1
THE SIZING PROCESS

1.1 INTRODUCTION

The old adage that sizing is the heart of weaving still holds good today. This statement is all the more important in today's environment when loom speeds have increased tenfold from those used in shuttle looms. The weaving process depends upon a complexity of factors which include the material characteristics, the sizing ingredients, the sizing operation, and the yarn parameters. Table 1.1 shows all the important factors that come into play in deciding the performance of warp yarns during weaving. On the whole, the aim of the textile technologist is to produce ''quality'' fabric economically and efficiently. Here these terms refer to the production of fabrics up to the loom stage.

The selection, evaluation, and performance of the warp (yarn/size system) for any specific fabric sett and the loom must be determined in the context of the developments and changes that have occurred in the spinning/winding/warping and the slashing processes. The following is a brief discussion of a number of considerations that a textile technologist must be conversant with when making a decision regarding the appropriate yarn/sizing system.

In the past four decades, the weaving industry has been subject to inordinate competition which has primarily come from the fashion (short runs), knitting, and nonwoven segments. The weaving machinery manufacturers answered the pressure of competition by concentrating on the design of looms that offered relatively very high speeds. Table 1.2 shows the relative speeds of various processes of manufacturing fabrics. Obviously, to meet the demands

Table 1.1 Parameters Affecting Performance of Warp Yarns During Weaving

Material characteristics
Fiber type, e.g., cotton, polyester, acetate
Yarn type and structure including blend composition, e.g. staple
Ring, open end, air-jet, combed, carded, core spun, continuous filament
Yarn hairiness.
Yarn preparation
Winding
Warping
Slashing
Tension on yarn during sizing
Moisture content
Drying temperature
Slashing machine parameters
Slashing speed
Size box characteristics
High pressure squeeze rolls, including hardness of rolls
Type of sizing method, e.g., single end, Cutt method, foam method
Amount of size
Yarn tension
Closeness of yarns
Loom parameters
Type of loom, e.g., shuttle, rapier, projectile, air-jet
Weave
Loom speed
Warp tension

of the higher productivity on the loom, the material characteristics and the quality and efficiency of the preceding processes also needed to be improved. This volume deals with the material characteristics, yarn structure and properties, yarn preparation, chemistry of sizing ingredients, and the performance analysis of sized yarns subjected to simulated loom parameters and its correlation with actual performance on the loom. The attempt to put this material in the present form comes at a time when the emphasis in the weaving industry is shifting away from simply higher production speeds toward optimization of the weaving process, dependability, and fabric quality.

The difficulty in predicting the performance of warp during actual weaving is compounded by the fact that there have been a number of developments in materials and preparation and processing techniques that have taken place

Table 1.2 Relative Production Rates for Textile Processes

Fabric/fiber sheet making process	Machine	Relative production rate
Weaving	Automatic loom with shuttle[a]	1
	Shuttleless looms	
	Rapier	2
	Projectile	3
	Air-jet	10
	Multiphase	30
Knitting and hosiery	Circular knitting machine (wide)	4
	Warp knitting loom	16
Nonwoven bonded fabrics		
Dry method	Stitch bonding machine	38
	Short fiber carding, nonwoven card	120
	Long fiber carding, garnetting	400
	Tufting machine	500
	Aerodynamic web-making machine	600
	spun-bonding machine	200–2,000
Wet method	Rotoformer	2,300
Paper manufacture	Paper-making machine (high powered type)	40,000–100,000

[a]Average output 5 m^2/h, 150 picks/min.

over the past three decades. The following is the discussion of some of the factors that needed to be considered when evaluating and predicting the performance of warp during weaving. With almost a constant demand for improving the quality and productivity in weaving there has been an equal emphasis on the development of better quality yarns with improved tenacity, elongation, elastic recovery, in both the dry and wet state, and above all in reduction in hairiness of staple yarns.

1.2 MATERIAL PROPERTIES

There have been a number of developments in the quality of cotton fibers produced around the world. Although there has been a constant and gradual improvement in strength and elongation of the upland variety, one noticeable development that is worth mentioning here is the significant improvement that has occurred in the area of the strength and elongation of extra long cotton fibers. The strength of most of these extra long staple cottons is in the range of 35–37 cN/tex, and elongation varies anywhere from 6 to 8%. These properties translate very well into improvement in yarn characteristics.

In practical mill operation, the strength property of the yarn has always been considered the prime factor that influences the performance of warp yarn during weaving. However, in recent years the mill supervisors and textile scientists have realized that other mechanical characteristics—such as elongation, elastic recovery in both wet and dry states, and physical characteristics such as abrasion resistance and moisture sorption—are equally influential in performance in the loom shed. On the other hand, as far as synthetic fibers are concerned, the trend has been more toward using finer fibers, especially when considering polyester fibers for blends with cotton. Polyester fibers of denier as low as 0.7 have been developed, but most commonly used fibers are in the range of 1 to 1.2 denier in current mill practice. This increases the number of fibers in the yarn cross section, which eventually enhances the strength, elastic recovery, and abrasion resistance of the resultant yarns. There has not been much change in the strength and elongation properties of synthetic fibers.

However, it is not the new material (fiber) properties alone that account for the continuous improvement in yarn quality; optimization of the processes, despite the increase in speed, has made the process of sizing and weaving much more efficient. This is true for most spun and filament yarns. The improvement in the quality of yarn over the last three decades can be best demonstrated by the data published by Zellweger Uster [1] for staple yarns. It is fairly safe to assume that there has not been much change in fiber length distribution, fineness, strength distribution and trash content in the raw stock of natural fibers; the properties of the yarns then are a function of the vagaries of the spinning processing technologies. The variations in a yarn that have an important influence on the efficiency of the weaving process are yarn mass variations, thin places, and strength variation. Numerous studies have demonstrated some correlation between thread breaks and thin places and variation in yarn strength. Figures 1.1 and 1.2 show the reduction in the coefficient of variation of strength and thin places of the 50% line of the Uster statistics of ring-spun combed 10 tex yarn, respectively. Even such a small reduction in the variation in yarn strength can significantly influence the yarn failure rate on the loom. There have been significant improvements in the quality of both ring- and open-end rotor-spun yarns.

Online monitoring of yarn quality during spinning and splicing during winding, clearing devices, and yarn tension control on modern machines have improved the final yarn quality that is delivered to the warping department.

Fiber and yarn characteristics are discussed in detail in subsequent chapters.

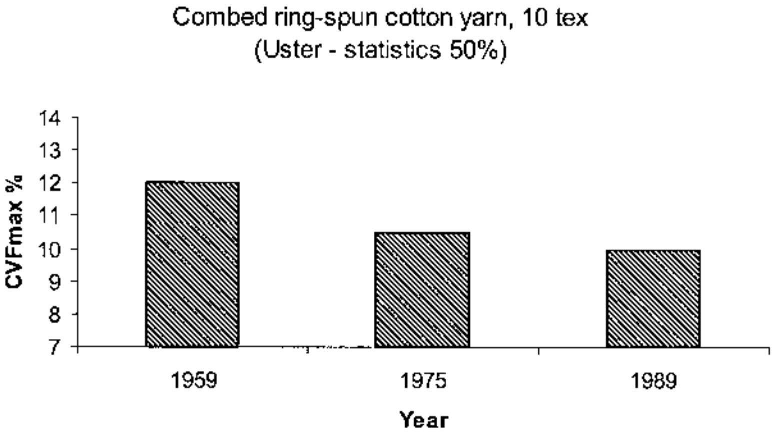

Fig. 1.1 Strength variation; percent CVF_{max}.

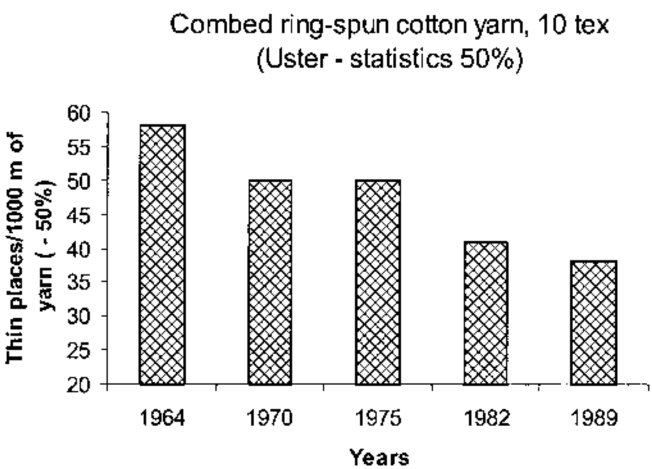

Fig. 1.2 Variation of thin places (imperfections).

1.3 SIZING MATERIALS

Natural starch and its derivatives still constitute nearly 75% of the sizing agents used in the textile industry throughout the world. It will remain the predominant ingredient, in the near future, for use in the industry because it is relatively inexpensive. The need for the development of different sizing agents other than starch and its derivatives was prompted by the introduction of new spinning and weaving technologies; these include, as previously described, spinning technologies that produce types of yarn structures that are different from the ring spun yarns and the various types of high speed shuttleless looms. The use of either starch or its derivatives proved inadequate for the achievement of quality and efficiency in the weave room. In addition, the environmental concerns regarding the discharge of effluent in local streams and wastewater treatment plants have also been influential in the search for new sizing materials. Generally, the amount of starch applied to staple yarn varies anywhere up to 15% of the weight of the yarn. The introduction of the new types of polymer synthetic sizing materials such as polyacrylates, polyesters, and polyvinyl alcohols (PVAs) has helped to reduce the amount of coating required to achieve similar if not significantly better quality warps and weave room efficiencies. However, there is still a lack of enough experience and data to allow prediction with certainty how a particular size material will behave during sizing, weaving, and desizing or in recycling of the materials.

Carboxymethyl cellulose (CMC) sizing has very good adhesion to cellulosic fibers, but due to the high viscosity, the concentrations used in the industry are limited to low levels. CMC sizes are combined with PVA or acrylic sizing agents to improve their performance and desizing characteristics. However, the sizes containing CMC are very difficult to recycle. PVA is sometimes combined with acrylics and acrylate type sizes.

1.4 PERFORMANCE EVALUATION

The performance of warp yarns on the loom is influenced by a number of factors as it is subjected to complex deformation including abrasion, cyclic bending and tension, and impact loading. Until recently, various constituents, such as size liquor, size film, yarn characteristics, and size/yarn behavior, have been characterized by a single measurement. For example, the size film and sized yarns have been characterized by the tenacity and elongation. Abrasion resistance is another criterion that has been used for establishing the protection provided by the size film to the yarn during weaving. None of the parameters on its own provided a reliable method for establishing a definitive correlation between the measurements made in the laboratory and actual performance of the yarn during weaving, especially during high speed weaving (over 400 picks/min). This is understandable because the process of yarn deformation during weaving is very complex. In the past two decades some progress has been made in devising a test method, empirical in nature, that incorporates the various modes of deformation that the warp yarns experience during weaving. Nevertheless, the method of data analysis to extract the information obtained from such a test method needs careful study so that the performance of warp may be predicted reliably.

In the current state of affairs, it is also important to mention that besides fulfilling the need for improving weaving performance the sizing material should not interfere adversely in the subsequent processes (e.g., dyeing and finishing) or obviously the environment.

1.5 SELECTION AND EVALUATION OF SIZE MATERIALS

At the outset it may be stated that there is no single size material that meets all the requirements as far as compatibility with every yarn being processed on any specific slasher for every fabric sett and weave room conditions. Obviously the objectives to keep in mind are that the sizing material should be easy to handle and apply to the yarn (and easy to remove) and the size–yarn system offers the best performance during weaving (improved abrasion resistance of size and yarn, yarn strength and resiliency, low shedding, and no size cracking).

In recent years several advances in improving the quality of sizing materials have been made. The properties that are important and that can be easily determined are (1) the viscosity or fluidity and (2) the mechanical and moisture sorption characteristics of the size film and the adhesion of the size to various types of fibers. For example, the polyvinyl alcohol film has an adhesive strength that is more than three times that of starch to polyester fibers. Starches have been chemically modified to improve their adhesion to fibers, strength, stability, and solubility of the size material.

The size formulations used for spun yarns (including blends) also contain other ingredients such as lubricants and binders. The lubricants help to reduce the friction and abrasion between the adjacent yarns and between yarns and heddles, dropwires, shuttles, rapiers, or projectiles. The lubricants also enhance the flexibility of the size film. The lubricants are generally fats, oils, or waxes.

In addition, another ingredient, usually a binder, is used either to enhance or suppress certain interactions between the size film and the fiber. The binder materials usually tend to reduce ‘‘skinning’’ in the size box and help reduce the force required to separate the yarns at the bust rods located at the front of a slasher. Acrylics and polyesters are generally used as binders. Some of these binder materials, especially acrylics, increase the viscosity of the size bath allowing better encapsulation of the yarn, which prevents hairiness of yarns from interfering in the weaving operation. Other ingredients, such as humectants, wetting agents, and defoamers, are added to the size formulation to ease the process of size application to the yarn.

The techniques to measure the size and the processing characteristics are well established, and it is important to establish standards that will help select the proper size or size blend that will give the best results. Some of the factors that need to be considered are the fiber type, yarn structure (ring spun, open end, air jet, or continuous filament), fabric sett, the slashing equipment, and such finished fabric requirements as fabric hand, brightness of color, and texture.

1.6 EVALUATION OF THE SIZING PROCESS

Weavers have been placing very stringent requirements on the quality of warp due to higher loom speeds and the need to produce first quality fabrics with an absolute minimum in defects. If the sizing is defective, the quality of the warp will be poor, which will affect the weaving operation and consequently the quality of the fabric.

In recent years a number of developments in process controls and sensing devices have made the process of applying the size and controlling the machine factors and yarn parameters much easier. The factors that need to be monitored and controlled on the slasher are as follows:

- Size add-on control
  - Viscosity of size formulation
  - Yarn speed
- Size encapsulation, which may be influenced by
  - Size temperature/viscosity
  - Size level
  - Amount of solids in the formulation and between different formulations
- Tension in size box
- Moisture in yarns
- Tension in the leasing section
- Tension in the creel section

1.6.1 Size Add-On

The amount and the uniformity of size add-on are extremely important in influencing the performance of warp during weaving. Size add-on is affected by the viscosity of the size bath and combination of warp speed and squeeze roll pressure. Modern machines are equipped with controls that regulate the squeeze roll pressure with respect to the warp speed. In other words if the warp is running slower, the squeeze roll pressure is increased to empirically regulate the amount of add-on. These controls are designed to monitor the size add-on as a percentage of the dry warp weight as a function of the warp speed with liquid size flow. Although with modern technology both measurements can be accurately made, the time element is such (requiring approximately 30 to 45 s to compute) that with each event a large length (approximately 50 to 75 m) of the warp passes through the machine before any adjustment is made. There are other factors, for example, the amount of solids in the size formulations, that have to be entered in the controls manually, and the controls do not compensate for evaporation and the errors due to incorrect formulation. In recent years very precise gauges, e.g., low energy source nuclear gauges, have been used for maintaining web density. This type of device, as shown in Fig. 1.3, is used for online measurements of the density of the incoming warp and the sized warp. The sensors are calibrated to take the amount of moisture (both in the incoming warp and the sized warp) and the stretch (extension) in the warp into account in the sensing process. Even though the nuclear gauges provide high accuracy in the measurement of web densities, they are not as effective over the whole range of slasher speeds (including deceleration and acceleration of the slasher) in adjusting the size add-on by regulating the squeeze roll pressure. Consequently, additional sensors in the form of microwave sensing and conductive kiss rolls are placed at various locations along the squeeze rolls. Both these methods sense wet pick-up, but they require calibration to compensate for the web density and the electrical conductivity of different size formulations. These can be used in conjunction with high accuracy nuclear gauge to obtain a fast response and thus control the add-on at all speeds during deceleration and acceleration of the slasher.

1.6.2 Yarn Encapsulation

In addition to the optimized and uniform size add-on, another factor that influences loom efficiency and warp breaks is the degree of encapsulation of the staple fiber yarn. This is necessary to suppress the deleterious effect of yarn hairiness, which has been formed due to abrasion in the weaving process to have a very strong influence on warp breaks during weaving. In recent years

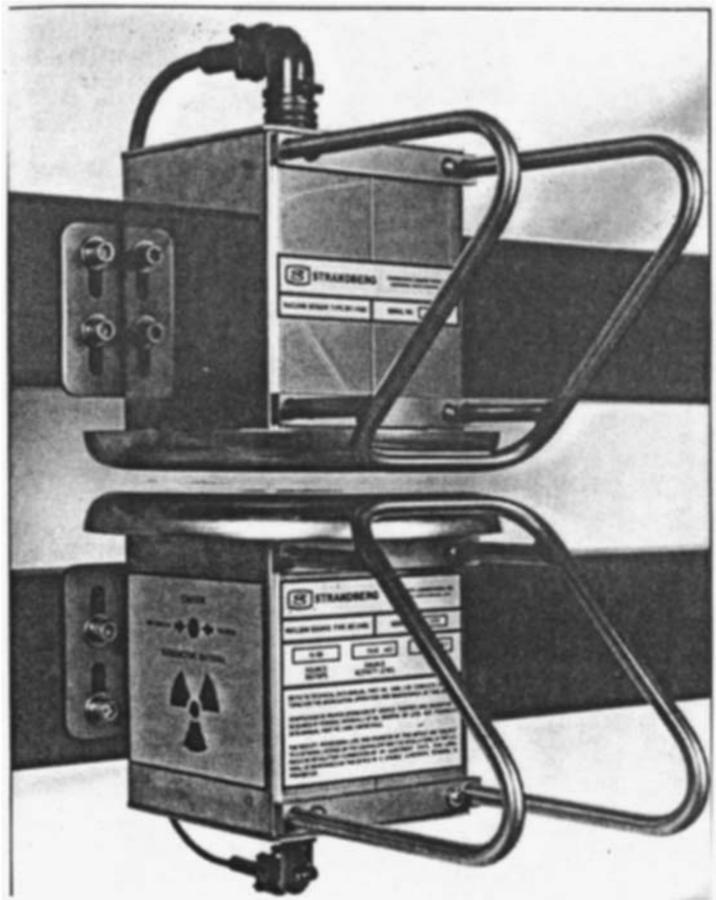

Fig. 1.3 Fabric density sensor (also for slasher wrap). (Courtesy of Strandberg Laboratories, Inc.)

sensors have been introduced which monitor the hairiness of yarns in the sizing operation. The developments in machine vision technology have enabled the monitoring and efficient acquisition of data (images), such as on web density, of randomly arriving objects. This is accomplished by triggered cameras that take snapshots on demand. On higher speed continuous web, such as warp sheet in a slasher, cameras that can scan in time delay and integration (TDI) mode are mounted for efficient acquisition of material influence. One such sensor is the Strandberg Size Encapsulation Monitor shown in Fig. 1.4. The sensor for encapsulation is based on the principle of monitoring the hairiness of a yarn before and after sizing. Yarn size encapsulation here is defined in terms of the protruding hairs 360 degrees around the yarn diameter integrated over a set length (e.g., 1 m or 1 yard). The empirical relationship is given as follows:

$$\text{size encapsulation} = 360\left(1 - \frac{Hd}{Hc}\right) \text{degrees}$$

where Hd is hairiness of yarns at delivery and Hc is hairiness of yarns at entry. There is evidence that the optimal amount of encapsulation is achieved at an optimal size add-on. The encapsulation efficiency deteriorates when the size add-on is either increased or decreased from this optimal value of add-on. The optimal add-on for optimal encapsulation is highly dependent on the yarn type and the other yarn physical parameters. Studies have also shown that warp breaks on the loom are strongly influenced by the degree of encapsulation. Specifically, the optimal size encapsulation is dependent on four primary factors: (1) moisture in the yarn when it contacts the first drying cylinder of the final dryer, (2) temperature of the first drying cylinder of the final dryer, (3) yarn tension in the leasing section, and (4) the size add-on. The qualitative relationship between these four factors is shown in Fig. 1.5. There is an optimum for each factor where the optimal size encapsulation is achieved. A process controller being used in the textile industry to monitor and control size encapsulation as a function of all the four factors is shown in Fig. 1.6.

The amount of moisture in the sized yarn is also an extremely important parameter that affects the quality of a warp. The constancy of the amount of moisture throughout the length of the warp will depend on the efficiency of drying. Consequently, new controls have been developed and are currently being used on the machines to regulate and control temperature of drying cans to arrive at the desired moisture content in the entire warp at all speeds. The final moisture content in the warp can be closely controlled by automatically controlling the wet pick up, which is affected by constant regulation of squeeze roll pressure. Obviously, the instrumentation used in these highly automated operations is designed to control the moisture in different types of fibers, fiber blends, and warp densities. The sensors are highly sophisticated and have the capability of regulating moisture within very narrow tolerances ($\pm 0.1\%$). A moisture-sensing transducer assembly mounted on a slasher is shown in Fig. 1.7.

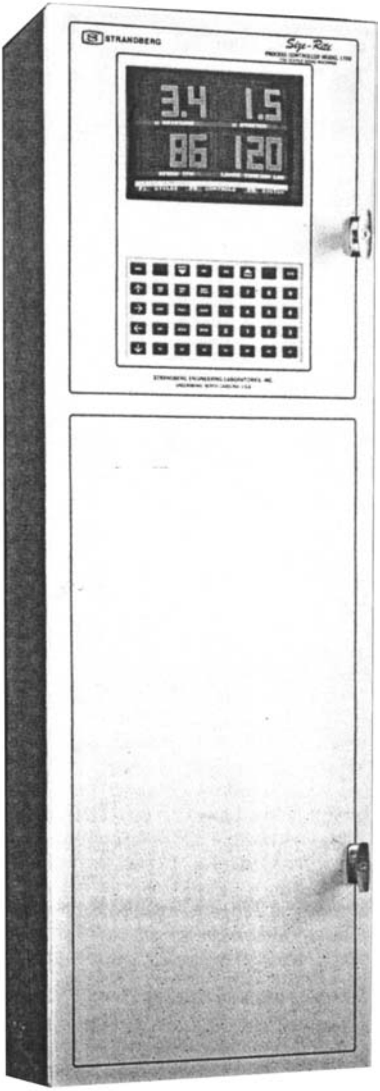

Fig. 1.4 Encapsulation monitor. (Courtesy of Standberg Laboratories, Inc.)

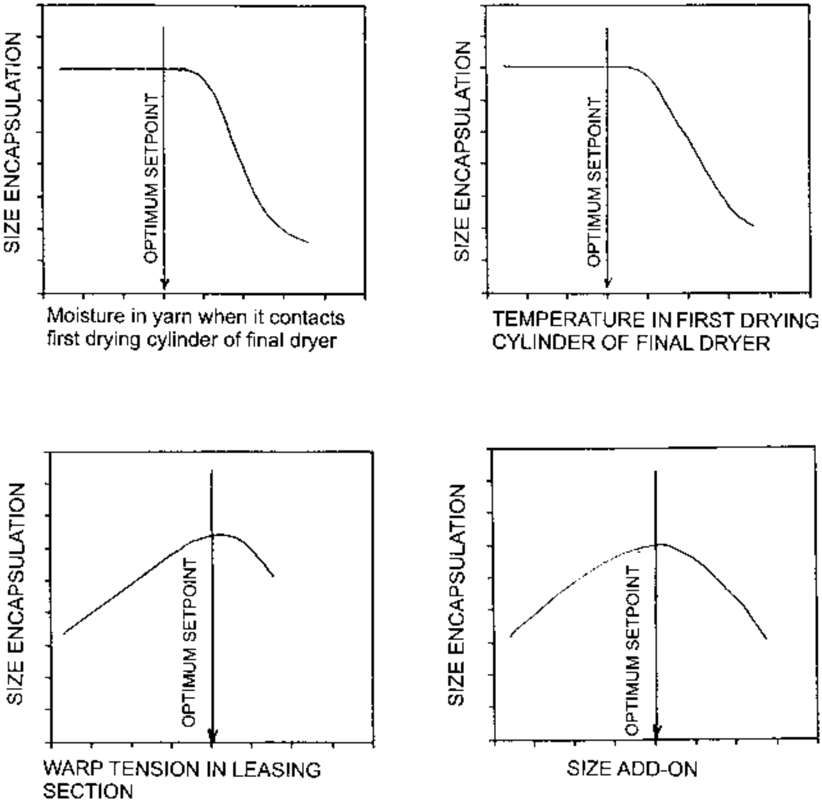

Fig. 1.5 Optimization of size encapsulation.

Another area of extreme sensitivity is the yarn strength in the wet stage which occurs between the size box and the first drying cylinder. Machinery manufacturers are using highly sensitive sensors, some of which are surface-driven sensors that can also sense stretch down to near zero running speed and thus help in automatically controlling motors that control the speed of Positive Infinitely Variable (PIV) Variators or variable speed transmission systems. There are a number of different types of sensors available in the market that allow the control of temperature and consequently the viscosity of the size formulation in the size box.

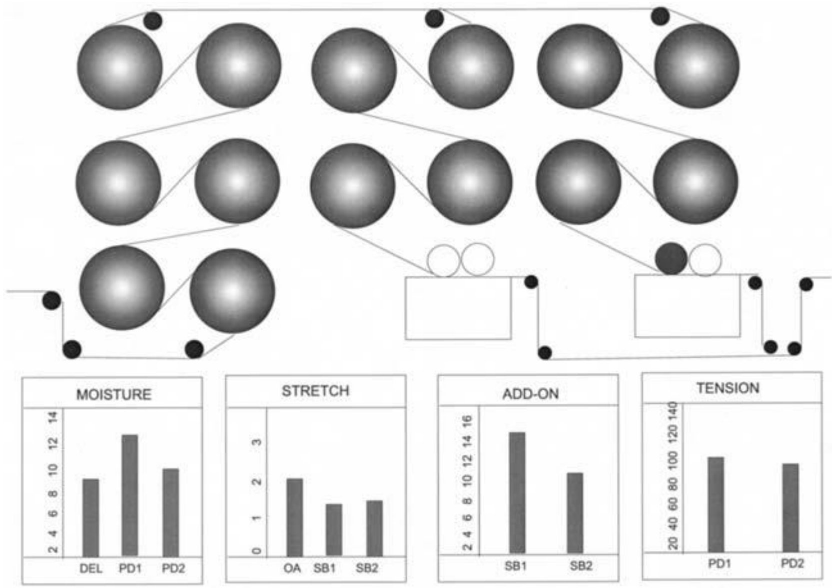

Fig. 1.6 Process controller to monitor and control size encapsulation as a function of moisture, stretch, add-on, and tension.

Strain gauges are being used in controlling warp tension through the entire length of the slasher all the way from creel, between drying sections, to the lease rods and winding. Torque motors are used for controlling the tension between the drying sections and the leasing sections, while pneumatic brakes help control tension in the creeling sections.

The use of cameras located at strategic points also helps in the timely detection of faults and in instantly stopping the machine for repairs. The camera devices are sensitive enough that even a single thread passing within its focal point will actuate the device. The actual controllers along with their recording devices have become very useful in enhancing the quality of the sized beams. Some of these controls and data collection devices include the history of the processing of a sized beam. The following data may be generated, as one of the manufacturers of controls has suggested [2]:

Date and time at start of each beam
Time to make a beam

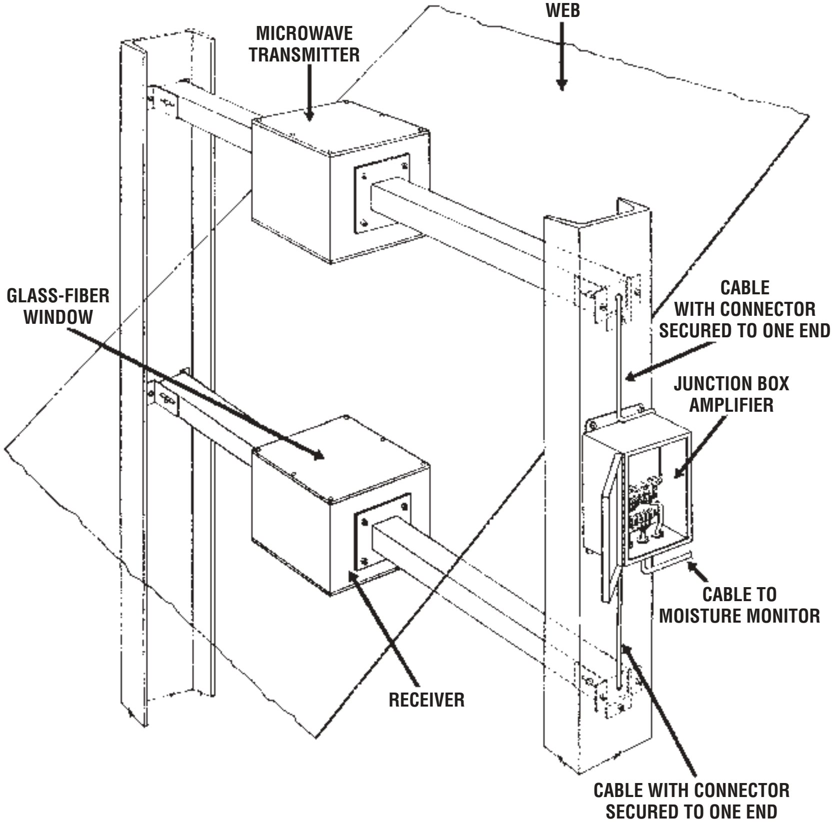

Fig. 1.7 Typical moisture-sensing transducer installation consisting of transmitter, receiver, junction box amplifier, hardware, and cables.

Time during stop of slasher
Time during slow movement
Warp length in meters delivered
Warp length delivered in slow motion
Average slasher speed
Average moisture content in beam
Average stretch in yarn from each size box to delivery
Average stretch in creel

Average overall stretch
Average tension in creel
Average tension in each warp sheet in first to final dryer
Average tension in the leasing section
Average add-on in each box size
Average total add-on
Average degree of yarn encapsulation by size
Average number of stops

Factors such as crawl speed and variations in stretch, tension, add-on, and encapsulation will have a profound effect on the overall performance of the warp on the loom. Consequently, along with the average values, the standard deviations from the average values of moisture content, stretch, tension, and size encapsulation should be recorded. The statistical process control can help to optimize the performance of the slasher, which is the ultimate goal; consequently, this will result in the optimization of the beam quality and warp performance during weaving.

1.7 EVALUATION OF WARP PERFORMANCE

For efficient operation of the weave room, it is important to know how the warp yarn will perform during weaving. Until recently weaving technologists believed that by determining (1) the adhesion of size to the yarn, (2) the ease with which the size wears or rubs off (abrasion), and (3) the improvement in the tenacity of the yarns, the performance of warp during weaving could be predicted. Obviously, various test methods have been devised to determine these factors both qualitatively and quantitatively. However, a closer examination of the weaving process indicates that yarn failure during weaving is controlled by a very complex mechanism. Yarn failure does not occur due to abrasion of the size or in simple tensile mode. The warp yarn on the loom is subjected to very complex deformation modes which include abrasion, cyclic bending, cyclic tension, pseudotwisting/untwisting (torsion), and cyclic impact loading in addition to the base tension applied to the yarn. The literature is full of studies where researchers have tried to establish simple one-to-one correlation with the abrasion characteristics, tensile strength, and hairiness of warp yarn with performance on the loom. Studies have also been reported in the literature that try to show that the behavior of yarns during weaving and the number of breaks during spinning (all these on yarns before they are sized) can also be correlated with loom performance. However, the complex fatigue mechanism that controls the failure of yarns on the loom has been the subject of recent studies in which this mode has been simulated in the laboratory. The Sulzer-Ruti Webtester is one such experimental method. Nevertheless, because of the nature of the fatigue results of yarns, it has been difficult to establish one-to-one correlation with the yarn performance in the laboratory with that observed in the weave room. Our studies have attempted to establish such a correspondence. This is the subject of discussion in Chapter 5.

1.8 CLOSING NOTES

In this volume we give readers an idea of the complexity of the problem of the sizing of yarns for weaving. The chemistry of sizing material, the additives, the types of fibers and yarn structures, the method of application of size, and the control of the material and machine factors compound the task of establishing simple relationships between various parameters. Nevertheless, we hope this compendium will prove to be of great help to both mill practitioners and the students of textiles and especially weaving.

This volume is primarily concerned with familiarizing the reader with the current status of sizing machines, chemistry of different sizing materials, and above all the laboratory methods of evaluation of sized yarns. In addition, the correlation between the fatigue behavior of sized yarns determined in the laboratory and in actual loom trials will be presented.

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