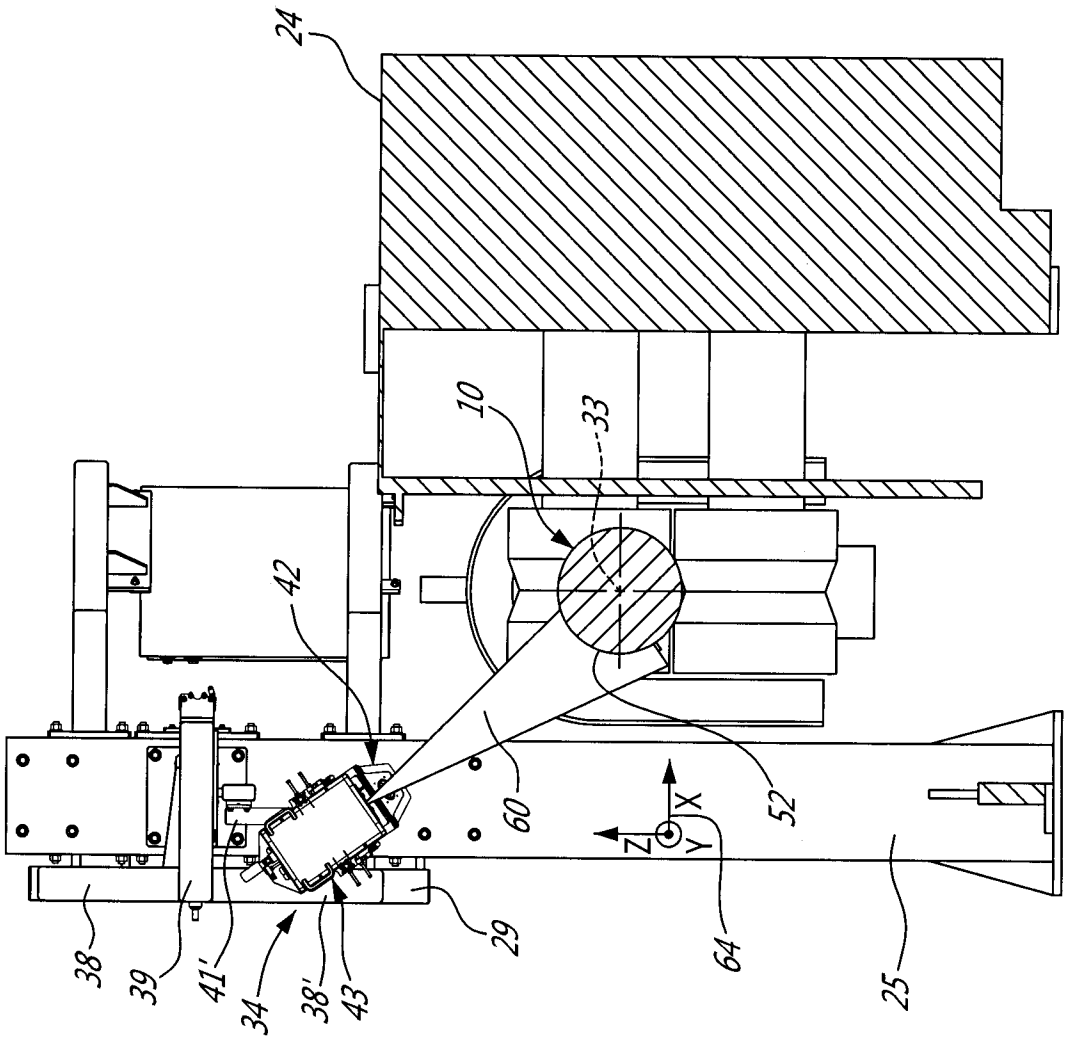



Fig - 6

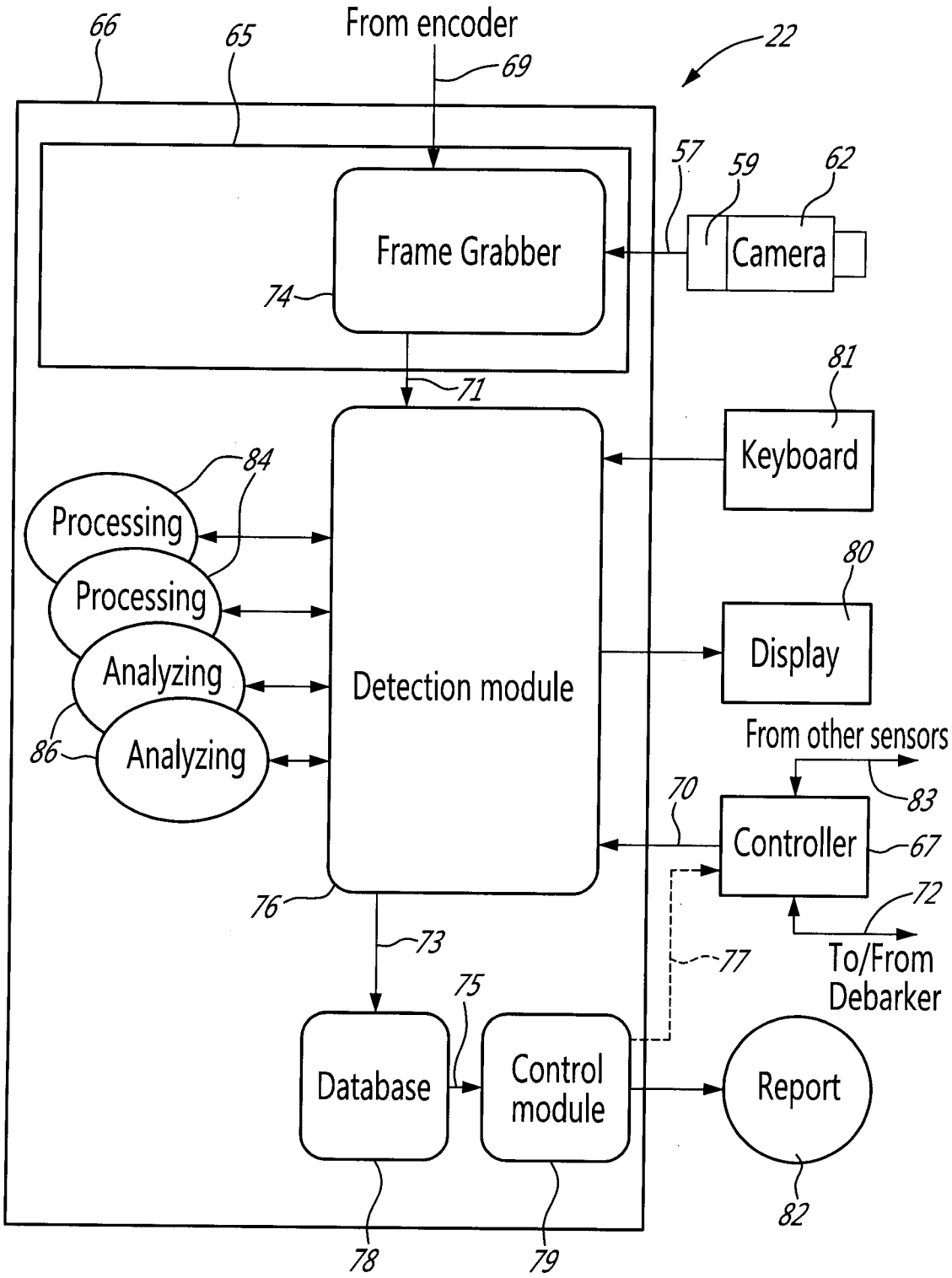

66
65
From encoder
69
22
57
59
62
Frame Grabber
Camera
74
71
81
Keyboard
84
Processing
Processing
Analyzing
Analyzing
86
Detection module
80
Display
From other sensors
83
70
Controller
67
72
To/From Debarker
77
73
75
Database
Control module
Report
82
78
79

Fig. 7

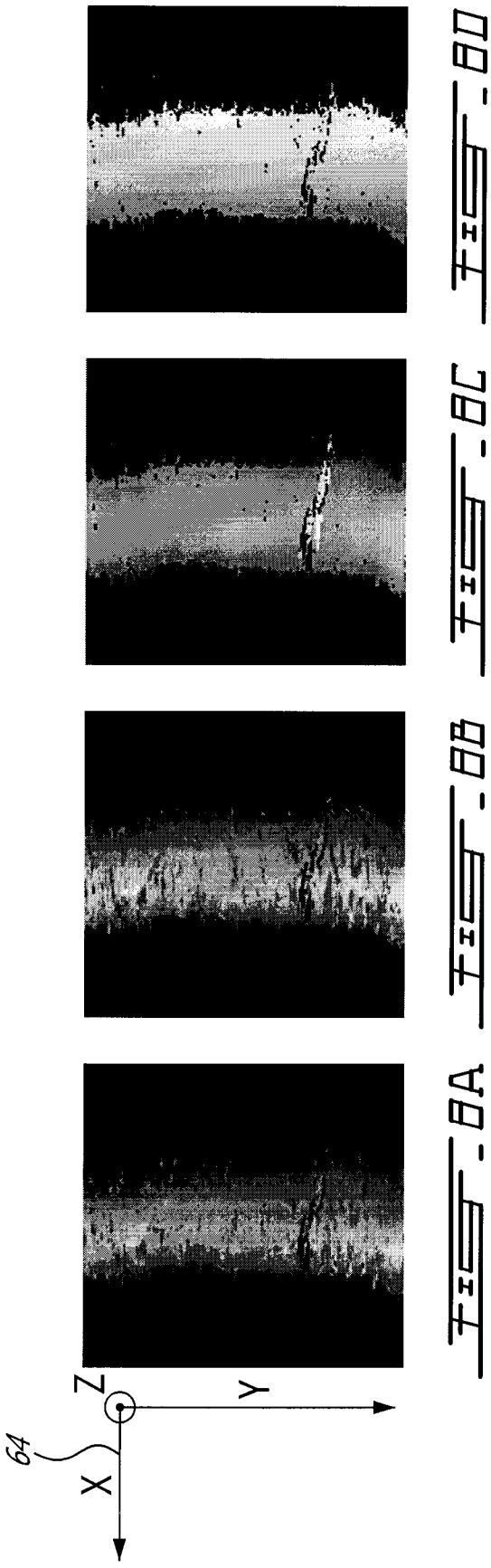



Fig-8A

Fig-8B

Fig-8C

Fig-8D

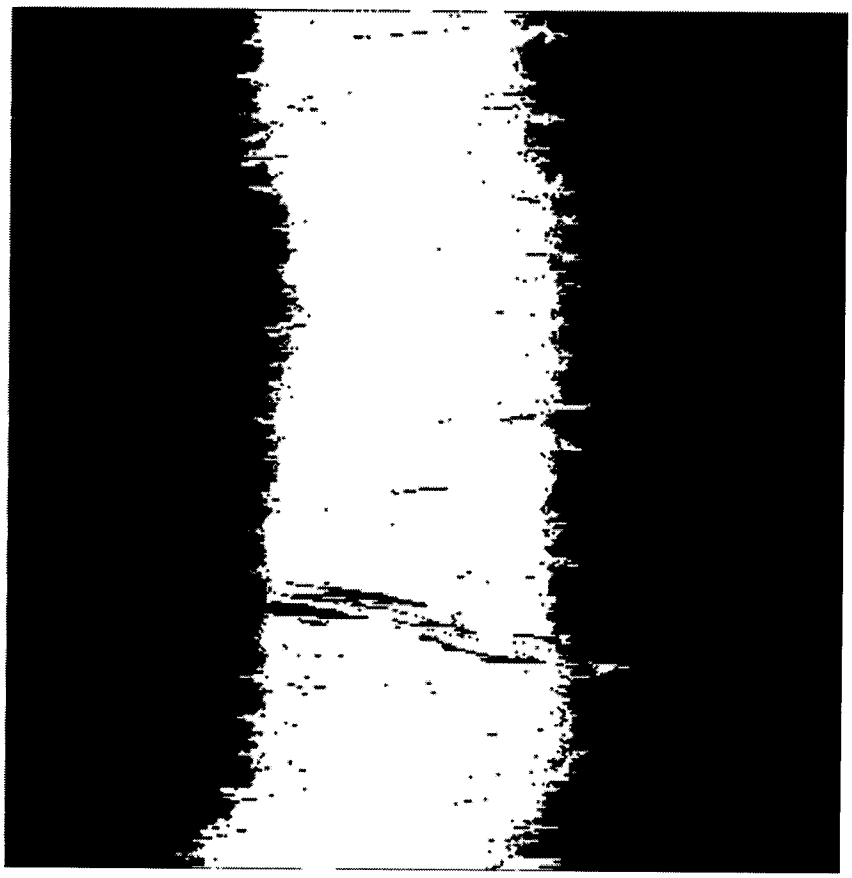


Fig. 9

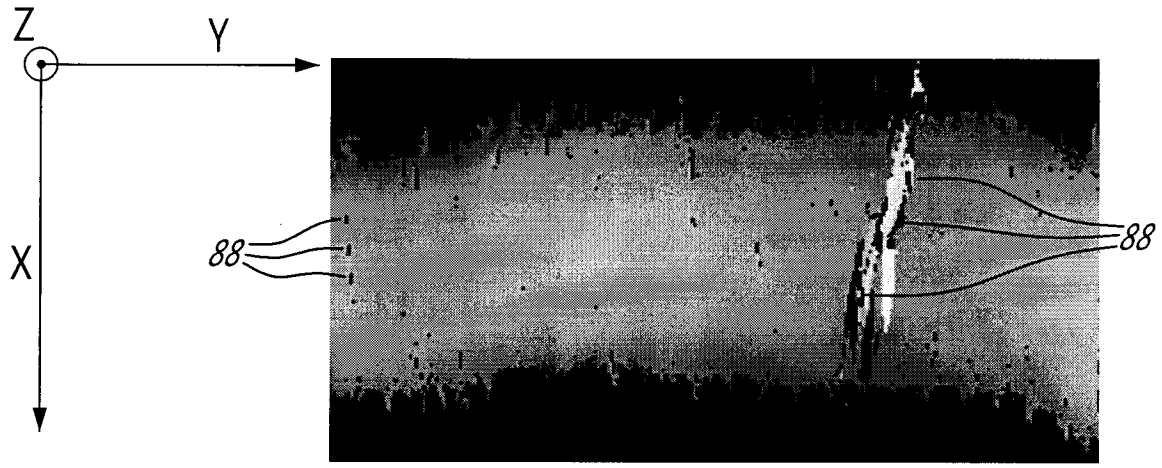



Fig. 10A

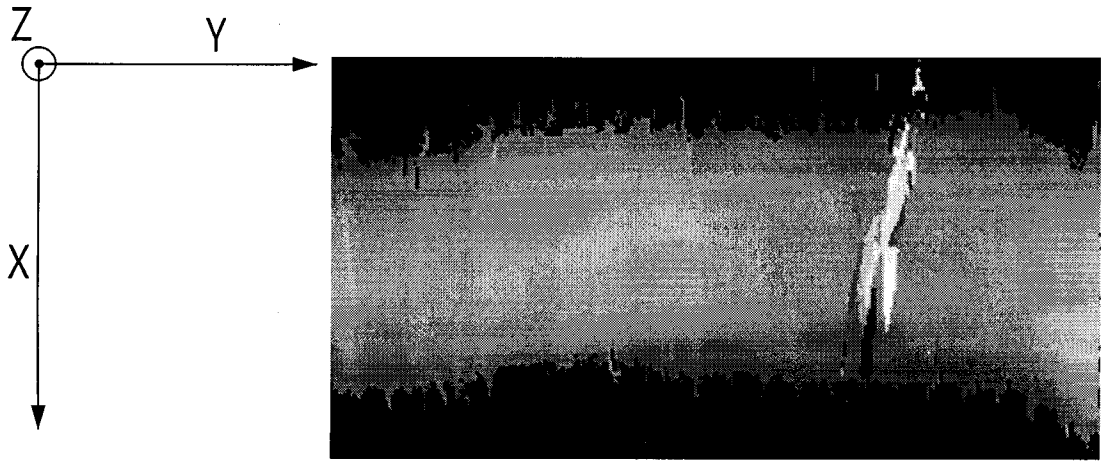



Fig. 10B

Fig. 11A

Fig. 11B

Fig. 11C

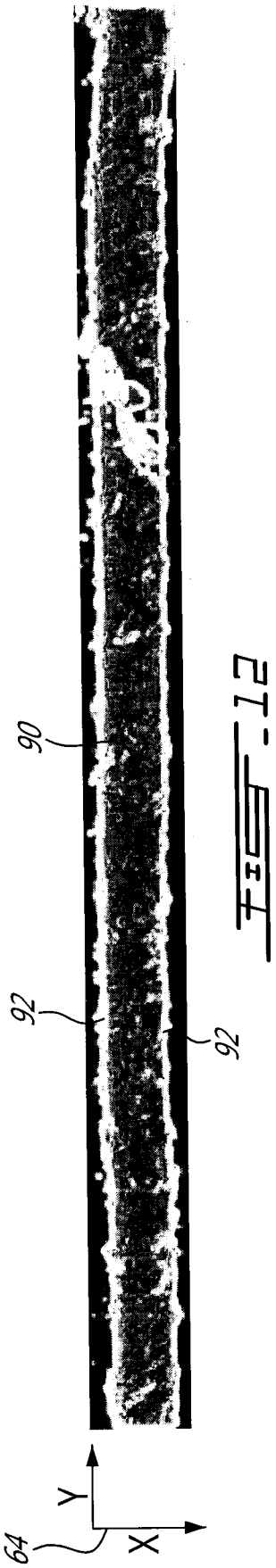



Fig-12

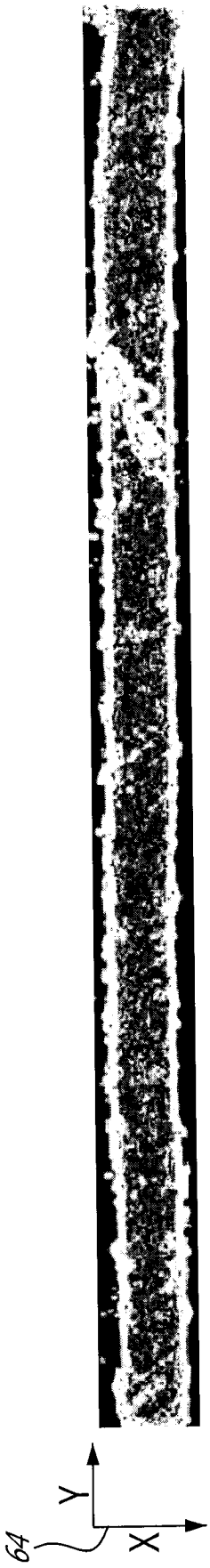



Fig-13A

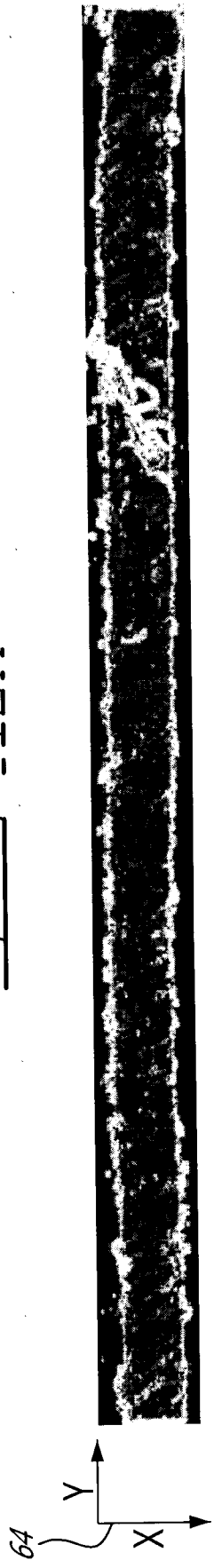



Fig-13B

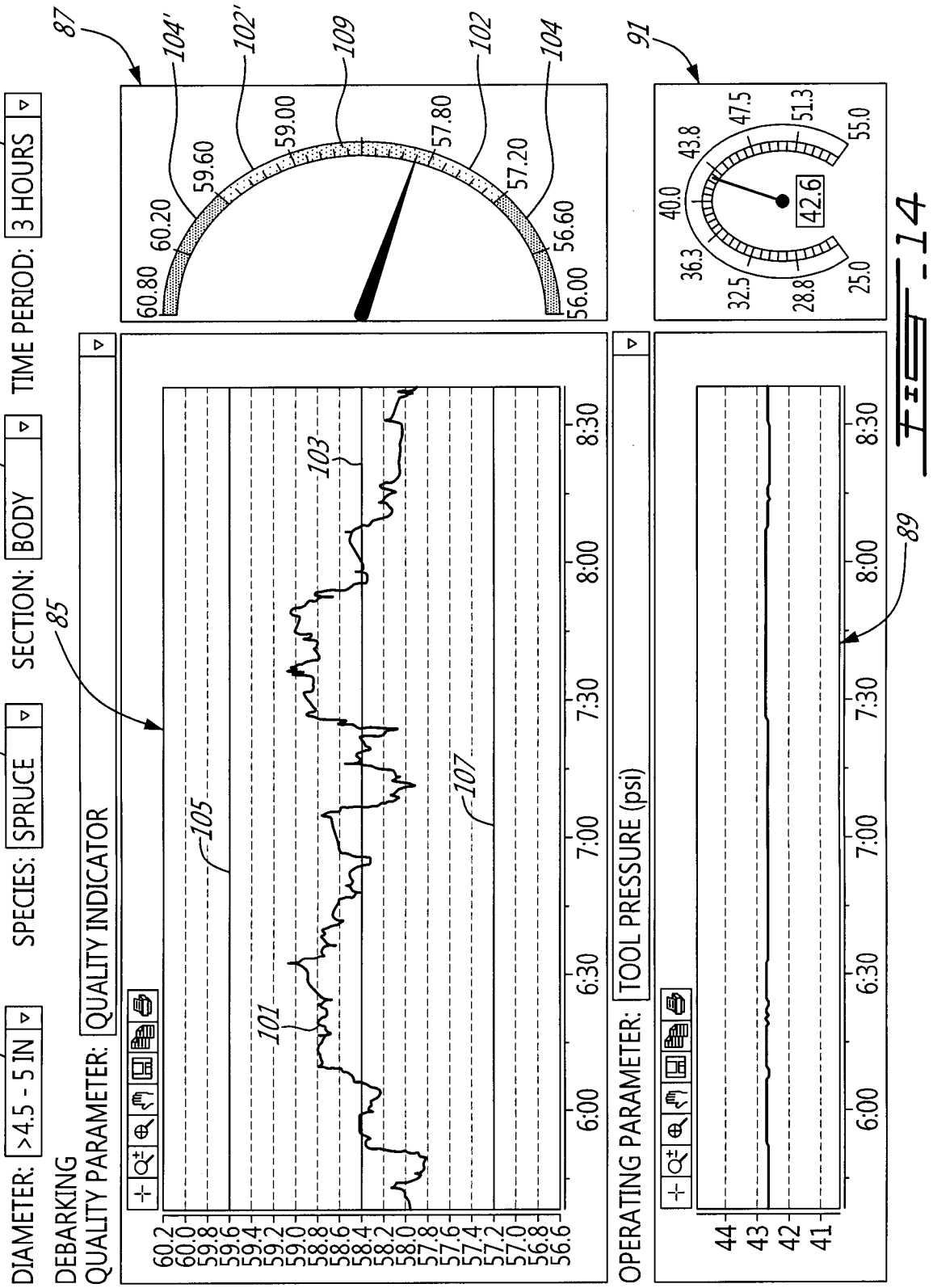

DIAMETER: >4.5 - 5 IN
SPECIES: SPRUCE
SECTION: BODY
TIME PERIOD: 3 HOURS
DEBARKING QUALITY PARAMETER: QUALITY INDICATOR
OPERATING PARAMETER: TOOL PRESSURE (psi)
60.80
60.20
59.60
59.00
57.80
57.20
56.60
56.00
36.3
40.0
43.8
47.5
51.3
55.0
32.5
28.8
25.0
42.6
6:00
6:30
7:00
7:30
8:00
8:30
87
91
93
95
97
99
85
89
101
103
105
107
102
102'
104
104'
109

Fig-14

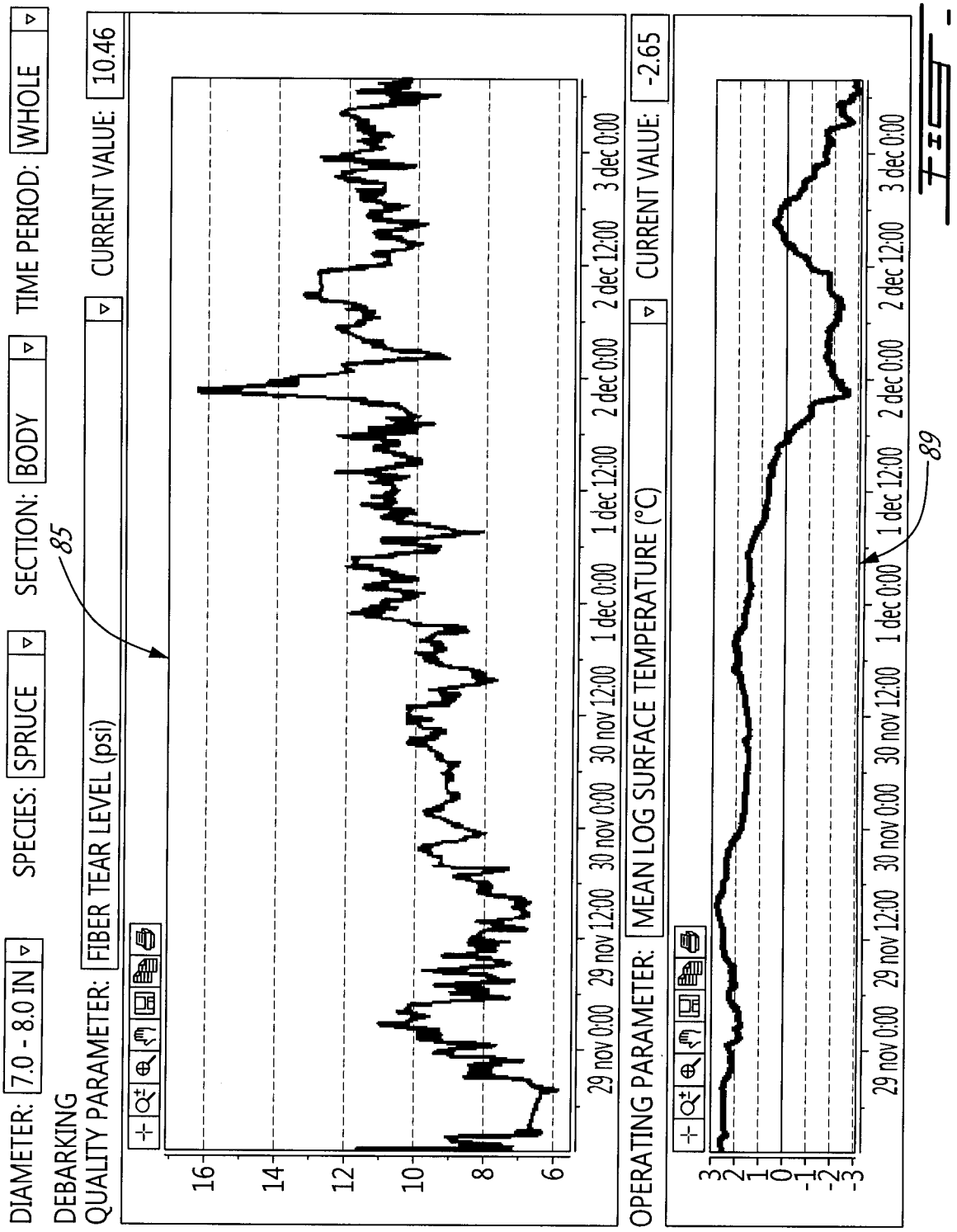

DIAMETER: 7.0 - 8.0 IN
SPECIES: SPRUCE
SECTION: BODY
TIME PERIOD: WHOLE
DEBARKING QUALITY PARAMETER: FIBER TEAR LEVEL (psi)
CURRENT VALUE: 10.46
85
16
14
12
10
8
6
29 nov 0:00
29 nov 12:00
30 nov 0:00
30 nov 12:00
1 dec 0:00
1 dec 12:00
2 dec 0:00
2 dec 12:00
3 dec 0:00
OPERATING PARAMETER: MEAN LOG SURFACE TEMPERATURE (°C)
CURRENT VALUE: -2.65
89
3
2
1
0
-1
-2
-3

Fig - 15

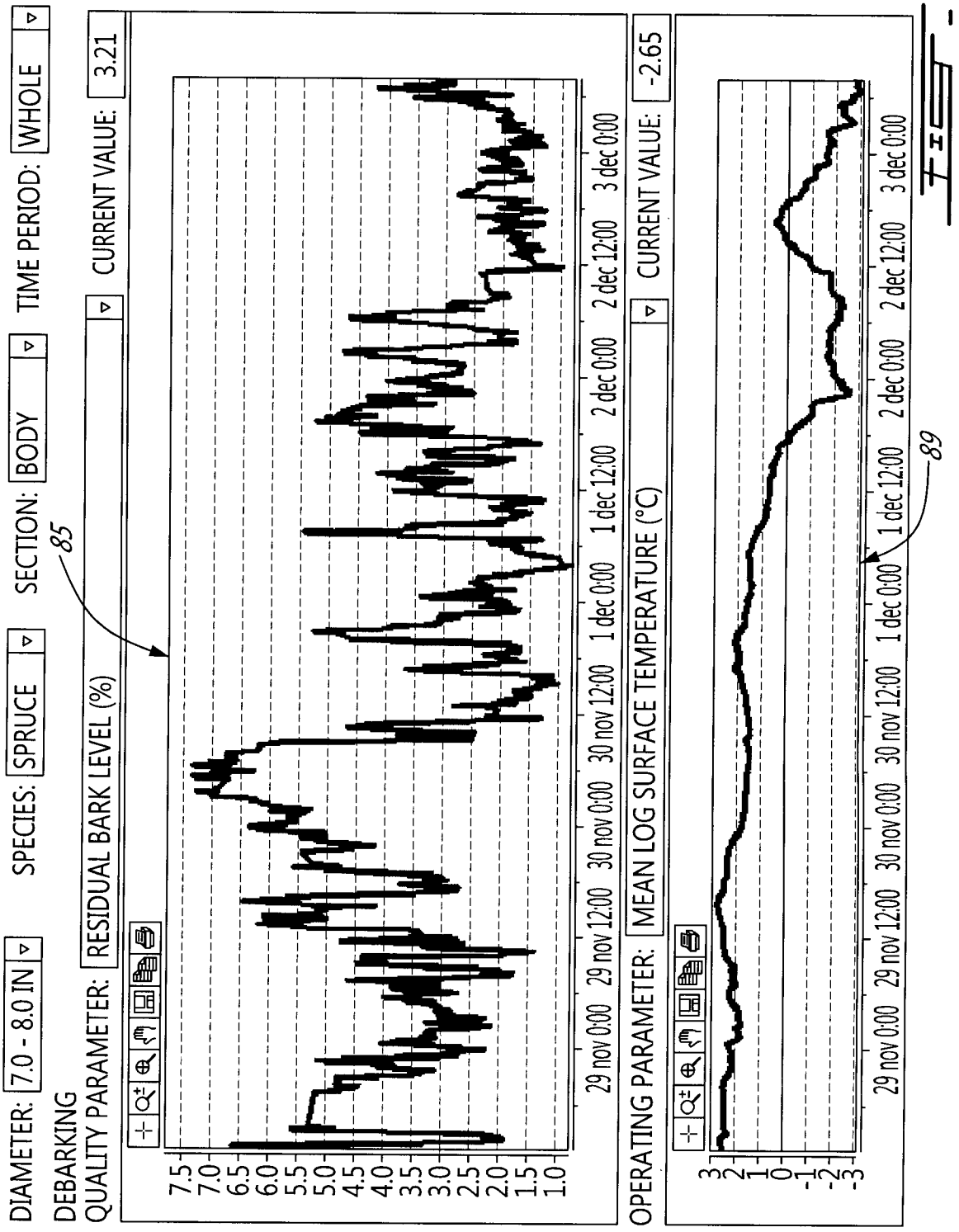

DIAMETER: 7.0 - 8.0 IN
SPECIES: SPRUCE
SECTION: BODY
TIME PERIOD: WHOLE
DEBARKING QUALITY PARAMETER: RESIDUAL BARK LEVEL (%)
CURRENT VALUE: 3.21
85
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
29 nov 0:00
29 nov 12:00
30 nov 0:00
30 nov 12:00
1 dec 0:00
1 dec 12:00
2 dec 0:00
2 dec 12:00
3 dec 0:00
OPERATING PARAMETER: MEAN LOG SURFACE TEMPERATURE (°C)
CURRENT VALUE: -2.65
89
3
2
1
0
-1
-2
-3

Fig - 16

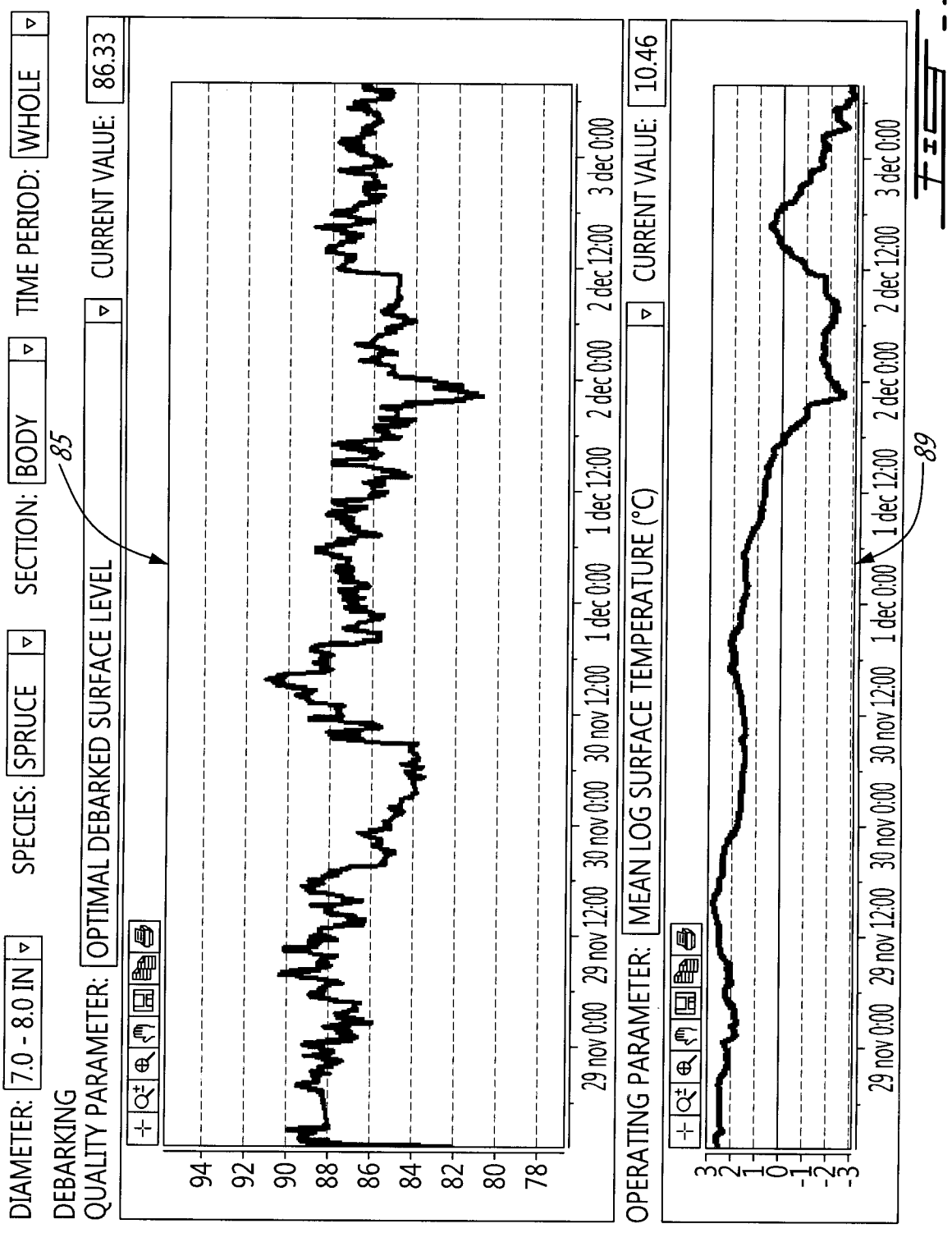

DIAMETER: 7.0 - 8.0 IN
SPECIES: SPRUCE
SECTION: BODY
TIME PERIOD: WHOLE
DEBARKING QUALITY PARAMETER: OPTIMAL DEBARKED SURFACE LEVEL
CURRENT VALUE: 86.33
85
94
92
90
88
86
84
82
80
78
29 nov 0:00
29 nov 12:00
30 nov 0:00
30 nov 12:00
1 dec 0:00
1 dec 12:00
2 dec 0:00
2 dec 12:00
3 dec 0:00
OPERATING PARAMETER: MEAN LOG SURFACE TEMPERATURE (°C)
CURRENT VALUE: 10.46
89
3
2
1
0
-1
-2
-3

Fig - 17

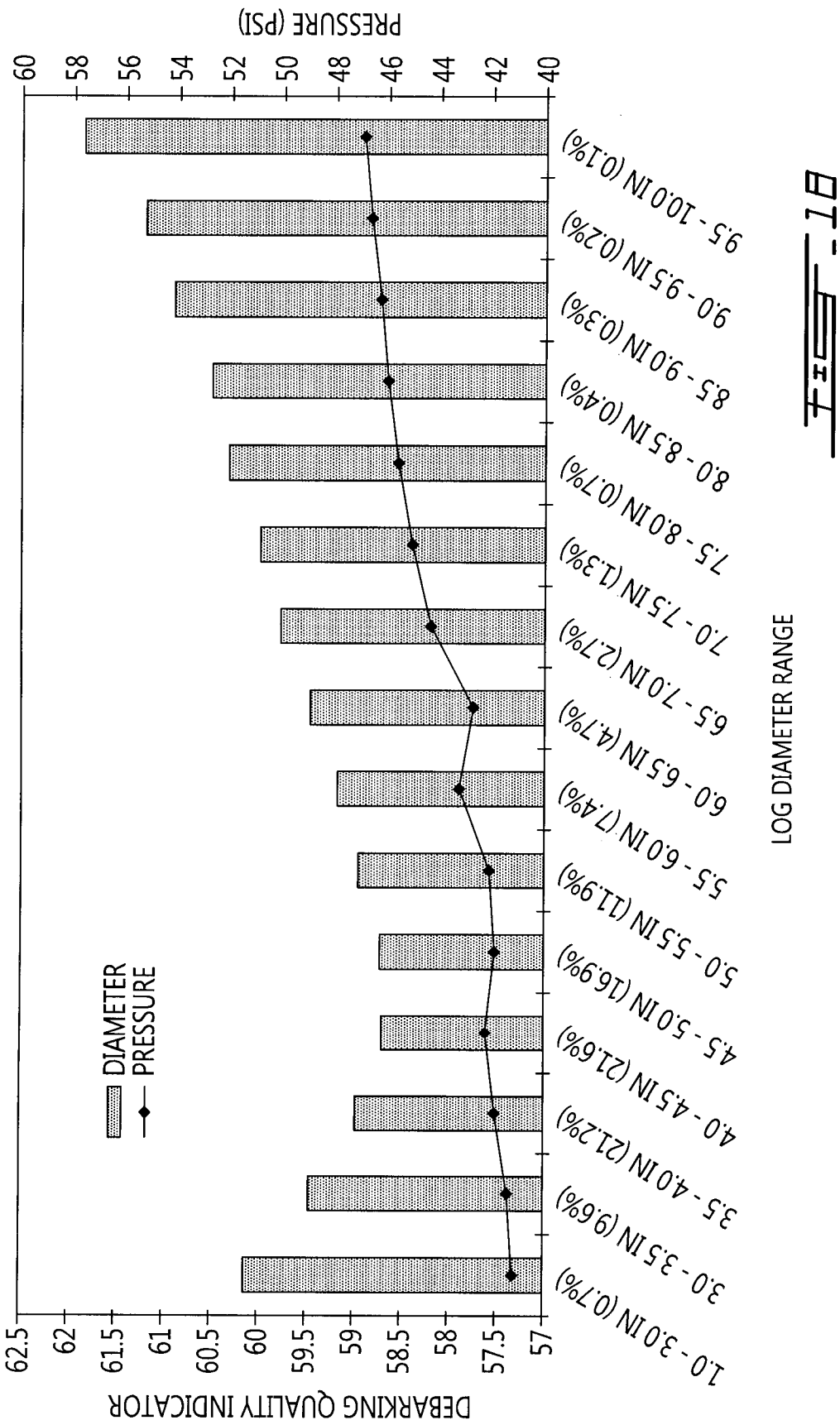

PRESSURE (PSI)
60
58
56
54
52
50
48
46
44
42
40
DEBARKING QUALITY INDICATOR
62.5
62
61.5
61
60.5
60
59.5
59
58.5
58
57.5
57
DIAMETER
PRESSURE
1.0 - 3.0 IN (0.7%)
3.0 - 3.5 IN (9.6%)
3.5 - 4.0 IN (21.2%)
4.0 - 4.5 IN (21.6%)
4.5 - 5.0 IN (16.9%)
5.0 - 5.5 IN (11.9%)
5.5 - 6.0 IN (7.4%)
6.0 - 6.5 IN (4.7%)
6.5 - 7.0 IN (2.7%)
7.0 - 7.5 IN (1.3%)
7.5 - 8.0 IN (0.7%)
8.0 - 8.5 IN (0.4%)
8.5 - 9.0 IN (0.3%)
9.0 - 9.5 IN (0.2%)
9.5 - 10.0 IN (0.1%)
LOG DIAMETER RANGE

Fig-18

Fig. 19

Fig. 20A

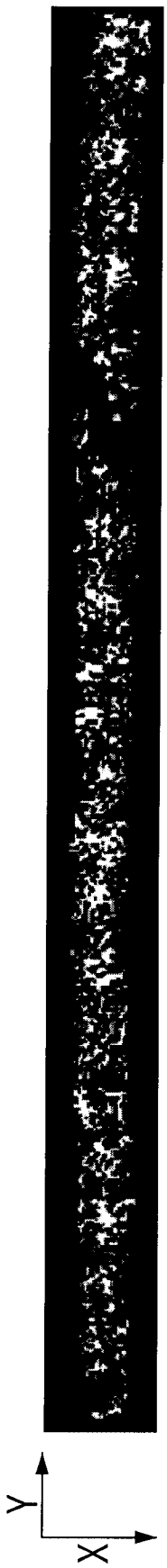



Fig. 20B

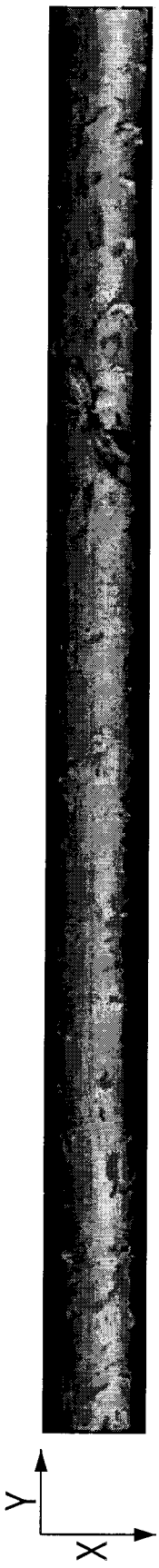



Fig-21A

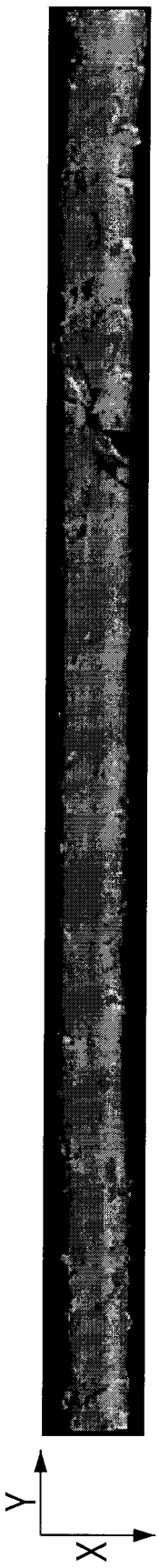



Fig-21B

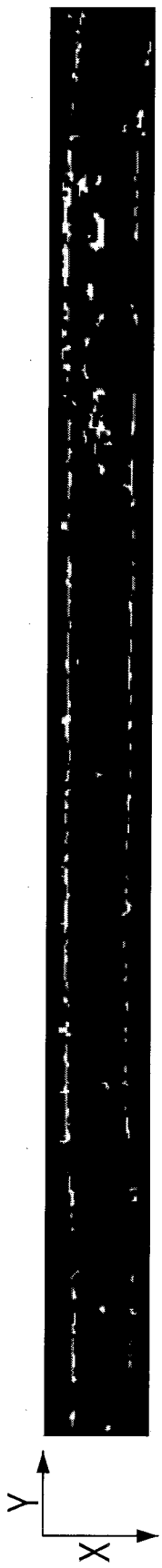
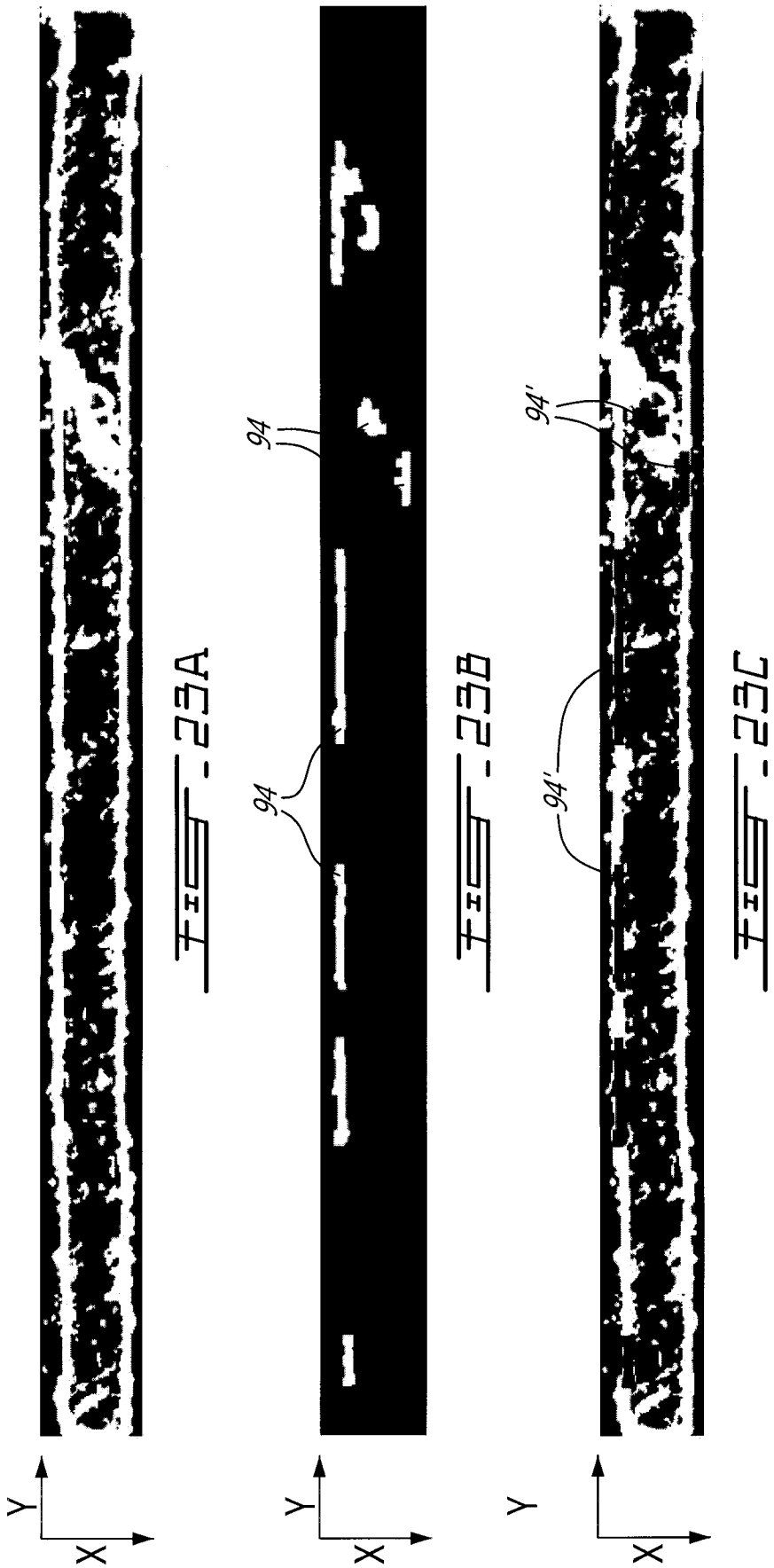



Fig-22


94
94
94'
94'
Y
X
Y
X
Y
X

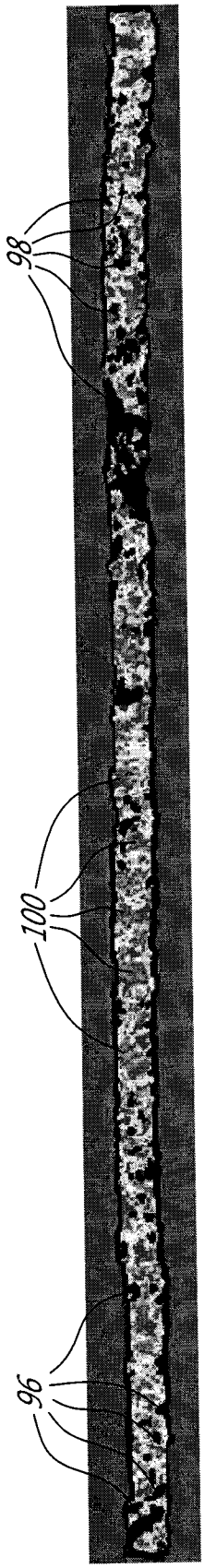



Fig - 24

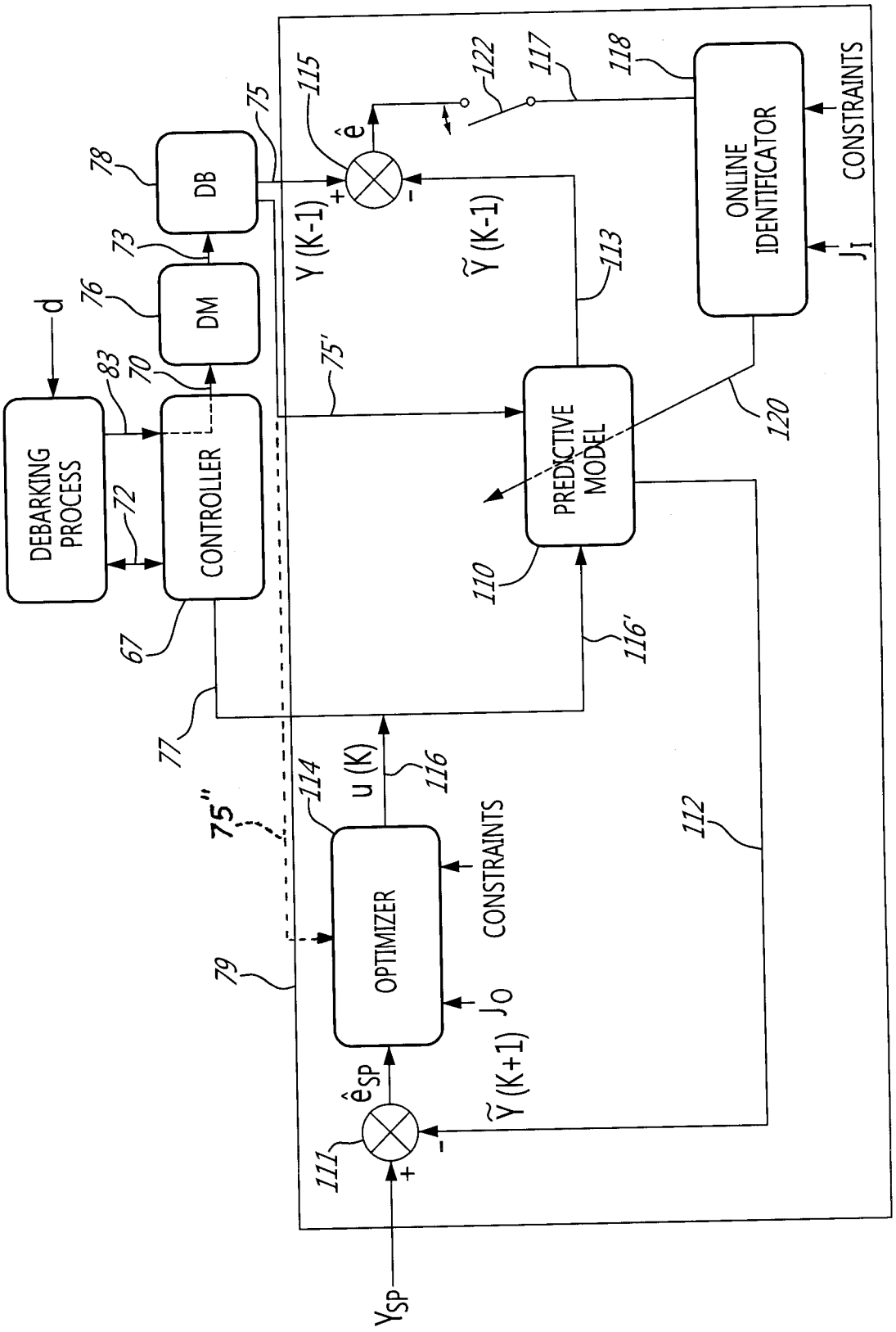

DEBARKING PROCESS
CONTROLLER
DM
DB
d
67
72
73
75
76
78
83
70
77
75'
75"
79
114
u (K)
116
OPTIMIZER
CONSTRAINTS
$J_O$
$\hat{e}_{SP}$
$\tilde{Y}$ (K+1)
111
$Y_{SP}$
112
PREDICTIVE MODEL
110
116'
113
Y (K-1)
$\tilde{Y}$ (K-1)
115
$\hat{e}$
122
117
118
ONLINE IDENTIFICATOR
CONSTRAINTS
$J_I$
120

Fig - 25

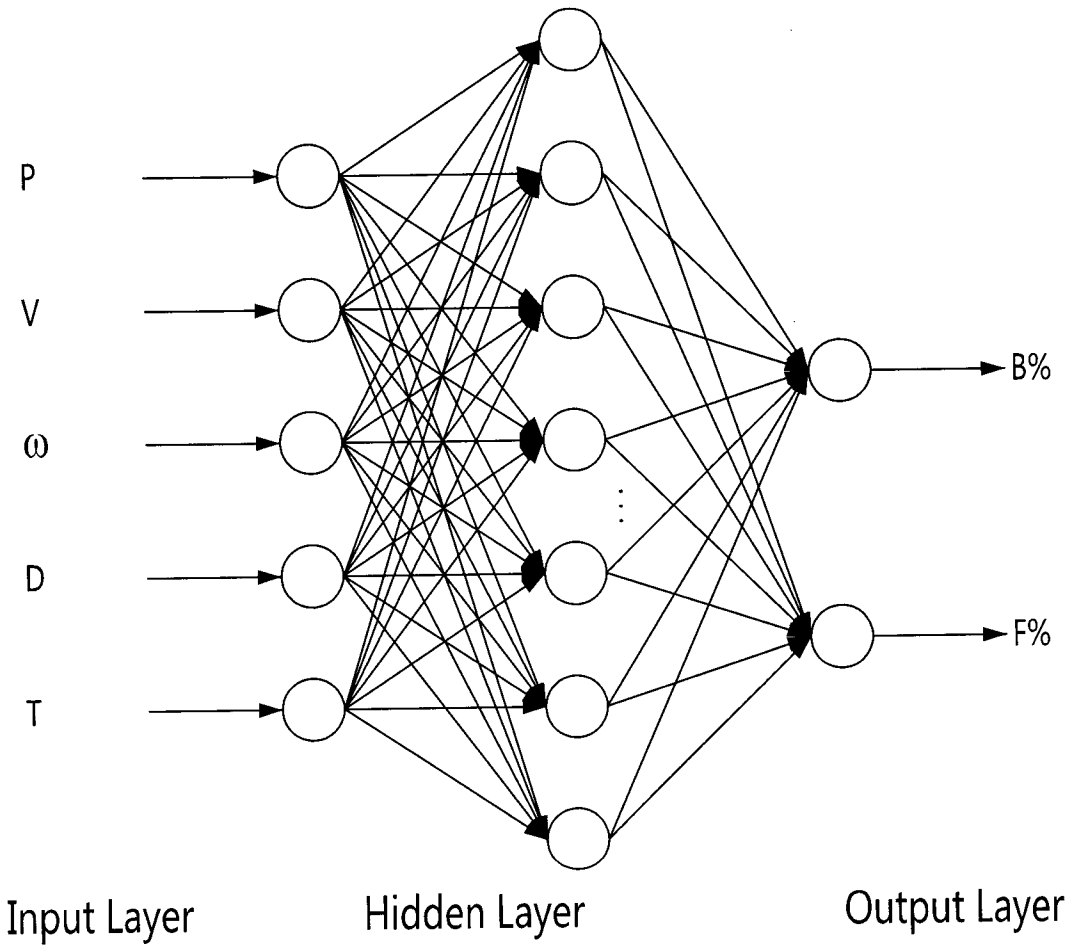
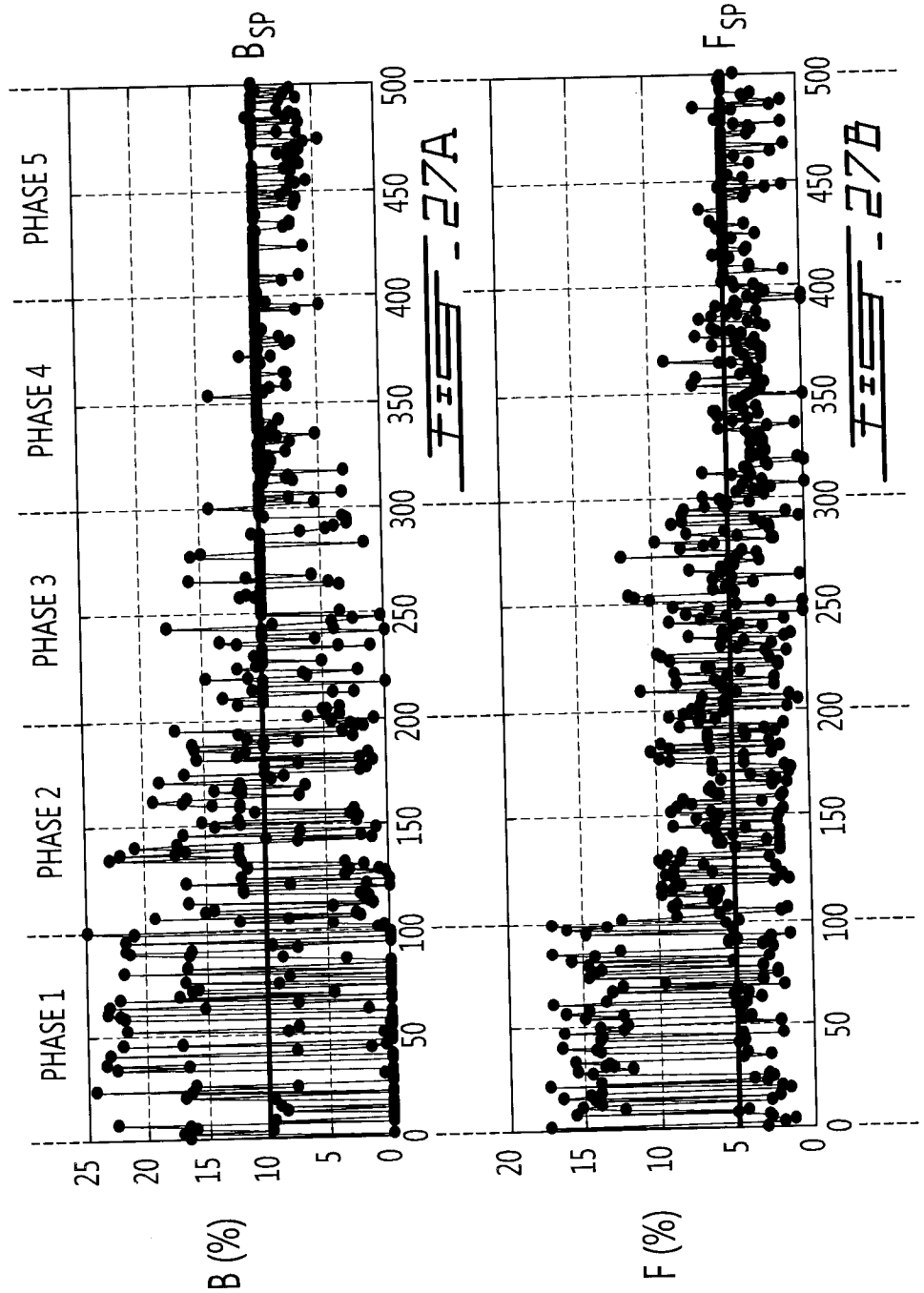
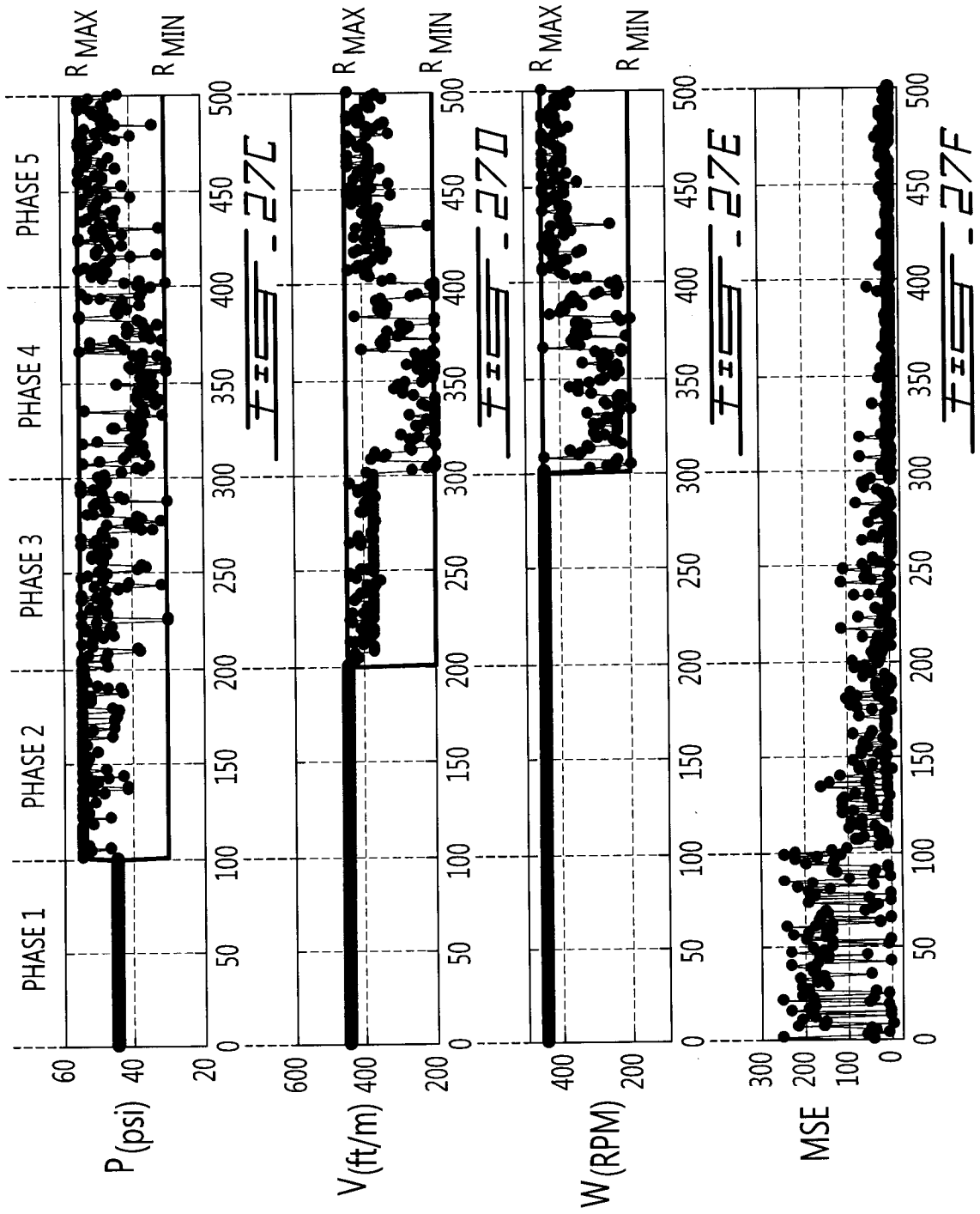



Fig. 26


B SP
F SP
PHASE 1
PHASE 2
PHASE 3
PHASE 4
PHASE 5
B (%)
F (%)
0
50
100
150
200
250
300
350
400
450
500
0
5
10
15
20
25
FIG - 27A
FIG - 27B


R MAX
R MIN
PHASE 1
PHASE 2
PHASE 3
PHASE 4
PHASE 5
P (psi)
V (ft/m)
W (RPM)
MSE
0
50
100
150
200
250
300
350
400
450
500
20
40
60
200
400
600
FIG - 27C
FIG - 27D
FIG - 27E
FIG - 27F

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/CA2013/000368

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***B27L 1/00*** (2006.01) , ***G06T 7/40*** (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: ***B27L 1/00*** (2006.01) , ***G06T 7/40*** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
EPOQUE (EPODOC)
KeyWords: light, camera, image, three dimentional, 3D,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | WO2010037206 A1 (BRDICKO, J. et al.) 8 April 2010 (08-04-2010)<br>*[30]-[33], [36], [37]; Figure 5* | |
| A | WO9107653 A1 (JOHANSSON, L. et al.) 30 May 1991 (30-05-1991)<br>*Abstract; Figures 1-7* | |
| A | US2769468 A (SWANSON, W. R.) 6 November 1956 (06-11-1956)<br>*Abstract; Figures 1, 5, 6* | |

[ ] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 9 July 2013 (09-07-2013) | 9 July 2013 (09-07-2013) |

| Name and mailing address of the ISA/CA | Authorized officer |
|---|---|
| Canadian Intellectual Property Office<br>Place du Portage I, C114 - 1st Floor, Box PCT<br>50 Victoria Street<br>Gatineau, Quebec K1A 0C9<br>Facsimile No.: 001-819-953-2476 | Zachary Rokosh (819) 956-0848 |



Nicholson Manufacturing Ltd.
EX-1004, Page 89

| Patent Document Cited in Search Report | Publication Date | Patent Family Member(s) | Publication Date |
|---|---|---|---|
| WO2010037206A1 | 08 April 2010 (08-04-2010) | CA2737326A1 | 08 April 2010 (08-04-2010) |
| | | CA2737326C | 08 January 2013 (08-01-2013) |
| | | EP2344307A1 | 20 July 2011 (20-07-2011) |
| | | US2010236664A1 | 23 September 2010 (23-09-2010) |
| | | US8215347B2 | 10 July 2012 (10-07-2012) |
| WO9107653A1 | 30 May 1991 (30-05-1991) | AT134270T | 15 February 1996 (15-02-1996) |
| | | CA2068650A1 | 15 May 1991 (15-05-1991) |
| | | DE69025408D1 | 28 March 1996 (28-03-1996) |
| | | DE69025408T2 | 05 September 1996 (05-09-1996) |
| | | EP0502041A1 | 09 September 1992 (09-09-1992) |
| | | EP0502041B1 | 14 February 1996 (14-02-1996) |
| | | FI922179A | 13 May 1992 (13-05-1992) |
| | | FI103076B | 15 April 1999 (15-04-1999) |
| | | FI103076B1 | 15 April 1999 (15-04-1999) |
| | | JPH05503990A | 24 June 1993 (24-06-1993) |
| | | SE466420B | 10 February 1992 (10-02-1992) |
| | | SE466420C | 17 June 1993 (17-06-1993) |
| | | SE8903821D0 | 14 November 1989 (14-11-1989) |
| | | SE8903821A | 15 May 1991 (15-05-1991) |
| | | SE8903821L | 15 May 1991 (15-05-1991) |
| | | US5274244A | 28 December 1993 (28-12-1993) |
| US2769468A | 06 November 1956 (06-11-1956) | None | |



Nicholson Manufacturing Ltd.
EX-1004, Page 90