Innovations in textile machine and instrument

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This paper reports an overview on the innovations in textile machine and instrument. The former is machinery system for manufacturing textiles, while latter is a kind of machinery system for measuring quality of textile materials in processing or products; both are however common in the points of both “textile material” and “machinery system”. In each of both these sections, general scope on the trend of its technological progress has been described based on a systematical classification and then some examples of significant innovative technologies are introduced.

Keywords: Fabric, Fibre, Textile measuring instrument, Textile machine, Yarn

1 Innovations in Textile Machine
1.1 Introduction of Textile Machines

Clothing, food and house are the big three essential needs for human life. One of the most important necessary conditions is that the clothing should be supplied with reasonable price. In the history of textile industry, very significant progress in production efficiency has been observed by several innovative inventions in textile machines. We would not enjoy life with plentiful clothing without such innovations. In 2003, the total production amount of textile machine in the world was about 18 billion US dollar, though it was less than 1% of those of textile / clothing industry.

In addition, the progress of textile machine has contributed to the progress of machines in other fields of industries. One of its typical examples was put forward by Toyota Motor Co. The many basic technologies of automatic weaving machine developed by Mr. Sakichi Toyoda were connected to the birth of the automobile manufacturing company.

Textile machine can be divided into the two categories, namely commercial or non-commercial. The former is commercially manufactured by machinery maker. The customer can usually use it without any patent restriction. In this case, the total processing technology comprises machine system technology belonging to its machine manufacture and operation technology which further belongs to machine user. In the competitive situation among machine manufacturers, machine user can usually obtain its common operation know-how from its supplier. Then the user can produce textile products from the machine by a comparatively easier way. On the other hand, the machine user has obliged to face with many competitors who bought similar kind of machine.

In case a textile producer has succeeded in development of a certain special processing technology for a value-added product using his original machine system, usually he must think of not to publicize the system technology and to keep be guarded from any outer party. Then the machine will become non-commercial. Most of highly profitable specialty products have been made based on such an original processing system. But if the market of the products is expected to be so voluminous that such kind of machine system can be commercialized, some of machine manufactures must naturally think to sell the system by overcoming the restrictive barriers. This way, some of non-commercial machine can become commercial. One of its typical examples is conventional melt spinning system for fibre production. Hence, non-commercial textile machine is usually limited to only highly advanced technologies for highly specialty products. In this paper, the main theme is focused on recent technological progressive trends and innovations in commercial machines.

Textile machines can be classified by production objects into the following 5 categories; namely machines related to (i) fibre manufacturing, (ii) spun yarn manufacturing, (iii) fabric manufacturing, (iv) dyeing and finishing, and (v) recycling. Concerning fabric manufacturing, it can be further divided into weaving, knitting, and nonwoven making. In the first

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part of this paper, textile machines are described according to such a classification.

Higher production efficiency, shorter processing step, higher quality of product, higher energy saving, easier operation adaptability for user and more flexibility for producing multiple products are commonly directive targets in technological progress of these machines, even though their priority is decided, depending on a case by case base.

1.2 Machines for Fibre Manufacturing
1.2.1 General Scope of Fibre Manufacturing

Representative system for fibre manufacturing is melt spinning system. There are some other types of spinning system such as wet spinning and dry spinning, but most of them are related to non-commercial machine system.

Various major melt spinning systems include the systems for making multi-filament, staple fibre, and bulked continuous carpet yarn. The system to make straight multi-filament is usually one step process which is consisted of extruding, quenching, drawing and winding as main parts. In the case of partially oriented yarn which is usually converted to textured yarn by false twisting, drawing is usually saved in the above-mentioned process.

Representative system for texturing multi-filament is false twisting machine whose main functions are simultaneous drawing and false twisting. It is usually composed of heating zone, cooling zone, drawing mechanism and false twisting mechanism.

1.2.2 Innovative Progress for Fibre Manufacturing

Considering the technologies for high productivity in melt spinning of multi-filament, it has been found that in the early stage of multi-filament production, drawn filament was produced by the following two step methods. In the first step, un-drawn yarn is spun by take-up winder with 2-4 ends, whose speed is about 1000 m/min. In the second step, it is drawn by draw-twisting machine. In the last 30 years, its production efficiency has innovatively increased by the following ways:

(i) The two steps have been converted into one step, in which drawing part is incorporated into spinning machine or into false twisting machine.
(ii) The speed of winder has increased from 3000 m/min to 6500 m/min.
(iii) The number of ends has much increased up to such as 24, which also causes a decrease in electric power consumption / end.

In the last 30 years, false twisting machine has much progressed in its high productivity, high quality products, and versatility for specialty yarn production. High temperature and short time heating zone with a non-contact method, rapid cooling mechanism after the heating, and winder with individual driving mechanism for each position are major contributing factors to increase the operation speed up to 1200 m/min. Monitoring and control mechanism at false twisting zone, high temperature heating zone, and improvement in false twisting spindle are major contributing factors to increase the operation speed up to 1200 m/min. Monitoring and control mechanism at false twisting zone, high temperature heating zone, and improvement in false twisting spindle are effective to realize high level of quality control. Individual driving mechanism for each position has given much freedom to match specialty yarn production.

1.3 Machines for Spun Yarn Manufacturing
1.3.1 General Scope of Spun Yarn Manufacturing

Figure 1 shows a classification for major short staple fibre spinning systems. Usually, in staple fibre spinning system, blocks of staple fibre are broken and opened into carded web. Then it is converted to sliver by the action of drawing and combing. The sliver is converted to spun yarn on the spinning frame. In this case, roving process is involved for ring spinning system. Further rewinding process is necessary for ring spinning system, in which the yarn length is enlarged for the next fabrication process.

Spinning method can be classified into real twisting and open end twisting. Ring spinning is representative of the former method and is traditional. In ring spinning, twist is substantially inserted into a yarn by using a circulating traveler. The twisted yarn is wound on to the spindle package whose rotational speed is greater than that of the traveler. In this method, twisting and winding of yarn are carried out...
at the same time by such a smart mechanism. But the size and the rotational speed of the spindle package are mechanically limited.

In open end spinning, twisting action and winding action are separately carried out by making open end in the course of yarn formation. In this, its available ranges in rotation speed for twisting and in the take-up speed of winding can be much enhanced. Several kinds of open-end spinning system have been developed. But rotor spinning and air-jet spinning are commercially well successful. As described later, as far as the production efficiency is concerned, they have far more great advantages over ring spinning. In that sense, they are truly innovative in spinning process.

1.3.2 New Splicing Technology

Yarn splicing is very important in spun yarn manufacturing. Traditionally, mechanical knotting has been utilized for this purpose. But the knot thus formed causes bad effect for successive fabrication process. Murata Machinery Co. presented air splicing machine at ITMA of 1979. In the machine, the two yarns to be connected are pneumatically untwisted. After overlapping, they are pneumatically twist-entangled with each other. The yarn thus connected has no knot as shown in the middle of Figure 2b. Air splicing is widely utilized in the process of rewinding and high speed yarn spinning. Recently, water splicing machine has developed in which twist entanglement is conducted by air stream containing water mist. The spliced part obtained by water slicing is more compacted and is smoother than that by air splicing as shown in the bottom of Fig. 2c (ref. 3).

1.3.3 Progress in Technologies of Ring Spinning

Double apron drafting has much contributed to obtain super high drafting such as 100 (ref.4). Electrically controlled draft system has enabled easy flexible production of fancy yarn.5 Several approaches with different ring design, such as orbit ring, ceramic ring and rotating ring, for reducing the limitation imposed by traditional rings, and travelers have been proposed.4 The tracking of spindles from the ring frame is very useful for process quality control, because it enables to identify those spindles responsible for producing defective yarn on the ring frame.4

Yarn produced by compact spinning has much less hairiness and higher strength compared to conventional ring-spun yarn, which causes better process-ability in sequential process. The improvement in hairiness causes clean appearance and higher pill resistance of the fabric. Figure 3 illustrates the principle of compact spinning.6 In compact spinning, drafting roll has a perforated band zone as shown in Fig. 4. By the pneumatic suction, the width of drafted sliver is reduced to $b_{com}$ and then the size of the spinning triangle is decreased, which effectively prevents to grow the hair of the yarn.

1.3.4 MVS Spinning

As shown in Fig.1, MVS belongs to air-jet spinning. Air-jet spinning was originated from fasciated yarn proposed by DuPont Co.. The fasciated yarn was commercialized as MJS using two serial air-jet nozzles by Murata Machinery Co. in 1980. By this method, medium to fine thickness yarns can be produced with a high speed as 300m/min. This method was successful in the yarn production of 100% polyester and blended polyester yarns. But it is not feasible to produce cotton yarn by the system. The handle of its fabric gives rather hard feeling. In this

![Fig. 2—Connection parts by three kinds of splicing methods](image)
situation, MVS spinning machine was presented in 1997 by Murata Machinery Co.

Figure 5 illustrates the yarn formation by MVS method. The front part of fibres in the sliver is mechanically pulled into the center hole of the spindle. The backside of the fibres remains at the outside of the spindle and these fibres are sequentially wounded on the forming yarn by circulating vortex air. Hence, the yarn is composed of straight parallel fibres in its core part and really twisted fibres in its sheath part. The fibres shorter than 12mm are mostly removed by the vortex air in the process.

Sliver obtained by drawing machine is supplied to MVS machine. The sliver drafted by rolls and aprons is transferred to spinning zone as shown in Fig. 5. Passing on the yarn cleaning device by which yarn defects are removed, the yarn is wound at a high speed of 450 m/min, which is higher than the speed of 250 m/min in rotor spinning. In MVS system, the yarn can be wound onto conical package by using a special yarn accumulation device.

Rotor spinning is feasible to the production of yarn in the thickness range from 15 tex to 240 tex. On the contrary, MVS is applicable to the range from 8.7 tex to 45 tex. MVS can be extended to worsted yarn spinning and also core yarn spinning.

MVS yarn has less hairiness than conventional ring-spun yarn and also rotor yarn. The tenacity of MVS yarn is lower than that of ring yarn, but higher than that of rotor yarn. The main features of MVS yarn fabrics are: clear appearance with less fuzz, higher pilling resistance, higher water transfer rate and no torque deformation in knitted fabrics.

1.4 Machines for Woven Fabric Manufacturing

1.4.1 General Scope of Woven Fabric Manufacturing

Process for making woven fabrics is consisted of preparatory process for weaving and weaving. In preparatory process, there are warping / beaming, (sizing), looming. (dyeing for yarn dyed cloth) and (twisting). Among them, warping / beaming and looming cannot be eliminated. Weft preparation is carried out into such form as conical cheese or weft bobbin, if necessary. Several kinds of machine for
loomings have been developed to reduce its labour involved.

Weaving machines are classified as shuttle loom, shuttle-less loom and some special kinds of loom such as circular loom, tri-axial loom and three dimensionally axial loom. Air-jet loom and rapier loom belonging to shuttle-less loom category are representative of major advanced looms. Significant technological progress in shuttle-less loom is oriented to higher productivity, lower energy consumption, easier access to operation, and higher versatility in its products. It has been carried out by making an effective use of mechatronics under severe competitive situation. Figure 6 shows the trend of progress in productivity of major shuttle-less looms. Air-jet loom is advantageous over rapier loom in terms of productivity. But as a whole, the latter is more excellent in versatility of fabrication than air-jet loom.

1.4.2 Multi-phase Loom

The research based on the concept of multi-phase weft insertion was started in 1955. Multi-shed formation was realized by the two basic techniques, namely wave-shed and multi-linear. At ITMA’ 83, some manufacturers demonstrated wave-shed technique. But technological obstacles prevented the concept to achieve market success. There were inherent shortcomings, such as the difficulty of repairing mis-picks, difference in weft tensions as a consequence of several weft-yarn carriers being activated at the same time and difficulty to achieve the required beat-up necessary to obtain uniform insertion across the entire weave length.

Sulzer demonstrated M8300 multi-phase loom at ITMA’ 99, which is designed exclusively to be a single-warp machine and earmarked for mass-production of standard fabrics without multi-colour mechanism. It has 4 sheds located in series across the circumference of a weaving central rotor. The individual shed is form-fit. Spreading the warp threads on the shed-holding element is achieved with the aid of warp positioners similar to needle bars of knitting machines. Insertion is performed with low-pressure blast of air through a weft channel formed by the shed-holding elements. Additional relay nozzles are placed within the shed-holding elements. Insertion rate is 1200m/min and then totally 4800m/min. The combs positioned on the circumference of the weaving rotor accomplish weft beat-up. They are located between two rows of shed-holding elements and replace the function of conventional weaving reeds. All motions are programmable to ensure adaptation to weaving requirements through electrically controlled drive.

The features of the loom are about three folded productivity with simple standard fabrics, lower specific energy consumption, and much lower noise level with lower process cost.

1.4.3 Weave Navigation System

Tudakoma Corp. has developed an operation software system named as “Weave Navigation System”, by which the user can easily find the right way for operating the loom manufactured by the company under several weaving conditions. In the system, know-how data accumulated in the company for operating the loom are incorporated. It is composed of the following four kinds of functional sub-systems, namely Tune Navi, Trace Navi, Self-Navi, and Auto Cruise. In the system, the loom itself has the main function of each sub-system and is connected with PC in the office by LAN. By inputting the data of the woven fabric to be produced into Tune Navi, the user can get the information on its optimal working conditions for weft insertion and warp tension, and at the same time, the loom can automatically select the new working conditions. The sub-system can also indicate the optimum level of air pressure, the optimum adjustment data on the mechanical condition, such as the position of tension roll, and data to be acted for preventing stop mark on the fabric. Self-Navi can deliver the information on effective maintenance of the loom. Auto Cruise has the function to automatically drive the loom for stable working and for minimizing fabric defect.
1.4.4 Flexible Preparatory System for Weaving Yarn-dyed Figured Cloth

Yarn-dyed figured woven fabrics are usually produced based on many lots, with small size. In their production, it has been quite usual that the frequent change in lots causes much loss of time and material with intensive labour work. Katayama Trading Co. and Murata Machinery Co. have developed a flexible preparatory system for weaving yarn-dyed figured cloth. Its main technological element is a new arranging winder as illustrated in Fig. 7. It works according to the program using PC. In the case of cloth having three colour vertical stripes like the fabric shown in Fig. 7A, a package of warp yarn which sequentially contain blue part, red part and pink part with precisely controlled length for each colour is made by the winder in the order of blue dyed yarn, red dyed yarn and pink dyed yarn as illustrate in Fig. 7B. The winder selects a coloured yarn according to the program. After connecting the yarn with the forward yarn, the length of yarn selected is mechanically measured and then intermittently wound on a package for warp yarn. Figure 7C shows the device for measuring yarn length.

Packages thus obtained are transferred to the process of sectional warping or beam warping. Using this system, the fabrics composed of warp yarn sequentially having several kinds of colours can be smoothly produced with very low cost and time involvement.

1.4.5 Automatic Fabric Inspection

Fabric defects are a cause of major concern for any quality conscious textile mill. These may be due to inherent defects in the yarn, bad preparation of warp and weft, improper machine condition, bad working practices, improper ambient and so on. In fact, it is impossible to produce 100% defect-free fabric. However, defect level can be minimized by taking appropriate measures. Till today, most of the mills are using visual examination of fabrics in which the fabric is inspected on the illuminated inspection table. Although, eye has approximately 10000*10000(=100million) sensor-elements with a processing capability of human brain equivalent to 50-100 million PC’s, 25% faults in the fabric go undetected during visual examination. Because of low production rate and variation in identification of faults due to subjective judgment of operator, this method fails to produce standardized fault-free fabric. In order to overcome this problem, the state-of-the-art technology for automatic fabric inspection and marking the defect position has been developed, which eliminates the human element involved, reducing the variance in the results to a minimum level. Although it is well established that the complex function of the eye cannot be simulated by any means but for the purpose of inspection of fabrics, a good and appropriate image acquisition system is being used for automatic inspection. Decision making is carried out with the help of pattern recognition algorithms. Fourier transform has been the fundamental basis for image processing. Software has been developed to store all the results of inspection which can further be used for analysis and giving feedback to back process in very short time. This would help in taking timely corrective action at various stages of manufacturing at a later stage where from the defect or faults are originated. There is a 100% fabric inspection and least variation in the
results of inspection. One vital aspect of automatic gray fabric inspection is getting information back to the weaving department when off quality goods are turning up. This is especially true when running defects are detected. This helps in follow up action for taking necessary corrective measures.\textsuperscript{15}

1.5 Machines for Knitting

1.5.1 General Scope of Knitting Machines

Knitted fabric can be classified into two categories, namely weft knitted fabric and warp knitted fabric. In the former, knitted loops made by each weft thread are formed substantially across the width of the fabric. Warp knitted fabric is composed of knitted loops in which warp threads forming the loops travel in warp-wise direction down the length of fabric. Weft knitted fabrics can be conventionally divided into flat knitted fabric which is made by a machine having straight needle bed, and circular knitted fabric which is made by a machine having the needle set in one or more circular beds.

Flat knitting machine is feasible to make fashioned parts to be linked and non-sewn seamless knitted fabrics whose typical example is WholeGarment\textsuperscript{®}. Circular knitting machine is designed to produce garment-length fabrics of seamless inner wear and high gauge fabrics for cut-sewing process. In warp knitting machine, threads are delivered from warper’s beam and therefore this process is less flexible. But it can produce fabric having more stable structure with higher productivity and can also be applicable to produce axially structured fabrics. Its fabric is mainly used for household, technical textiles and composite reinforcement.

The introduction of stitching motion and related mechanisms driven by electronic system in these knitting machines has given much rise in their freedom to create versatile fabric structures, and in their productivity. For example, garment-length fabrics have become applicable to seamless women’s innerwear, which can be produced by making an active use of the freedom in changing the stitch density and the number of stitch during knitting operation.\textsuperscript{16}

1.5.2 WholeGarment\textsuperscript{®}

Typically, a knitted garment consists of separate parts (the front and back body panels, and sleeves) which are sewn together afterward. In contrast, WholeGarment\textsuperscript{®} knitwear is produced in one entire piece, three-dimensionally, directly on the knitting machine. Hence, it requires no post production process. It can also save cut-loss incurred by cut & sew system.

Shimaseiki Co. presented the machine at ITMA’ 1995, which uses digital stitch control mechanism, four-bed technology and slide needles in stead of latch needles. Four-bed technology ensures to realize higher stitch density. Slide needle which was a newly designed needle for the machine gave rise to higher productivity by its smaller moving distance, and to natural loop configuration by its symmetrical loop formation (Fig. 8). In addition, the needle realized 12 ways loop forming technique contrasting with 6 ways technique of latch needle, by which so-called gauge-less knitting can be performed.

In the knitwear, bulky and annoying stitch at the shoulders, side and underarms are eliminated. Seams no longer interfere with the natural elasticity of knits. The knit wear can be made to three-dimensionally fit the body and to form good silhouette by computer aided designing. The company has also developed CAD system by which designer can conduct a visual design in terms of colour / pattern and silhouette. Then product planner can decide the knit wear to be produced by selecting / confirming the test samples made through the CAD system. Then the result can be easily converted to production. Therefore the CAD system in the combination with the machine can be practically a useful tool for mass customerization.\textsuperscript{17,19}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig8.png}
\caption{Comparison between latch needle and slide needle\textsuperscript{19} [(a) configuration and motion of needles, and (b) effect of slide needle for loop formation]}
\end{figure}
1.5.3 Machines for Axially Structured Warp Knitted Fabrics

Figure 9 (A) shows warp knitted fabric of uni-axial structure. Figure 9 (B) shows multi-axially layered sheet stitched by warp knitting mechanism, in which one layer is composed of web. From the viewpoint of warp knitting mechanism, they are manufactured by not so highly sophisticated technologies. But such axially structured warp knitted fabrics are now expanding as reinforcing materials for geotextiles and composites. Especially, the multi-axially layered sheet is used for the reinforcement of turbine in wind power plant and hull in small ship.

1.6 Machines for Nonwoven Manufacturing
1.6.1 General Scope of Nonwoven Manufacturing

Usually the nonwovens are produced by web forming process and bonding process in which web is integrated into a fabric. Figure 10 shows a total view of major production methods in terms of web forming and bonding.

The production method of microfibre web can be described by melt-blowing, flash spinning and spun-laying of splittable or island-sea bi-component fibre. But recently two kinds of new spinning methods have been proposed, namely Nanoval for producing microfibre web and electro-spinning for processing nano-sized fibre web.

Carding is most traditional among web forming and is usually disadvantageous in regard to production cost over spun-laying. But much technological improvement in productivity and quality, with respect to its inherent production flexibility have made carding still competitive to spun-laying. Some technologies including web-folding have been developed to obtain the nonwovens in which fibres are highly oriented in the thickness direction.

Bonding of spunlacing which entangles web by water-jet was commercialized in 1973 by DuPont. But since 1990, it has been much enlarged by the start of its commercial machine for bonding such types of web as carding, wet forming, spun-laying and air-laying. Recently, bonding using super-heated steam-jet has been developed. The bonding is accomplished by a combination of fibre entanglement and thermal bonding. Subsequent drying is not usually required. Fabrics having more bulkiness can be obtained by this bonding.

There have been many technological progresses in needle punching. In its advanced turn, high speed over 100m/min is possible with much lower energy consumption than spunlacing. Improvement in surface appearance is another example of the progress by elliptical needle path. Using specific needles, products having patterned rib and velour have been developed for automotive use.
composite nonwoven having space structure which can be filled by functional particles has also been commercialized.24

By the technological progress in the applicability of spunlacing to high line speed operation, the combination of spunlacing and spunlaying has become useful. Its product has high softness, absorbency and permeability with lower production cost. By applying splittable bi-component fibre to this combined system, microfibre nonwoven like Evolon® has been economically produced, because the splitting can be performed by the mechanical action of the aqua-jet in the spunlacing. The production system of combined nonwovens in which melt-blown web (M) is reinforced by spun-laid web (S) in-line have been commercialized. There have been several kinds of combinations such as SMS and SSMMS.

It must be noted that some vertical integrations in nonwoven machinery have significantly been carried out, by which the buyer can purchase complete manufacturing line with systematic operation know-how.21

1.6.2 Nanoval Technology

This technology has been recently developed by Nanoval GmbH & Co. of Germany. In the process, each monofilament melt fluid extruded from spinneret is drawn by the friction of air flow which is steadily accelerated, as schematically shown in Fig. 11. As soon as the internal pressure in the monofilament melt exceeds the external gas pressure, it is caused to burst open spontaneously. It can split into a multitude of very fine filaments, whose diameter is 2-10 µm. The number of split filaments from one monofilament is more than 20 up to several hundred. With the spinneret nozzles arranged in rows, these continuous micro filaments thus formed from many monofilaments are deposited as web on a conveyer belt. There is no specific limitation in the selection of the polymers to which this method is applied. The most significant point of its advantage over melt-blown method is much lower specific energy consumption.25 The author understands that the machine of this technology has not yet fully commercialized, but it can be available by certain license.

1.6.3 Electro-spinning Technology

Electro-spinning is one of the most appropriate methods to produce nano fibre web in which strong electro static field is applied between polymer dope capillary and collection screen as schematically shown in Fig. 12 (A). In the case that collection screen is nonwoven backed by an electrode, a nonwoven covered by a thin layer of nanofibre web can be fabricated.

Intensive researches on electro-spinning have been carried out across the globe. As far as author knows, some kinds of electro-spinning apparatus of laboratory scale have been commercialized. But it is
expected that there is a great difficulty in scaling-up such laboratory scale to commercial production, because huge number of spinnerets are needed to keep some level of productivity in the process.

Recently, a promising process for the scale-up has been proposed by a Czechoslovakian group, which is named as Nanospider® process (pamphlet of Elmarco at ANEX, 2006). In this process, many fibre streams are formed from thin layer of polymer solution on a rotating roll by the electro-static field onto upper collection screen, as shown in Fig. 12(B). Elmarco Co. has developed a pilot scale Nanospider machine. It is thought that it can be available by license base for the future potential users.

1.7 Machine for Dyeing and Finishing

1.7.1 General Scope of Dyeing and Finishing

The industrial sector of dyeing and finishing has traditionally consumed very larger amount of energy and water among the other sectors in textile industry. Hence, energy and water savings are big issues for this sector as a whole. The processes in the sector can be conveniently classified as preparatory process for dyeing, dyeing, and finishing. Dyeing can be categorized as high pressure solid dyeing, continuous solid dyeing and printing.

In the preparatory process, continuous treatment machine using ozone has been developed. Washing machines which utilize devices for effective water penetration into fabrics and devices of mangle and vacuuming for effective removal of water from the fabrics have been developed.

Concerning high pressure solid dyeing, there is a clear different direction in the form of machine using liquid flow between large volume production and small volume versatile production. Machines using a large drum vessel have been developed for large volume production. Several devices for water saving in tubular type machines have been developed for small volume production. On the other hand, dyeing machines using moist air flow have been developed for higher water and higher energy savings than liquid flow type machines.

Concerning continuous solid dyeing, smart devices such as a special precision nip roll and compact dye bath system for padding have been developed. The key point for energy saving in the dryer of this dyeing process is to effectively decrease water pick-up of the fabric at washing process. Jetting steam and / or mist to the fabric is one of very useful way.

Traditionally, several kinds of screen printing have been used. CAD systems have been applied to make the screen images. But ink-jet printing is going to give rise of an innovation to printing technologies.

Several kinds of finishing machines have been used according to the purpose of finishing. Concerning heat-setting machine, the main efforts have been made for energy saving by effective heat recycling, and by effective use of air / steam with suitable mechanical action to the fabric, which is also one of the most important factors for obtaining desirable fabric hand. There are also brushing machines to make the suede-like surface of the fabric.

It is expected that the treatments using super critical fluid are very useful for dyeing such fibres as polypropylene and p-aramid, and for introducing functional materials such as metal complex into fibres. But it is still at developmental stage.

1.7.2 Ink-jet Textile Printing

This type of machines has been developed to fit in dyeing fabrics based on ink-jet printers for sheets like paper and film. But the inks must be changed in textile printing and the necessary amount per unit area for textile use is increased by several times. A specific system for conveying device such as belt to which fabrics are fixed is also necessary for the machines.

The inks are jetted onto the fabric through a large number of nozzles such as 360 by a piezo-electricity. The ink must have lower viscosity with higher surface tension than that of the ink used in screen printing. A representative advanced printing machines exhibited at ITMA’ 2007 can be used for dyeing with 16 colours and 600dpi for 3200mm width by the speed of 80 m²/h. Reactive dyeing, acid dyeing, disperse dyeing and pigment dyeing have become applicable to the printing. In March 2008, a machine whose operation speed is 400m²/h at 600dpi with 8 colours was presented by a Japanese company group.

In the past, their printing efficiency was too small to apply them to commercial production. Hence, their use was limited mainly for very small amount of fabric dyeing, such as dyeing image sample. But improvement in their production efficiency has been making ink-jet printing the leading techniques in the field of printing. Images generated by CAD can be most precisely and directly transferred to images printed on the fabric. Filing of image data and their indexation are very easy. Therefore, ink-jet printing has much more feasibility to quick response than
conventional printing.

1.7.3 Aero-flow Piece Dyeing Machines

In this type of machines, the fabric transport takes place by means of a separate gas circuit through humid air or an air-steam mixture without using any liquid. Dyestuffs, chemicals and auxiliaries are dissolved in the processing liquor and injected directly into an air stream. In this way, the liquor is atomized and evenly distributed on the surface of the fabric. Then an optimal penetration of the liquor is carried out within the textile material. The liquor ratio is not dependent on the loading quantities.

Figure 13 illustrates the main part of THEN-AIRFLOW which is representative of this kind of machine. After dyeing, rinsing is carried out by spraying fresh water at the section 3. The fabric slides on the rods 6 covered by PTFE and a small amount of excessive liquor and water falls down to the bottom of the vessel. It is said that this system can save the consumptions of 50% water, 40% chemicals, 40% energy, and 40% operation time.

1.8 Machines for Recycling Textile Wastes and for Utilizing New Fibrous Resources

Ikegami Machinery Co. has developed a machinery system for recycling textile wastes and for utilizing new fibrous resources. The main components of the system are: a breaking machine (i), a tuft forming machine (ii), a tuft blending machine (iii), and a card or a mat forming machine (iv). All the machines except card have been specially developed for the system by the company. The machine (i) can effectively break several kinds of fibrous materials such as selvedge waste, which is equipped with rotating blades specially designed in their shape and in their material. The function of the tuft forming machine (ii) is opening fibrous block produced by the machine (i). The machine (iii) is useful for uniform blending the tuft produced by the machine (ii) with the tuft of conventional fibre. Mat forming machine has been developed to be applied to the tuft composed of very short fibre, in which the tuft and some ratio of thermo-adhesive fibre are air-laid on a net conveyer.

The system can be applicable to fibre skeleton mat obtained from FRP by solving away its matrix resin. Card web made of bamboo fibre having natural anti-bacteria has been produced utilizing the system from bamboo broken by pressured steam bursting.

2 Innovations in Textile Measuring Instrument

2.1 Introduction of Fibre and Textile Evaluation Technologies in Terms of Instrument

2.1.1 Fibre and Textile Evaluation

Evaluation of fibre and textile quality is indispensable in modern textile industry. In the case of fibres and intermediate textile materials, the evaluation is carried out for qualifying their feasibility to the following process, and for characterizing material properties in relation to their final products.

In the evaluation of inner structures of fibre materials, several kinds of physical and chemical analytical instruments can be mostly utilized in common for general materials. But in the other kinds of fibre / textile evaluation, the instrumentation is generally influenced by their fibrous and / or textile forms to a greater or lesser extent.

When we totally consider fibre and textile evaluations, there is a specific feature of the following. Quality in regard to aesthetic, physiological, and psychological feelings often becomes a key point for evaluating textile products. Therefore, it is desirable that some instrumentations related to such feelings are available at least in the evaluation of textile products specialized by such properties.

There are a large number of objective items in fibre/textile evaluation. In order to totally and systematically understand the evaluation technologies, it must be reasonable that the items are classified based on their structures and properties, and on their product types.

2.1.2. Classifications of Evaluation Items

Table 1 shows the classification of structural evaluation items for ordinary fibre materials and textile products. Most of these items related to item numbers 1 and 2.1 (Table 1) and some other items in the table can be instrumentally analyzed and /or observed. Table 2
shows the classification of properties evaluation items for ordinary fibre materials, textiles and textile products. Most of these items can be instrumentally measured. But some of them are sensually evaluated using standard grade samples. Classification of materials and products evaluation items is summarized in Table 3. It must be noted that the evaluation items based on such properties and products are closely related to the standards, such as ISO, ASTM and JIS for fibres and textiles.

2.1.3 Trends in Evaluation Technologies in Terms of Instrumentation

By introducing technological progress in mechanical device, electronic device, optical device, sensing device and data analysis using computer software into instruments, the automation and precision analyses in material measurement have been much enhanced. Applications of nano technologies to fibrous materials are much dependent on the instrumental progress related to the item 1.3 (super molecular structure) and 2.1c (surface structure, profile) in Table 1. The two representative examples related to 2.1c are ESCA (electron spectroscopy of chemical analysis) and SPM (scanning probe microscopy). DNA analysis has been effectively applied to the precise identification of

<table>
<thead>
<tr>
<th>Major classified items</th>
<th>Intermediate classified items</th>
<th>Detailed classified items</th>
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<tbody>
<tr>
<td>1 Inner structure</td>
<td>1.1 Polymer component</td>
<td>1.1a Chemical main component</td>
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<td></td>
<td>1.1b Copolymer component</td>
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<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
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<td></td>
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<td>2.4a Yarn component</td>
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<td></td>
<td>2.4c Yarn density, areal density and cover factor</td>
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<tr>
<td></td>
<td></td>
<td>2.4e Fabric surface profile, surface fuzziness, tufted profile and raised profile</td>
</tr>
</tbody>
</table>
natural fibres.

The instrumentations for evaluating sensual, physiological and psychological effects of textile products on human have been much progressed, which have significantly contributed to develop many kinds of specialty textile products related to tactile feeling and physiological comfort. Reliable technologies for instrumentations of utility function effects such as flame retardant effect, anti-bacterial effect, and deodorant effect have made it possible to establish the certification systems for these kinds of properties.

2.2 Innovative Technologies for Textile Measurement

2.2.1 HVI Testing for Cotton Specification

High volume instrumentation (HVI) is an assembly of integrated semi-automatic electronic instruments for rapid determination of the colour, fineness, length, length distribution, trash content and strength of raw cotton samples. The instrumentation has been widely
used to cotton quality in international commerce as a universal standard method.\textsuperscript{35}

2.2.2 Instrumentation for Properties Relating to Human Perceptions

2.2.2.1 Tactile Feeling (Fabric Hand)

Tactile feeling is mainly dependent on 3 kinds of mechanical properties, namely bending (pliable ↔ stiff), compression (soft ↔ hard), and surface friction (slippery ↔ harsh, smooth ↔ rough).\textsuperscript{36} KES system is well known for automatic precise measuring of these properties (pamphlet of KES FB Auto System, Kato Tech. Co, 2008) and analysis method.\textsuperscript{37} But surface friction properties are highly dependent on mimic finger tip for their sensing. Hence, it is still a remaining research problem.

2.2.2.2 Wearing Mechanical Feeling

Several trials have been made to find suitable sensor for wearing pressure. But now air-pack\textsuperscript{38} is most widely used for evaluating both wearing comfort and wearing effectiveness for improving style and / or muscle.

2.2.2.3 Physiological Feeling Related to Micro-climate

There have been several kinds of instruments for measuring micro-climate using artificial skin which can simulate human skin in heat growth and/or sweating. Measurements of temperature and/or humidity are carried out by placing a fabric sample on a flat plate covered by artificial skin or by dressing a garment on a mannequin covered by artificial skin.\textsuperscript{39}

2.2.3 Measurement Based on Image Processing Technology

Image analysis technology, which has rapidly developed since 1960s, is especially useful in textile manufacturing and inspections, including texture evaluation and inspection of textile surface profile.
Computerized image capture and image analysis offer promising applications and very rapid, accurate and objective measurements, in a wide range of textile material properties. In recent research, it is demonstrated that how a simulation model can be built to predict the 3D behaviour of a garment during wear. The research method tries to put forward a new concept in which textile materials can be created and viewed in the virtual world by specifying fundamental properties. Virtual materials can also be created and viewed in a 3D sequence, from which their behaviour and important attributes are determined in accordance with consumer understanding.40

Image processing is basically the technique of manipulating and improving grey scale video images using mathematical functions. Image analysis involves calculations on a final image to produce numerical results. In general, a typical image processing system contains three fundamental elements, namely an image acquisition element, an image processing element, and an image display element. The objective of image analysis, in general, is to extract, from the very large amount of data in an image, that small set of measurements containing the information of interest. The standard strategy to achieve this is to break the whole task into a sequence of smaller, independent steps. The objective of each step is to achieve a limited but significant reduction in the amount of data by discarding irrelevant information. The result after each stage is a new representation of the image. Objects in an image have to be separated from each other and from their background before any measurements of object properties can take place. This strategy is analogous to the way in which human visual system works, as one visualizes an object in a scene only because that object is different and thus separable from its surroundings in some manner.40

Image processing has been used as an established technique in many area of research, such as digital aerial video recording, high capacity image archiving, medical imaging, motion analysis, flow studies, spurious event capture, video payback on demand, process monitoring / analysis, security, on-line transaction processing, hyper spectral imaging, human brain development analysis, semiconductor inspection, automated or interactive measurement, on-line inspection and gauging, part counting sorting, product packaging inspection, printing process inspection, bar code reading, template matching, colour analysis, defect and failure analysis, etc. Imaging technique has already started making in road into the textile field in a big way. Research works have been carried out for the investigation on fibre cross-section analysis, maturity measurement of cotton, estimation of trash in cotton, measurement of pore size distribution, assessment of warp stripeness, analysis of fibre crimp, fibre blend, yarn structure yarn hairiness, determination of weave type, detection of fabric defects, measurement of yarn shrinkage, fabric drape, pilling, wrinkle measurement, carpet appearance, seam pucker, screen print inspection, etc.40

3 Conclusions
All the textile machines and instruments are common in the points that their objective material is textile material and that they include at least a kind of hardware system. But their basic principles are differed each other by their own functional objectives. There are two kinds of innovations in these system, namely principle driven and mechatronics / information technology driven. MVS system is a typical example of the former. But most of innovations have been performed by the latter. This paper deals mainly machines and instruments which are commercially opened. But it must be noted that most of advanced textile products are manufactured by their own non-commercial plants.

References
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34 *Textile Terms and Definitions, 10th edn* (The Textile Institute, UK), 1995, 163.
38 [http://my.internetacademy.jp/~s1106413/index0.htm](http://my.internetacademy.jp/~s1106413/index0.htm) (15 April 2008).