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Woollen Spinning, Weaving, Knitting, Dyeing, Bleaching and Printing Technology Handbook

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Spinning is a major industry; it is part of the textile manufacturing process where three types of fibre are converted into yarn, then fabric, then textiles. The textiles are then fabricated into clothes or other artifacts. The fundamental operations for the stocks of fibers from which a woollen yarn is made are opening, cleaning, mixing, forming a slubbing or roving and finally thinning the roving to the required yarn number and twisting it to produce a yarn possessing the requirements for subsequent processing such as warping, winding, weaving, finishing and dyeing. These demands vary with the different conditions confronted in manufacturing but include the following features: strength, elasticity, uniformity in weight per unit length and even distribution of twist. Woollen spinning involves three principal operations, irrespective of whether the mule or the frame or ring spinner is used, namely: Drafting, final drawing out, Twisting, or insertion of twist, Winding on, or packaging. Weaving constitutes the actual production of cloth or fabric, i.e., to combine the essentially one dimensional textile structure thread or yarn in such a way as to result in an essentially two dimensional structure of cloth of certain appearance, hand and strength. Knitting is the art and science of constructing a fabric by inter lacing loops, there are two types of knitting: warp and weft knitting. In recent years whole new classes of dyes such as fiber reactive, disperse, cationic basic, neutral dying premetalized have been discovered and produced for the dyeing of the natural and new synthetic, hydrophobic fibers. Bleaching improves whiteness by removing natural coloration and remaining trace impurities from the cotton; the degree of bleaching necessary is determined by the required whiteness and absorbency. Cotton being a vegetable fibre will be bleached using an oxidizing agent, such as dilute sodium hypochlorite or dilute hydrogen peroxide. If the fabric is to be dyed a deep shade, then lower levels of bleaching are acceptable, for example. However, for white bed sheetings and medical applications, the highest levels of whiteness and absorbency are essential. Wool fiber production technology necessitates full understanding of its growth, pristine structure, physical, chemical and functional properties as well as processes involving manufacture of textile fibers.

Some of the fundamentals of the book are woollen spinning, atmospheric conditions in wool manufacturing, Bradford system top gilling or top finishing, the principle of weaving, woollen and worsted weaves, knitting, the changing outlook of the knitting industry, influence of fiber fineness on quantity of dye required, altering the affinity of the wool fiber for dyes, dyeing of yarn according to the packing system, special wool finishes, water repellent, stain resistant treatments for worsted and woollen fabrics, the printing of wool piece goods, lustering of wool fabrics, fluorochemicals, mothproofing etc.

The present book is of its own kind which covers woollen spinning; knitting, dyeing, bleaching and printing, special wool finishes etc. This is an important reference book for wool technologists, scientists, new entrepreneurs, research scholars and all others related to this field.

Content:

Sample Chapter:

Woollen Spinning

The fundamental operations for the stocks of fibers from which a woollen yarn is made are opening, cleaning, mixing, forming a slubbing or roving and finally thinning the roving to the required yarn number and twisting it to produce a yarn possessing the requirements for subsequent processing such as warping, winding, weaving, finishing and dyeing. These demands vary with the different conditions confronted in manufacturing but include the following features: strength, elasticity, uniformity in weight per unit length and even distribution of twist.

In the woollen yarn making process, there is only a single spinning operation following carding, permitting no further cleaning or mixing, its only functions being as stated above to thin or draft and impart twist in fact, the thinning actually achieved is only of the order of 50%. Therefore, the carded roving should be free from impurities, homogeneous in fiber composition, and as uniform as possible in weight per unit length. All that can be done in spinning to improve yarn quality is to improve uniformity and with so little drafting even this possibility is limited.

Woollen spinning involves three principal operations, irrespective of whether the mule or the frame or ring spinner is used, namely:

Drafting, final drawing out.

Twisting, or insertion of twist.

Winding on, or packaging.

Drafting or drawing, concerns the last reduction or attenuation can be toping itself to that weight or thickness required in the final woollen yarn. In the mule this is accomplished by a so called *spindle* draft instead of a *roller* draft, as is done on the woollen ring spinner.

The drafted roving is then twisted to give the yarn sufficient strength for it to be knitted or woven. On the woollen mule this process is partly combined with drafting, but mainly accomplished by *spindle twisting.* On the woollen ring frame the twisting is done by use of a ring and traveller, and is termed *ring twisting*.

Winding on consists of putting the spun yarn into a form such as *cops* or *bobbins* suitable for succeeding weaving or knitting operations.

Mule Spinning

The Self acting Mule

The evolution of the spinning mule was dealt with in a recent paper by Catling. The modern mule on which woollen yarns of all sizes and descriptions can be spun is often termed the self acting mule, because of its practically automatic operation. Most people divide the whole machine into two main sections, i.e., the *head stock* and the *carriage*. The former receives its power from the main shaft, and in it originate all the important motions of a mule. This part of the mule is usually stationary. The carriage, however, is movable and bears the spindles that draft and spin the roving into yarn, and then wind it on the bobbins. The carriage extends over the entire width of the machine, and slowly moves in and out during the spinning procedure (Fig. 1).

The general spinning procedure as described in *Wool Science Review* is as follows:

The delivery rollers *H A H* of the mule intermittently feed forward a supply of carded roving from the jack spool *M* of measured length to each spindle of the moving carriage. During this part of the mule cycle the spindles retreat from the rollers at the speed of delivery, while they are at the same time revolving at constant speed, and so imparting twist to the roving presented to them. When the required length has been presented the rollers stop, but the carriage continues to move away from them, and the spindles continue to revolve. The roving is thereby attenuated by a stretching action called spindle drafting. During this

operation, an increasing tension is developed in the drafting thread, and the only factors which control the response of the fibers to this increasing tension are the interfiber forces of cohesion, determined by the frictional and elastic properties of the fibers, and the radial pressure set up in the thread by the twist.
The required amount of attenuation having been achieved the carriage is stopped, but the spindles continue to revolve and perform the last essential requirement of yarn making the twisting of the thread to produce a yarn of adequate strength. This is accomplished by the roving slipping over the top of the spindle. The spindle *S,* being placed at an angle, does not hold the yarn, but simply allows it to slip over the top as shown in Fig. 1. One turn of twist, therefore, is put into the roving for every revolution of the spindle. The extra twist thus added produces a greatly increased tension in the threads, and if it were not relieved, the majority of them would snap the carriage is therefore gradually moved in for a few inches to allow the threads to contract. This environment is called jacking in.
Twisting having been completed, the spindles are stopped, rotated for a few turns to unwind the yarn wrapped round the bare spindle (an action known as backing off), the carriage is run in, and the lengths of spun yarn are wound up in the form of conical packages *C* on the spindles themselves. This is accomplished by rotating the spindles slowly as the carriage runs in. The fallers *D* and counter fallers *Di* meanwhile come into action to guide the yarn, and traverse it in such a way as to build a package of the required shape on each spindle. This package *C* is conical in shape, being built as a series of successive, interpenetrating cones of yarn one on top of he other. As the linear rate of winding of the yarn is approximately constant (as dictated by a fairly constant carriage speed), it follows that the spindle speed must be varied continuously during the run in, in order to build the yarn uniformly into a cone. Thus the variety of spindle motions required during mule spinning is made even more complicated.
The spinning mule therefore performs an intricate series of mechanical actions, and it has developed into a cumbersome machine. Its separate functions, however, are not really complicated since they depend essentially on the action of just three different components, the carriage, spindles, and delivery rollers, the motions of which must be coordinated and correctly tuned, to build up the total spinning cycle of the machine. None of these motions is very complex in itself their coordination is the difficulty, and it is the spinners art to achieve this coordination with as few yarn faults as possible.
Just as the machine consists of three components, so the sequence of operations which it performs may also be subdivided into three essential actions: drafting, twisting, and winding on. Delivery may be regarded as an essential preliminary to drafting, jacking in as a necessary consequence of twisting, and backing off as a pre requisite of winding on.

The Operations of Mule Spinning

Drafting

During drafting the thread is stretched in a softly twisted condition what is the nature of the response of the fibers? It has been a view held for a long time by practicing spinners that in this thread, twist gathers preferentially in the thin places, and consequently the soft, thick places are drafted preferentially. It is further believed that as this preferential drafting of thick places proceeds, the twist continually redistributes itself in such a way that the thinner portions are always given most support. Thus after a thick place has been drawn down, it will receive an influx of twist drafting will stop in this section and will restart in another section which is now somewhat thicker. If matters were really as simple as this it can be seen that spindle drafting would soon reduce the thread to a uniform or level state, which would be a desirable result. Furthermore, it would seem that, providing sufficient twist was added during attenuation to maintain the cohesion of the thread as it became finer, this theory would suggest that drafting could go on almost indefinitely.
In practice, however, although it is agreed that a levelling of the thread does take place in a well spun yarn,

it is known that if the draft used is excessive the levelness of the final yarn is impaired, and, furthermore, many ends begin to break down and so impede production. The spinners task during this part of the mule cycle is therefore to adjust conditions to the optimum, which will allow the maximum draft consistent with the achievement of as level a yarn, and as few ends down, as possible. The controllable factors which he has at his disposal for a given material are the amount of twist he inserts before drafting, the rate at which twist is inserted during drafting, the speed at which the operation is carried out, and the amount of draft applied. His synthesis of these factors to give optimum spinning conditions is the spinners craft, and is not fully understood scientifically.

Other factors which are not so readily under his control, but which could be adjusted to meet his requirements if it were clear how such adjustments would assist him, are such things as the amount of oil applied to the wool, the properties of this oil, the degree of cohesion given to the roving by the rubbers of the condenser, and the physical properties of the fibers as they are affected by such preparatory processes as scouring and dyeing. The physical properties referred to are the frictional and elastic properties of the fibers. The former may affect the relative motion of fibers during drafting, and the latter will determine the cohesion of fibers bound together by twist, since stiff fibers will require more twist than supple fibers to achieve the same degree of intimate interfiber contact during drafting.

Analysis of Spindle Drafting. Angus have investigated the behavior of rovings being drafted on conventional mules, as well as on a single spindle apparatus constructed to carry out the spindle drafting of a single end of yarn under experimental conditions. McNair has made similar investigations using the electronic mule designed by Chamberlain as a drafting device which conveniently allows a wide range of drafting conditions. He has also examined the reaction of twistless rovings to draft using a Cambridge Extensometer.

Angus concentrated his attention on two main features of the process: the tensions generated in the drafting thread and the progressive changes in thread irregularity which ensued. Changes in tension were investigated because it was felt that these would give some guidance as to the behavior, or activity, of the fibers in the thread during the process.

When the drafting of a partly twisted roving commences, the initial tension is zero. This induced tension, or drafting force, increases fairly rapidly, and at an increasing rate, in the early stages of drafting. Subsequently the *rate* of increase declines to zero, so that the force extension curve passes in turn through a point of inflection and a maximum. Thereafter the force declines, as extension is further increased, until such time as the thread breaks and the force again drops to zero. Figure 2 shows a set of curves which are typical of all the results obtained by Angus. It will be seen that as the twist content of the drafted thread under investigation was increased, the induced tension at any given draft became greater, the maximum tension developed increased, and the breaking extension of the thread was reduced. Alteration of drafting twist was not accompanied by any alteration in the form of the curves. There was an indication, however, that a certain low value of twist content could be discerned which gave an optimum maximum extension at break, i.e., which allowed maximum draft.

The percentage extensions at which the points of inflection and of maximum force occur vary according to the conditions. Thus, values between 25 and 50% were obtained depending upon the type of wool used, the twist condition of the thread while drafting, the angle at which the spindle was inclined to the axis of the drafting thread, and apparently, the physical characteristics of the fibers as they had been affected, by previous wet treatments. All these factors govern the value of the extension at which maximum force is produced, and also affect the magnitude of the force generated for a given extension. For example, other things being equal, a revolving spindle inclined to the axis of the thread will induce a smaller maximum force than a spindle in the same line as the thread axis, and at the same time a greater extension will be achieved before the maximum force is reached. The significance of these observations is not yet fully

understood, but interesting parallels were found when the concurrent changes in thread irregularity were investigated.

Two Phases of Drafting. Angus put forward the view that fiber activity during drafting could be regarded as taking place in two phases. The first phase, it was suggested, is a simple stretching phase in which the curls and convolutions of the randomly arranged fibers are straightened out. It is not until after this phase is completed that the second and most usually considered aspect of drafting fiber slippage occurs. It was concluded that the initial rise in tension takes place during the stretching phase, and that the point of inflection on the force extension curve announces the onset of fiber slippage. If this is a true picture of fiber activity, then it would appear that levelling of the thread only occurs while the fibers are adjusting themselves to the drafting force during the first phase of the process, whereas slipping of fibers with respect to one another during the second phase leads to a rapid increase of irregularity. The assumption that the initial changes are due mainly to a fiber straightening process is confirmed by the observation that when worsted roving is drafted on a mule the point of inflection on the force extension curve occurs at only about 4 5% extension.

Another interesting observation was the occurrence, during the drafting of some samples, of a very irregular decline of the force from the minimum. In these cases very sharp falls followed by partial recoveries, reminiscent of stick slip phenomena, were noted. The interesting feature was that this phenomenon never occurred in the early stages of drafting while the force was increasing. This observation seemed to be consistent with the belief that fiber slippage does not occur until the force is in the region of the maximum. This unlooked for occurrence is interesting in itself in that it does suggest one mechanism whereby threads may deteriorate, and then suddenly fail, during spinning.

Discussion of Fiber Movement in Drafting. McNair comments that although this work has revealed for the first time the basic character of the drafting process in woollen rovings a number of points remain obscure. He is of the opinion that the concept of fiber straightening without fiber slippage during the initial stages of drafting would seem to err on the side of oversimplification. In the roving there will be some fibers less crimped, or less curled, than others and they will be straightened first. Thereafter these fibers will have to be stretched, if they are not to move bodily relative to their still curled neighbours. He points out that if fiber straightening is all that occurs, the extension should be largely reversible whereas he found that (for extensions up to 20% or so) only about half of it is reversible. Although McNair puts forward no specific alternative explanations, there seems no doubt that his general contentions are correct.

Perhaps it might now be suggested that what we can think of as occurring during the first phase is a straightening of fibers plus a sort of fiber shuffling, in which contacts between adjacent fibers are released one by one as the fibers adjust themselves to the induced forces, but that this type of fiber activity is different from that which arises in the second phase of mule spinning where fibers, or groups of fibers, move bodily over one another with the *simultaneous* disruption of *all* fiber contacts between them. This would produce a kind of flow, rather than an agitation as is visualized for the first phase.

McNairs force extension curves for twisted threads were of the same form, and showed the same characteristics, as those obtained by Angus and Martindale.

Other Factors in Spindle Drafting. McNair showed that the degree and type of rubbing which a roving undergoes at the condenser also affects its tensile properties in the early stages of spindle drafting, although he reported that the differences in tensile behavior disappeared as extension proceeded. This observation suggests that fiber movement in the first phase of drafting is sufficient to destroy the initial dissimilarities in structure. He also showed that the drafting behavior of rovings from which the oil had been extracted was different from that of the original rovings, and this, taken with observations by Angus that wools scoured in different ways and wools dyed in different ways also give force extension curves with different maximum drafting forces, and different extensions at which these maxima occur, provides another

problem for future investigation the explanation of the part played by the properties of fibers and fiber assemblies, and their significance in determining optimum drafting conditions.

One ought also to make particular reference to the observation by Angus that a spindle inclined to the axis of the thread produces a different response from a spindle which also line this axis, and to which the thread is clamped. In the first case each revolution of the spindle causes the thread to be wrapped around the spindle tip for half a turn before being thrown off. This action produces a high speed plucking of the drafting thread, which is consequently maintained in a state of continual vibration. Such vibrations apparently have some effect on fiber activity, and presumably promote conditions favourable to fiber movement. It is therefore interesting to note that under such conditions the first fiber behavior was prolonged to greater extensions. It was remarked earlier that the limited part which the mule plays in the sequence of operations producing a woollen yarn indicates that it can contribute comparatively little to the final quality of the yarn, most of the desirable properties already being inherent in the material present to it. On the other hand it is easy to impair these inherent qualities by poor adjustment of the mule.

Twisting

Twist Motion. Each revolution of the spindle S imparts one turn of twist to the yarn, accomplished by the slipping of the yarn over the smooth and round tip of the metallic spindle for which purpose the spindle is inclined away from the vertical toward the feed rolls. The tendency of the yarn already spun is to rise to the top of the spindle, where it slips over the end, putting in one turn for every *slip*.

The twisting motion goes into action as soon as the draw rolls stop the delivery of roving. The required twist for the length of drawn roving, i.e., 74 76 in., is now put in by increasing the speed of drum *A* so that the required twist has been inserted when the draw is complete. Since the yarn shortens as it twists, the ends would snap off if there were not some method of easing in or backing off.

Amount of Twist. The amount of twist is normally governed by the economic factor, and accordingly most yarns have the minimum twist inserted in accordance with the least trouble in subsequent processes. The amount of twist bears a relationship to the strength and elasticity of a yarn. An increase in twist will lead to an increase in strength up to a certain amount, after which further increases lead to a decrease in strength. Also, the degree of twist affects the bulkiness in the case of knitting yarns and in the case of weaving yarns the finishing process and the handle of the cloth. The amount of twist in a yarn is expressed in turns per inch (tpi), in turns per ten centimeters (tpcm), or turns per meter (tpm).

Worsted Topmaking

During 1967 the wool topmaking industry had an estimated total in production of tops of 1,290,000,000 lb. Approximately one third was the output of the six EEC countries, with a total output of 452,000,000 lb.

The topmaking industry presently still differentiates between two distinct systems:

The English or Bradford system developed in England for processing wools whose average staple length is not less than 2½ in.

The French or Continental system developed in Alsace Lorraine for wools whose staple length can be less than 2½ in.

There is little fundamental difference between Bradford and French carding except that the French equipment is usually set up and clothed to handle the shorter and finer wools. A very small amount of oil or emulsion (less than ½%) is usually applied to the scoured wool before carding on either systems to provide surface lubrication for the fibers and to minimize fly in the card room.

The first distinct difference between the systems appears in the combing process. The Heilman or rectilinear comb is used on the French systems, and the Noble or circular comb on the Bradford system. While the slivers are backwashed after combing on the French system, they are backwashed before

combing on the Bradford system. The only other significant difference is that 1 3% of oil is added before combing on the Bradford, while no additional oil whatever is used on the French system.
While the flow of material often varies from mill to mill, the flow sheet, Table 1 shows the general comparison between the conventional Bradford and French systems.

Worsted Carding

After the wool has been thoroughly washed, dried, lubricated and otherwise prepared, it is subjected to carding.

The objects of worsted carding are:

To straighten, separate and, in general, to make the long wool fibers lie parallel.
To clean the fibers, that is to remove as for as possible all vegetable impurities such as burs, shives, and other extraneous vegetable matter and dust.
To blend distribute, and mix the different lengths and qualities harmoniously into one quality.
To arrange the fibers into a continuous sliver of definite weight and thickness.
The carding action is basically the result of the relative motion of two interacting rollers, which are densely covered, with specially shaped hooks of fine steel wire. (Figs. 1 and 2).
The objectives of worsted carding are accomplished actually by essentially simple means. Wool, deposited in a fairly thick layer on a slow moving cylinder, is transferred to a fast moving roller this results in an opening and thinning out of the wool stock. As this operation is repeated many times over on a carding machine, a small amount of wool is distributed over a large area in a very thin web. To render this thin web mechanically manageable for forming into a continuous sliver, the above described operation is reversed by transferring the wool fibers back to a slow moving cylinder from which it is drawn off and formed into a sliver of loosely joined fibers.
Whereas the woollen carder is more concerned with sufficient blending, the worsted carder is most interested in parallelism of the fibers, the preservation of the full fiber lengths and the elimination of neps and pin points. Since worsted yarns are distinguished by strength, uniformity of spin, and great fineness, with a consequent higher cost, every precaution must be taken in carding to attain these objectives.
To properly process the different types and lengths of wool, four types of cards are in general use:
The single cylinder worsted card, with four lickerins for long staple wools. (Bradford System). (Fig. 3).
The double cylinder Bradford card, with four lickerins and dividers for merino wools (64/70s quality) (Fig. 4).
The double cylinder continental cards, with burr breast workers, and strippers for shorter wools (merino type) (Fig. 5).
The all metallic wire worsted cards for French and Bradford systems (Fig. 6).
For fine and crossbred wools, irrespective of the system of drawing or spinning used, worsted mills prefer the double cylinder card. For very open wools, as scoured by the Australian solvent process, a single swift card works well.
The preliminary breastworks, as pointed out above, may consist of four lickerins or a metallic breast, as the individual carder prefers. No definite advantages exist for either one of the two methods of opening the wool, stock, however, great differences of opinion are held regarding them. The main factor in the choice of a metallic breast or of fillet covered lickerings in the worsted card is to avoid fiber breakage and the shortening of the carded fiber.
Worsted cards are generally of all metal construction, rigidly built and relatively light in weight. Main cylinders are usually cast iron or steel, workers are aluminum, and strippers are steel tubing. The standard card widths are 60, 72, 84, and 100 in. Of these the most common in use is still the 60 in. width and 54 in. diameter of the main cylinder. However, the tendency is definitely toward the wider cards.
The production of a worsted card varies with the speed at which it can be safely and economically operated

and the type of wool that is being handled. On a 60 in. card it varies from 60 to 100 lb/hr on long crossbred wools and from 40 to 60 lb/hr on fine Merino wools, with cylinder speeds of 90 125 rpm. A 60 in. all metallic wire card with produce up to 120 lb/hr on Merino wools if comparatively free from burs and other vegetable matter.

The product of a card is judged to the amount of noils it produces in the comb and by the number of neps in the sliver everything else being equal, close cooperation between carder and comber is necessary for a minimum of noilage in combing.

A worsted card generally consists of series of rollers of various diameters, speeds, and direction of rotation. A card may be divided into three main parts or sections: (1) the feeding section, (2) the worsted carding machine proper, and (3) the delivery section.

The Feeding Section of Worsted Card

The costly and non uniform hand feeding of former years has been completely eliminated with the introduction of the automatic hopper feeders. These units have been perfected to the extent that uniformity in sliver weight can be accurately effected. The method of supplying these hopper feeders with wool varies from mill to mill and can be accomplished in the following manners:

As the scoured wool leaves the dryer it is dumped into large box type trucks which are pushed by hand or by mechanical means to the hopper feeders of the cards for loading the feeders.

The scoured wool is blown to large bins or stock rooms for temporary storage. Usually these bins are located on the floor above the card hopper feeders. An opening in the floor directly above each card feeder, connected with a chute, serves to keep the automatic hopper feeders full at all times, requiring little attention.

In the most advanced method the dried wool is blown into a large magazine equipped with a slow moving lattice apron, which advances the stored wool to an automatic feeding station from which any desired number of card feeders can be filled automatically over a system of conveyors.

The automatic Hopper Feeders. Automatic card hopper feeders are designed and built by numerous machine manufacturers here and abroad. Aside from minor variations the basic design and working principle of modern feeders are as follows:

Large capacity hoppers with bottom aprons do not require frequent stock replenishment. A spiked, vertically moving lattice apron carries the wool upward, passing an oscillating beater comb so adjusted to the lattice apron as to prevent large lumps of wool from passing this point. The beater further serves to distribute the quantity of wool uniformly over the entire width of the apron and the wool then passes over the top of the hopper where the spikes point downward. At this point the wool is beaten off by a fast moving rotary beater into a scale pan extending the whole width of the card and located directly over one end of a horizontal feed apron. When sufficient wool is deposited in the scale pan the movement of the vertical spike apron and the horizontal bottom apron of the hopper are stopped by either mechanical or electrical means. The pan bottom opens and the exact amount of wool is deposited on the slowly moving, horizontal feed apron. There it is dabbed down uniformly by a dabber and is moved forward by a push board to occupy a definite space on the feed apron. Thus the amount of wool going into the card is positively controlled. Adjustments to alter the amount of wool fed into the card are made at the weigh beam. The feeder is similar to the one used in woollen carding.

The Worsted Carding Machine

The worsted carding machine proper generally consists of the following parts: (1) The breastworks with its feed rollers lickerins, bur cylinder and bur guards (2) The main cylinders with their workers, strippers, and fancies and (3) the doffers with their dickeys.

The stock as it is fed into the card is controlled by the slowly turning feed rollers. The rollers of 2 3 in. in

diameter are clothed with inserted sawtooth wire or they are fitted with brass rings spiked with intersecting steel pins. Generally, two feed rollers with one stripper clothed with wire or brush fillet are used. For fine quality wools, four to six feed rolls and a stripper are preferred to reduce fiber breakage.

The wool as presented by the feed rolls is picked up by the lickerin. For longer types of wool, up to five lickerins were formerly thought to be necessary. This theory has been discarded in favour of all metal breastworks and burring attachments for short burry wools. Since many mills are still equipped with lickerins (three to five, with top and bottom dividers) it will be appropriate to explain their action. These cylinders vary in diameter from 20 to 30 in. They are covered with inserted metallic garnett wire and angular teeth made flat on top to reduce the spaces or indents with the object of keeping the burs, shives and other extraneous matter on the surface, so that the bladed bur beaters can remove them. Round wire between the metallic wire serves the same purpose. A common metallic wire is an 18×24 diamond point wire on the first lickerin. Succeeding lickerins are now metallic wire covered, whereas in the older cards coarse filleting of No. 24, No. 26, and No. 30 wire was used.

Whenever wool stock has mestiza or spiral burs and other foreign matter in fairly large quantities, it becomes necessary to use a bur cylinder or automatic bur cleaner preceding the preparers or lickerins or to substitute the bur breastworks entirely in place of them. (See Fig. 7, which shows bur breastwork). Various machinery builders offer devices for this purpose. In English cards a Morel wire covered roller approximately 27 in. in diameter is substituted for the third lickerin. Its purpose is to allow the material, which is well opened by the previous lickerins, to be pressed down into the spaces between the rows of wires, leaving the burs and other vegetable matter protruding on top of the Morel roll. To be knocked off into a tray by a fast revolving bur beater. Scraper blades or brushes clean the bur trays at periodic intervals and deposit the accumulation into a can located on the side of the card.

The number of bur cylinders or Morels used depends on the quantities of burs in the stock and the desired degree of bur removal. It is advisable to remove as many burs as possible to avoid possible damage to the card clothing.

Much more difficult than the removal of large burs is the elimination of the smaller burs which normally pass the bur beaters. To remove these, many continental carders install a Harmel crusher between the first doffer and the second cylinder. This unit consists of a smooth 10 in. diameter steel roller against which two 5 in. diameter fluted steel rolls are pressed. The web removed from the first roller passes over the plain roller and through the nips of the fluted rollers. Consequently any burs passing through these nips will be broken into short pieces and are ultimately removed in the subsequent carding of the second cylinder.

The commercial method of assessing the efficiency of bur removal only visual examination of the individual, or more often, the compounded rejects obtained from the card for wooliness of the rejects. Valuable information on the relative importance of a deburring point, or the comparison of the efficiency of one card with another, can be obtained where the weights of rejects and card throughout are known. The results give in Table 3 were obtained in this manner from trails carried out by Bownass Janney, and Lowe, to assess the efficiency of bur removal of two types of cards, Bradford and Continental using a range of wools of different fault content.

The Bradford car was fitted with four bur beaters: First top divider beater third licker Morel beater second Divider beater, and second or middle Morel beater (Fig. 4).

The Continental card was fitted with three bur beaters: First taker in beater, first Morel beater, and second or middle Morel beater (Fig. 5).

The rejects from these beaters were collected and weighed and in addition the shoddy dust collected by the shoddy tins S1 and S2 was also weighed. It can be seen that the major part of deburring on the Bradford card is achieved by the third licker Morel beater, whilst it is shared by the first Taker in and first Morel beaters on the Continental card. This was fund to be true for all types of wool processed. Coupled with

visual assessment, the general conclusions were also drawn that little difference existed in deburring efficiency between the two cards for clear wools, but for wools containing a high proportion of spiral bur, the Bradford card was slightly more efficient and produced a card sliver with far less vegetable matter specks than did the Continental card. The important rejects contained approximately 75% of actual vegetable matter for the Burry wool No. 2 and only 40% for the clear wool No. 5.

If an extreme amount of burs is present in the stock, it should be subjected to carbonizing for complete elimination of all vegetable matter.

The Main Cylinders. The stock having been prepared, sufficiently opened, and freed of large burs, is then subjected to a thorough carding by the main cylinder, its workers, and strippers. Typical card constructions are shown in Figs. 3 6.

The Action of the Worker and Stripper. The action of these rolls are the main function of the carding operation. The wool locks or tufts lying on top of the teeth of the cylinder pass under the stripper and are pushed lightly between the teeth of the cylinder. As the wool approaches the contact point between the worker and cylinder, the fibers which are above the teeth of the cylinder are being pushed against the teeth of the slow moving worker and become held by the worker and the cylinder. As the fast moving cylinder moves forward, the fibers become tightened and finally slip off the cylinder wires but, being held by the worker wires, will receive a thorough combing by the passing wires of the cylinder. However part of the locks and tufts will remain in the cylinder wires and pass on to the next worker for a chance to be carded and combed in the same manner. The wool, which has been collected on the worker, is upon contact with the stripper returned by it to the cylinder (Fig. 1).

As can be noted from the diagrams, the number and diameters of workers and strippers vary from card to card depending on the type of wool being processed as well as on the amount of carding desired. Newer card constructions feature a total of up to 13 workers, including the breastworks, instead of the 5 to 7 found in the antiquated systems of former years. In the advanced stages of carding a closer setting of workers to cylinders and the use of finer card clothing becomes necessary. (See Table 4).

The distance between the cylinder and its workers has to be selected very carefully. The number of workers offers a fair range of adjustment. The opinions and practices of technicians often vary widely on this subject. Starting with the first worker of the first main cylinder, it should be set approximately at 0.045 in. gauge setting and the distance slowly reduced until it reaches 0.015 in. gauge setting at the last worker of the second cylinder.

The opening of the wool locks and the draft the material has to undergo at each worker depend greatly on the surface speed of the opposing rolls. Therefore, the efficiency of a carding machine is directly influenced by the speed of each individual roll.

The determining factors of the actual carding action taking place on a carding machine are the number of points per square inch, the surface speed of the opposing rolls and their setting to each other.

Tables 5 7 illustrate common surface speeds found on various types of carding machines.

Action of Fancy. After the wool has been thoroughly carded and returned to the main cylinders, it becomes fluffy and voluminous. It is the function of the fancy to raise the carded fibers to the top of the wires of the main cylinders and allow the doffers to remove them. The location of the fancy is usually above the doffer, provided with a hood to prevent fly and wind from up setting the operation on account of its high speed. See Fig. 2. The wire of the fancy is long and its surface speed is approximately 30 40% in excess of that of the main cylinders. Its wire points opposite to its direction of rotation and is back against back with the cylinder wire, effecting strictly a raising action. The fancy is 10 12 in. in diameter and its speed is adjusted to suit the speed of the cylinder and the kind of wool running in the machine.

Action of Doffer. The doffer serves the purpose to take the carded and raised stock from the main cylinder in a uniform web deposit on its wire surface. Working in connection with the doffer is an oscillating doffer

comb, which takes the fiber web from the doffer to be passed through a funnel to the drawing off rolls.

Dickers and Doffer Dickeys. They are employed only in worsted cards and are small rolls covered with long, flexible toothed card clothing which, working against the doffer, raise any stock that may have passed the comb, and hence is removed on the next revolution. Another advantage of a dickey is that it prevents shives or other foreign material from remaining in the clothing of the doffer, and keeps the wire sharper and in a much better condition. The action is about the same as an ordinary fancy.

Worsted Card Clothing**.** For card clothing employed in worsted cards rubber faced, 5 8 ply filleting is commonly used. The number of points per square inch varies, depending on the grade of wool processed. While various authorities are not in complete agreement on this subject, the clothings given in Table 8 are commonly found on cards processing 64s wool. The various types of card wires referring to gauge numbers, counts, and crowns as well as the different types of metallic wires.

Grinding Worsted Cards**.** Flexible wire covered worsted cards must be ground at regular intervals to keep the wire points in optimum working condition. The methods and equipment for this operation varies considerably. Information regarding grinding, stripping, and setting details is to be found in the chapter on woollen carding.

The use of a special garnett or metal wire on worsted cards has been quite successful. Figure 6 shows the arrangement of the rolls and other details of a metal worsted card. It has no lickerin and dividers, usually considered necessary. The machine also employs smaller rollers and cylinders, exactly half the size of the card just described. The builders claim reduced fiber breakage, fewer neps, and less vegetable matter in the card sliver, almost double the production, and no stripping or waste made from stripping. Grinding is done away with completely. Half the floor space is required and less power is consumed. Metallic card sets have also been installed for the woollen system on carpet wools and asbestos.

Factors Responsible for Nep Formation**.** The factors responsible for the formation of neps in worsted carding leading to increased noilage in combing have been investigated by Townsend and Spiegel. They found that the most important cause of nep formation is undoubtedly the tangled nature of the scoured wool normally fed to the card, for when broken tops are carded the sliver is practically free from neps. It was found that the neppiness of the carded sliver is at a minimum when the regain of the feed wool lies between 30 and 50%. In addition, if the amount of residual grease in the wool exceeds 0.5%, the neppiness is accentuated, just as it is when the amount of added oil exceeds is 1%. The presence of bur in scoured wool is without influence on neppiness, except insofar as it necessitates the use of bur beaters, which promote nep formation.

As regards mechanical alterations to the machine, the nep content of the carded sliver decreases with increasing speed of the card as a whole but an increase in throughput leads to a higher nep content. On the other hand, a reduction in the relative surface speed between feed rollers and first lickerin causes a reduction in neppiness. A further factor of importance is the setting of the workers to the swift the closer these rollers are set to each other, the clearer is the sliver. Assuming a constant worker swift setting, however, any alteration to the setting of the licker section is not reflected in the nep content of the sliver. The action of the dividers, in reversing the direction of the wool at the divider licker point of contact, is responsible for a fair proportion of neps, and the ratio of the surface speeds of fancy and swift is highly critical. If the fancy runs at a surface speed higher or lower than the critical value, there is a large increase in the nep content of the sliver. As would be expected too, grinding has a great influence on neppiness a newly ground card reduced the nep content to half the number present in a sliver produced immediately before grinding.

The Delivery Section

The delivery of the stock from a worsted card can be accomplished by several means: (1) Center drawing

balling head, (2) side drawing balling head, (3) conveyor balling head, (4) can coiling head, and (5) direct gilling.

Center Drawing Balling Head. The carded stock leaves the doffer of a worsted card in the form of a web. This is gathered over a curved brass guide and drawn through a funnel or trumpet by a pair of calendar or delivery rollers. The formed sliver is wound onto a bobbin about 20 in. wide, having no flanges which traverses back and forth giving a cross wind to the sliver.

Side Drawing Balling Head. For low cross bred wools, mohair, camel hair etc., which require support, side drawing balling heads are preferred or even necessary. This system collects the stock in a right angle to the doffer. It is equipped with a revolving sliver tube for inserting a false twist. The formed sliver is wound in a conventional manner onto a bobbin for further processing.

Conveyor Balling Head. The so called railway balling head is used extensively on the French system. Slivers from 5 10 cards are collected on one conveyor belt and delivered to a balling head at the end of the group. The railway balling aids in mixing the stock from the various cards but is only advantageous if a number of cards can be run on the same stock.

Can Coiling Head. The can delivery method is gaining much favour here and abroad. The wool web as it leaves the doffer is well condensed by means of a funnel or trumpet and coiled into fiber cans ranging from 14 to approximately 40 in. in diameter and up to 48 in. in height. The usual way is to coil the sliver in circles against the side of the can while the can rotates simultaneously with the coiler head. The can coiling method is preferable over ball winding because the slivers are well protected and are more easily manipulated in the following process.

Direct Gilling. The most advanced method is made possible by a high speed intersecting gillbox capable of a top speed of 6000 faller drops per minute. As the slivers are drawn off the cards in the usual manner, they are collected on a conveyor belt and fed directly into the high speed gillbox for the first gilling prior to combing. The gilled sliver is then either coiled into large cans of up to 40×48 in or the sliver is wound into large balls. The latest available machines will doff cans and/or balls automatically.

The object of the foregoing delivery variations is to wind the sliver into a practical and convenient form in which it can be efficiently handled in the processes which follow. The sliver should be uniform in weight throughout. In order not to damage the sliver and to avoid roughing and consequent pill and nep formation the spools or balls should be handled as little as possible hence the preference for can delivery.

The Principle of Weaving

Weaving constitutes the actual production of cloth or fabric, i.e., to combine the essentially one dimensional textile structure thread or yarn in such a way as to result in an essentially two dimensional structure of cloth of certain appearance, hand and strength. The process of weaving is distinguished from other methods of producing fabrics such as knitting, braiding, lace making, or bonded web manufacture. A first fundamental fact that can be noted from examination of any woven goods are its length and width. The width of a finished fabric may be from 18 to 35 in. such fabrics are called narrow goods. If the width varies from 36 to 130 in., then fabrics are known as broad or wide goods. Felts, carpets, draperies, etc. are woven in still greater width. The widest loom built in the world was a loom of 540 in. in width for the manufacture of paper makers felts. Such fabrics, however, are of extra and unusual width. The length of a piece or cut is usually 50 70 yd long, and in a few cases, 120 140 yd, known as double cuts. Upon further examination of a woven cloth one can observe that there are a series of yarns or threads running lengthwise, spaced equally or unequally, but generally running parallel to each other. Another system of yarns runs cross wise (from selvage to selvage) mostly equally spaced. These two sets of yarns normally intersect or interlace at right angles to each other and form a solid, well bound, and often thick fabric. Fabrics differ in character, surface, and texture. They may be thin or thick, single or double, rough or smooth, open or closely set, and so forth.

But, whatever the fabic, the following simplified definition of weaving applies:
Weaving is the forming of a textile by the inter lacing, at right angles to each other, of two sets of yarns, one running lengthwise in the loom and termed the warp and the other running cross wise in the loom and termed the filling or weft.
Woven woollen and worsted fabrics are produced on what is termed a loom in recent years the term weaving machine is often used instead. According to German standards this is the official term for mechanical looms. A weaving automat describes a machine in which the replenishment of the filling pirn is performed automatically. The Chapter on weaving will describe the basic motions necessary to produce a woven cloth and will consider the conventional methods as well as new developments that have been introduced successfully in the field of woollen and worsted fabric weaving.

The Essential Motions of a Loom

For the manufacture of woven fabrics on any type of weaving equipment, six principal mechanical motions or operations are involved and must be co ordinated in a certain sequence. They are:
Vertical movement of the warp yarns to form the shed: Shedding, harness or head motion.
Picking motion (insertion of the weft).
Beating up or lay motion (placing picks into the cloth).
Letting off motion (warp supply).
Taking up motion (winding of the woven cloth).
Automatic stop motions (weft control, warp thread control and protection mechanism).
These basic operations are usually supplemented by additional mechanical motions depending on the type of weaving machinery used:
Box motion in multiple box looms, for multicolour weaving or weft mixing.
Weft pirn replenishment motion in automatic looms.
Before proceeding with the explanation of these mechanical motions, it becomes necessary to explain the simple principles of mechanical weaving in general. This will be done on the basis of a simple side elevation of a weaving machine and its essential parts (Fig. 1). The sheet of the required number of warp yarns is properly prepared and placed on warp beam, from which the warp yarns are usually passed in a vertical sheet upward and over the back rail, which brings the warp yarns into the horizontal level with the harnesses or shafts. Before the yarns pass into the heddles of the shafts, they are threaded through two lease rods, which serve the purpose of separating the warp yarns into two groups. Now follows the zone of the drop wires of the automatic warp stop motion and from here, the yarns are drawn through the heddle eyes of the heddles placed on the harnesses of which only two are shown in the diagram. There may be as many as twenty eight in modern worsted looms. For a plain weave one end is drawn through one harness, the next through the other, and so on alternating constantly. The function of the harnesses is to separate the yarn sheet into two groups, one upper and one lower forming an opening known as shed. At first, harness 5*a* is up and harness 5*b* is down and on the next movement or pick, harness 5*a* is down and harness 5*b* is up and so on alternating consecutively with each pick inserted. This is technically known as the shedding operation. In front of the harnesses is located a lay or batten, which carries the reed and has a race or race plate. Lay oscillates forward and backward as shown by the two positions in the diagram. The warp yarns pass through the dents of reed which spreads the yarn evenly across the desired width and acts as a backrest to the shuttle, which carries the weft yarn on a pirn. The shuttle passes through the open shed when the lay is essentially in its backward position it travels in front of reed on the race plate and from one side of the loom to the other.
In recent years, other weft insertion methods have been developed: Instead of using a pirn carrying shuttle, a light weight gripper shuttle may be employed, or the weft is picked by means of rapiers or is carried by an

air or water jet. When the shuttle has passed through the yarn shed and has introduced one weft thread, or, as it is technically called, a pick or shot, the lay moves forward and the shed closes, pushing the inserted filling yarn by means of the reed up to the fell of cloth, where the last pick is now located. The propulsion of the shuttle is known as the picking motion and the forward motion of the lay with its stationary reed is known as the beating up motion. The operations of shedding picking and beating up take place successively and they constitute the three principle motions in weaving any cloth. When the last pick is beaten up, the lay moves backward again and while the harnesses change, the warp yarns again separate into two groups forming a new shed, ready to receive the next pick. This operation repeats itself rapidly at the rate of 120 to 300 times a minute, depending upon machine weaving type, fabric width and construction.

The cloth begins to take shape at the fell of cloth and slowly moves on over breast beam or breast rail down over the sand roll or take up roll, circling its circumference almost completely and over a guide roll down to cloth roll which winds it up at full width. Sand roll is covered with perforated tin or fine sandpaper and moves the woven cloth very slowly in direct accord with the number of picks that are to be inserted per inch of woven cloth. On modern looms, the operation of replacing the empty pirn in the shuttle by a full one is done automatically without stopping the machine. The let off pertains to the constant supply of warp yarn as needed. The take up concerns the motions necessary to move the cloth and warp at such a rate as is required by the number of picks on the cloth.

The weaving process requires from the mechanical side utmost precision of timing and synchronization of all moving parts. The weaving cycle diagram informs about the relative motions of the crank, warp threads (shed) and weft yarn during one rotation of the crank shaft. Position 0º denotes the lay at the beating up position while at 180º the lay has moved to the far back. Realizing that the time for one rotation may take from ½ sec on older looms up to ¼ sec on modern machines, it is easy to recognize that considerable acceleration and deceleration of the moving parts take place. The picking only requires approximately 10% of the cycle time (from 1 to 2) the free shuttle flight, depending upon weaving width, average shuttle velocity and machine speed between 25 and 50% (from 2 to 3).

Details of Principal Components of Weaving Machinery

Shedding or Harness Motion

The equipment and mechanism needed to exercise the vertical movement of the warp yarns, i.e. the shedding motion depends largely upon the design patterns and their variations, which a particular loom must be able to produce. If the patterns require relatively few shafts and are not changed very frequently a cam treading system will suffice, otherwise, the looms must be equipped with a dobby mechanism. In its simplest form, the harnesses are actuated by cams inside the loom frame. The cams are mounted onto the shaft that drives the picking eccentrics, therefore rotate with half the crank shaft speed, which will result in an alternating up and down movement of the harnesses. Only the simplest cloth designs using up to 4 harnesses can be produced by this treading system. If more shafts must be activated it becomes necessary to install the drive mechanism outside the machine frame. The so called outside treading systems consist of a package of up to 12 grooved cams, forcing an equal number of shafts positively up and down by means of a follower roll combined with a lever system.

A limited number of design patterns can be obtained by the selection of various earn shapes and drive ratios with respect to the crank shaft. The design possibilities are increased if the treading system permits to run two cam groups at different speeds, as is the case on certain new loom makes. For the production of design patterns requiring a larger number of shafts, and when pattern changes occur frequently, the loom must be equipped with a dobby or head motion, which is controlled by punched cards, roller cards or wood peg cards. It gives the advantage of flexibility without need for exchanging heavy cams and it can operate,

depending upon the design with up to 24 32 shafts.

The selection of the two shafts to be lifted is initiated by either positive (wooden pegs or roller chains) or negative (punched paper or cardboard) dobby cards. With positive cards, the dobby mechanism is simpler however, such cards have a limited number picks per repeat and long cards are rather heavy and not very practical for storage. The negative punched cards, although their use requires a reading in machine on the dobby, are much handier. Today they are widely used for high speed double lift motions. A comparison of four types of dobby control cards is given in Table 1, indicating the great advantages offered by paper cards. The various dobby systems may be characterized with respect to shed formation, to shed geometry at the moment of beating up, to positive or negative shaft motion and to the speed of the crank shaft.

Shed Formation. In principle the shafts may be pulled up all the way from a neutral position (upper shed motion), or they can be pulled all the way downward (lower shed motion), or the shed is formed by lifting, respectively lowering the shafts by a distance corresponding to half the shed height (center shed motion).

Shed Geometry at Beating up. When at the beating up moment, all warp yarns have returned to the central position, the dobby is a closed shed motion. On the other hand, if the warp yarns remain either in the upper or lower shed except for those which are called to change from upper to lower shed or vice versa for the next pick, then a so called open shed motion is used.

Positive or Negative Shaft Movement. In positive motions, lifting and lowering of the shafts is performed by mechanical linkage systems pulling and pushing the shafts up and down. A negative motion depends for the downward movement of the shafts upon spring force or gravity.

Relationship between Dobby and Crankshaft Rotation. In the single lift mechanism, dobby and crankshaft have the same rotational speed, each shaft is controlled by one draw hook only. On the other hand with a double lifting motion, two picks are inserted during one cycle of the dobby. Each shaft is controlled by two draw hooks that are put into action alternatingly. While one hook is working, the other can be prepared for the next pick.

On conventional woollen looms, the single lift, closed shed motion with positive shaft movement has been most important. Because rather high forces are required to lift and lower the warp thread when weaving heavy cloth a positive acting motion is a necessity. Furthermore, when the warp consists of relatively weak yarns, a better and more trouble free operation is generally obtained with the closed shed motion since during beating up phase, the total tension exerted onto the warp sheet is evenly distributed over all warp threads.

With the ever increasing loom speeds however, the time available for making the shaft selection and to drive the shafts in time is becoming critically short. For this reason the double lift open shed motion dobbies gain importance also in woollen and worsted weaving, particularly since several makes of double lift motions combined with positive shaft movement are now available.

The Stäubli dobby, for the Sulzer machine can make 20 independent selections (18 shafts and 2 for colour change) and is able to operate at 240 rpm on the 85 in. wide machine.

Let off Motion

Older types of woollen and worsted looms are equipped with comparatively simple friction let off motions. These systems are brake devices and as such passive working let off motions. One end of a rope, chain or steel tape that is wound around a friction drum on both sides of the warp beam is fixed to the loom frame while the other end is attached to a weighting lever mechanism. The warp tension is controlled by the weight applied, and it therefore becomes necessary to reduce weight as the warp diameter decreases in order to keep the warp tension constant.

On modern looms, improved warp tension control is provided by automatic let off motions. Depending upon their operational characteristics, the mechanism is called positive or negative let off motion. It must be

pointed out, that the definition of these terms is not uniform over the world. Wira uses the following definition:

Negative Let off Motion (is) a motion in which the warp beam is pulled round by the warp tension whenever the latter reaches a value equal to, or slightly greater than, that required to overcome the braking force applied to the beam. Positive Let off Motion (is) a motion in which the warp beam is turned at a rate which tends to maintain a constant length of warp sheet between the fell and the beam, the means of applying the warp tension being separate from the beam driving mechanism.

The most common regulators belong to the former group consisting of a tension controlling mechanism and a beam driving mechanism. Tension to the warp is often exerted by using a pivoted back rail which is pressed against the warp sheet by a weighted lever or a spring system. As the beam diameter gradually diminishes, the geometry of the forces acting on the warp changes, causing a variation in warp tension if no compensation is provided for. This situation can be cured if an extra rail is placed between the warp beam and back rail in order to keep the warp angle on the back rail constant. Another method for maintaining constant tension is to adjust (increase) the pressure on the back rail as the beam diameter decreases.

The basic requirement of the beam drive mechanism on the other hand is that it should maintain a reasonably constant length of warp sheet in the weaving zone, i.e. the let off rate should be the same as the take up rate of the warp at the fell. On many motion designs this automatic control is also tied in with the back rail position, in which cases the rail serves as an indicator for the length of the warp sheet rather than a warp tension feeler.

A motion that deviates from the above described method in that it operates without employing a moving back rail is shown in Fig. 3.

The warp tension is governed by the spring, which exerts a counterclockwise torque onto the worm gear carriage, and herewith onto the warp beam shaft. Thus the warp tension is caused by the tendency for the spring to turn the beam in the direction opposite to delivery. As the beam diameter decreases, the torque must also be reduced to maintain a constant warp tension. This compensation is achieved by reducing the extension of the spring: The position of the feeler determines through the teethed segments the position of the upper end of the spring. The beam drive mechanism is activated by the fixed oscillating movement of the slide arm, pivoted at. Let us suppose the condition where the beam rotation is less than the take up rate. In this case, the warp beam and the worm gear carriage would be pulled clockwise (warp becomes shorter) and the peg would move to a position further away from the pivot shaft. The rotational angle of the worm gear and herewith of the warp beam will increase, therefore giving more length to the warp sheet. This in turn will cause the carriage to make a counterclockwise motion, and thus the stroke length exerted to peg is reduced again. In continuous operation, the carriage performs a rocking motion, keeping the warp sheet length essentially constant.

The Take up Motion

This motion serves to take up the cloth as it is woven and to pass it on to the cloth roll. Together with the let off motion, the take up motion determines not only the number picks inserted per cloth length but also the disposition of the weft yarns in the cloth. If the weft yarns are evenly spaced, i.e. if the take up beam moves precisely the same amount each pick, this is called a regular disposition of the weft yarn. On the other hand, if the amount of take up is such as to provide a close pressing up pick after pick, the cloth is woven with an irregular weft disposition. The difference in cloth structure becomes apparent, however, only if uneven weft is being woven: In the first case, with regular disposition, thick and thin places will appear in the cloth, and it becomes streaky. While with an irregular weft disposition, a fairly even cloth can be produced.

The take up motions (or regulators) suitable for regular weft disposition are called *positive* motions, in

which, through gear train and ratched or worm driven sand roll, the cloth is taken up exactly the same length with each pick inserted. Positive take up motions work in connection with friction let off mechanisms or negative let off regulators. These combinations are suited for weaving worsted weft yarns and other materials of good uniformity, especially if weft mixing with two or three shuttles takes place. Furthermore a weave design in which the picks are not closely pressed against each other can only be obtained by the positive take up motion.

In the woollen weaving sector however, the *negative* take up motion is often preferred and required, especially for weaving yarns of highly irregular thickness. The impulse for driving the sand or cloth beam in the negative motion is given by a weight or spring force, For obtaining uniform cover with non uniform weft yarns, the necessary irregular weft disposition is made possible only in connection with a negative let off motion, furthermore, the drive force of the take up motion should be small so that the actual forward movement of the cloth only takes place under the influence of the reed force at the fell of the cloth during beat up of the lay.

The basic principles of positive and negative take up motions are shown in Fig. 4 where (1) represents the lay, (2) the weight in the case of negative motion acting over ratchet motion (3) and (4) onto the sand roll (5). The cloth roll (6) is pressed from below against the sand roll and is therefore friction driven. In both cases, a pawl (7) prevents from undesired backwards rotation of the roll. On other take up arrangements, there is no contact between take up roll and cloth roll, which requires a clutchdrive for the latter roll.

The positive take up motion in Fig. 4 is an example for the cloth threading method whereby the weaver will see the backside of the fabric when it appears on the cloth roll, which on certain weaves may be of advantage in view of quality control.

Full Width Temples

When weaving cloths with a close setting of picks, additional work must be done by the beating up action, taking the form of a displacement of the cloth fell by the reed toward the breast rail of the loom. If conventional temples are used weaving a plain worsted cloth, considerable warp tension peaks can occur each time the reed beats up.

If it is possible to shorten the length of the cloth between the fell and the take up roller (where tension variations due to the beating up action are observed), then the tension peaks can be reduced. The use of the Wira full width temple offers the possibility of holding the cloth length in the weaving zone at a minimum. In this way, the high tension difference between the warp and the cloth, necessary for weaving a close pick setting, is already reached after a relatively small fell displacement. This displacement is sufficient to reduce the cloth tension considerably (becoming practically zero) however, it is small enough not to increase the warp tension by a great amount.

The working principle of a full width temple is illistrated in Fig. 5. An L section bar (1) winch is longer than the widest cloth to be woven, is secured by brackets (2) to the breast rail (3). A second bar (4) of similar length to (1) has an inclined edge to form a sloping face (5) and is fastened to (1) by screws which pass through slots in (1). This enables the bar (4) to be moved backward or forward as required relative to the lip (6). Between the faces of (5) and (6) is positioned rod (7), underneath which the cloth must pass. When the reed is away from the fell, the warp tension pulls the rod upwards, therefore the cloth is gripped firmly and it cannot move through the temple. During the beating up, however, the tension on the cloth side of the reed is reduced, the grip released and the cloth will move forward a distance of one pick. The rod (7) consists of three to five pieces placed end to end depending upon cloth width. Furthermore the rods are threaded to ensure that the cloth is held out to width.

Woollen and Worsted Weaves

The manufacture of woollen and worsted fabrics of all descriptions requires a knowledge of textile design. A piece of cloth can be compared to a bridge, the design of which requires an engineer and draftsman before construction. In the woollen mill, the designer is the engineer or draftsman. Upon him rests the construction of a cloth, its composition, or weave structure, the amalgamation and combination of such weaves, and the mixing and blending of colours. Hence a textile design may be compared to a blueprint of a cloth, and represents the specifications of a fabric. On this design, or pattern, planned ahead of actual production, depends the success of any line of fabrics and, subsequently, that of the mill itself.

A study of weaves involves their application to various kinds of yarns, constructions, and weights. Each mill keeps its own records of patterns, designs, drafts, and samples made. The designer is technically trained in all practical mill operations and is required to possess a natural sense of colour harmony. The finished plan or design of a fabric is usually so complete that any boss weaver, finisher, or any department head knows or can learn from the layout exactly what is wanted without further questions. He specifies all details concerning the composition, finished appearance, and weight of a fabric.

Methods of Describing Weaves

Use of Design Paper

In order to be able to do this preparatory work intelligently and thoroughly certain mcans are placed at the designers disposal. One of his most important tools is cross section paper, also known as squared or design paper, on which he designates the weave or combination of weaves, the drawing in draft, and the sequence and arrangement of the harnesses of a loom. The design paper consists of fine and heavy black or blue lines, running at equal distances both horizontally and vertically. The paper comes in large sheets or in pad form, depending on the size required or most convenient.

The object in using this paper is to portray the method or system by which the individual warp and filling yarns will interlace to form the weave of a fabric. Fig. 1 shows the most common woollen and worsted weaves, and gives an illustration (somewhat reduced) of the paper used and how the weaves are designated on it. In order to understand this more clearly, it should be explained that the spaces between the fine vertical lines represent the individual warp threads or ends, whereas the spaces between the fine horizontal lines represent individual filling threads or picks in a cloth. The occasional heavy lines merely aid in counting the spaces more readily, being spread eight, ten, or twelve squares apart in either direction.

Since the wrap or ends run lengthwise in the fabric or loom and the filling picks are inserted horizontally and at right angles to the warp, there are only two possibilities of interlacing. Any individual warp thread can only lay on top or over the filling thread, or under it. To indicate which it is meant to do on design paper, the square can be left blank or it can be filled in with a cross or completely filled in with pencil or ink. If the square is left blank, it means to all designers that the particular warp yarn is to lie below the particular filling pick at that intersection. If the square is filled in with a cross or completely filled in, it means that the particular warp yarn is intended to be raised over, lie on top of the particular filling yarn, or pick. Hence, all crosses, dots, circles, or other marks in any square in the design paper represent raised warp threads, unless otherwise specified by the designer. This system of designation is universal among textile designers, and technicians, and is used in the following pages.

Verbal Designation of Weaves

As an alternative to using design paper, weaves are expressed in other ways in conversation and in writing. The warp and filling threads are designated as being up or down. Hence, the plain weave could be stated in a letter, for instance, in the manner 1/1. The word up or the figure above the line, indicates the number of threads raised on each pick, while the word down or the figure below the line designates that such threads should be lowered for the filling to pass over. For instance, in the case of the basket weave, it can be stated as a 2 by 2 basket, or a 2/2 basket. This method of description applies very well to the simple weaves but

when it comes to twills and satins stating just the threads up and down is not sufficient. The class or kind of weave and, in other cases, the degree of twill and so forth should be given to clarify what is meant. Nevertheless, this does constitute another method of indicating the weave of a cloth, aside from drawing it out on design paper, which, with the elementary weaves, is not ordinarily necessary.

The Plain Weave

To illustrate this system by the simplest weave used in woollen and worsted fabrics, known as the plain, tabby, or cotton weave, reference is made to design 1 in the weave chart. In this weave there are only two single movements, one thread is up and one thread is down, or all even numbered warp threads are up and all odd numbered warp threads are down, and vice versa. If this weave is made in contrasting colours, say white warp and black filling or vice versa, it would look exactly like the design pictured and resemble a checkerboard. Of course, it must be borne in mind that the sequence of this method of inter lacing cannot be broken or interrupted in any way, without interfering with the continuity or appearance of the weave throughout the width and length of the cloth.

The extent to which the weave is carried out depends generally on its repeat in both vertical and horizontal directions. The plain weave in the illustration is extended to 16 by 16 pick, simply to show its appearance in both directions. It is not necessary to carry it out as far and careful examination of the first, second, and third end (warpwise or vertically) will prove that the first two ends act exactly opposite with respect to the filling: i.e., where one is up (that is, over the filling or filled out) the adjacent one is down or under the filling. However, the third warp thread from the left acts exactly the same as the first thread, the fourth end acts like the second, the fifth like the third and first, and so on. Therefore, the plain weave really repeats itself every two ends by two picks. This is the simplest method of inter lacing the warp with the filling yarns and requires a minimum of two harnesses, shafts, or leaves in the loom to weave it. Referring to design 1, the first pick at the bottom, the warp threads one, three, five, seven, etc., are down and threads two, four, six, eight, etc. are raised in that shed. At the next pick, threads one, three, five, seven, etc. are up and threads two, four, six, eight, etc. are lowered.

This weave is employed a great deal in woollen and worsted fabrics, from the finest challis to the coarsest coating or carpet. It gives an exceedingly strong, firm cloth and a smooth surface, but gives the cloth a harder feel and less elasticity than fabrics woven with other weaves. This weave is commonly employed where a flat texture or face is desired. Of course, the nature of the yarn, the stock, the direction of the twist, and the closeness or openness of the cloth construction will affect the surface appearance of the finished fabric. That is true of all weaves.

Derivatives of the Plain Weave

There are three types of weaves derived from the plain weave, which find much use in woollen and worsted fabrics. They are the *warp rib weave*, the *filling rib weave*, and the *basket weave*. The first two as a group are known as rib weaves, because they form ridges in the cloth in either warp or filling direction. The simplest way to form rib weaves is to weave two or more threads together as one. For an illustration, refer to design 2 in Fig. 1. This is known as a 3 × 3 warp rib weave, meaning three warp threads weave as one with single picks only, and that the rib thus formed would run in the direction of the warp. They are made with two, three, or four threads, depending on how much of a rib is desired. The three warp threads in each group can be drawn on individual heddles on each of two harnesses, or three ends into one heddle on each harness. The latter method may cause rolling of the ends over and under each other, which is objectionable in fine worsteds, for instance. These can alternating regular, combined, or fancy, and constitute the source of many interesting rib effects in dress goods and mens wear.

The next illustration or design in number 3 in Fig. 1 and consitutes a filling rib weave. Here each warp yarn floats over three picks, alternating over or under and repeating, forming a rib or ridge in the direction of the

filling in the cloth. The one illustrated is a 3 X 3 filling rib weave. They can be made in all even or uneven combinations such as 2 × 2, 3 × 3, or 3 × 2, 4 × 1, etc. There is no limit to such combinations. These rib weaves are valuable in that they alter or break up the monotony of the plain weave and fine considerable use in striping goods with or without colour and in combination with other weaves as well.

Design 4 constitutes what is commonly referred to as a basket or hopsack weave. It is a derivative of a plain weave in which two or more adjacent warp and filling threads are raised and lowered together as if they were a single thread. It produces a checkerboard effect more pronounced than in the plain weave. The basket weave illustrated in design 4 is designated as a 2 × 2 basket (two warp threads work with two filling threads). They can be made larger, such as 3 × 3, 4 × 4, 6 × 6, and 8 × 8 threads. They can also be made unbalanced by using different numbers of threads, such as 8 × 4, 2 × 1, 4 × 2, etc., giving unlimited possibilities. Colour can be made to play apart in these checks and many pleasing effects are obtained. The warp threads working side by side can be drawn on separate shafts or on the same shaft. Warp ends of different colours which weave side by side alike on the same harness motion (split basket) should be drawn in separate dents in the reed to prevent rolling ends. Because several picks are introduced into the same shed a binder thread at each selvage must be used to prevent the filling from being drawn in during weaving. This is also true in the warp rib weave.

In order to get squares of the same width and length, the same number of ends and picks per inch should be used. If this cannot be done, and the warp is set closer than the filling a weave having more warp than filling threads working together is used to prevent the squares from becoming oblong or unbalanced. Squares of different or alternating sizes can be woven in the same pattern also, providing unlimited combinations. These weaves are used extensively in womens dress goods and coatings as well as mens wear. Of course, these derivatives of the plain weave become looser owing to the larger number of threads that are working in a group.

The Twill Weave

The twill weave in its various ramifications is the one most commonly employed in woollen and worsted dress goods, coatings and mens wear. In all its forms the twill weave is distinguished from the plain weave in that it develops a more or less pronounced diagonal line in the cloth. The twill weave is characterized by the fact that the float of each filling thread is advanced one or more warp thread to the right or left of the preceding filling thread, assuming, of course, that all the floats are alike.

The simplest twill that can be made is a three harness twill, often called a prunella or filling face twill. These names vary according to the nature the material or the relation of the warp and filling in the construction of the cloth. This twill is illustrated in design 15. Close examination of this weave discloses that it is a 45° twill and a filling face twill. In written form it is expressed as a ½ 45º twill, or a 1 up and 2 down 45° twill. It is a 45° twill because it advances one end to the right with every pick. It is a filling effect twill because two thirds of the filling shows on the face of the cloth and only one third of the warp, proportionately. No matter from where one starts to read the weave, it is a one up and two down. The weave repeats every three ends and three filling picks, but is drawn out to 15 × 15 to show its appearance and effect in a cloth which has the same number of ends and picks per inch.

It can be noted that the first warp thread at the lower left corner is filled in, meaning that it is raised above the first filling pick. The first pick from the bottom passes under the first warp thread and over the next two warp threads (to the right) and repeats that way across the width of the fabric. The second pick directly above (horizontally) passes over the first warp thread, under the second, and over the third, fourth, and so on repeating. The third pick passes over warp threads one and two, and under warp thread three. The next pick is just like the first and the fifth and sixth picks just like the second and third, respectively. Looking at the whole design, the twill is complete, continuous, and unbroken.

According to the kind of cloth it is used in, design 15 makes a very line and delicate diagonal. If the warp ends are made of fine worsted yarns and crowded together, the twill angle will become steeper without employing a steep twill weave. If the picks are increased and laid closer together in the loom the twill line becomes reclining. The twill as it is shown is a right hand twill (the usual way of making it), because it runs from the left to the right. If it is reversed and made to run from right to left, it becomes a left hand twill, which is less common in the wool trade.

To make this twill a warp twill or warp effect twill, its formula 1 up and 2 down, is reversed to read 2 up and 1 down. The reversal will bring the warp to predominate on the face, whereas it showed on the back of the cloth previously.

Such twilled fabrics are generally softer, and more pliable than fabrics made with a plain weave. In weaving, twill cloths take the picks much more easily than the plain woven fabrics; hence they can be set closer in the warp and reed, making the cloth heavier, everything else being equal. The three harness warp twill weaves are popular in medium weight worsted, suitings and in flannels.

Balanced or Even Twills

The most common will employed in all types of serges, gabardines. over coatings, etc. is the cassimere, shalloon, or common twill. This weave is illustrated in design 5. It is designated as the famous 2 up and 2 down 45° twill, which makes it a balanced twill because one half of the warp and one half of the filling show on the face. Also, because it is made with an even number of risers and sinkers in the weave pattern, it is known as the even twill. It requires a minimum of four harnesses in the loom and repeats on four ends by four picks. Attention is called to the angle of the twill, which is 45° with the horizontal. It is continuous and unbroken.

In designing this twill or making up other twills, one should always begin in the lower left hand corner of the design as is done in design 5. It is noted that the 2 up and 2 down 45° twill shown commences with the first warp thread (from the bottom) up on the first two picks, down on the next two, up for the next two picks, and so forth as far as one wishes to go. The second warp thread commences with 1 down and 2 up. then 2 down, 2 up, and so forth. In other words, the raised part, which forms the twill line or diagonal, is always advanced one pick. This is characteristic of all 45° twills. The third warp thread commences with 2 down, then 2 up and 2 down, showing again that the twill has been moved up again one pick. The fourth warp thread starts with one end up for one pick, then down for two picks and up again for two picks and so forth up the line. The next or the fifth warp thread operates exactly like the first, the sixth like the second, the seventh like the third, and the eighth like the fourth end, and so on. Hence, the weave repeats on four ends and four picks as indicated. This is one of the most important weaves in the twill family.

Effect of Yarn Twist on Twill

The direction of the twill and the twist in the warp and filling yarns has a great influence on the appearance of the twill in the cloth. In order to make this perfectly plain, it is necessary to come to an understanding about the direction of twist in single woollen or worsted yarns. Single wool yarns, which are twisted to the left, are termed *S* twist, whereas single twist yarns, which are twisted to the right, are termed *Z* twist (A.S.T.M. designations). Two ply yarns usually have an opposite twist to the single ply. S twisted warp yarn used running from left to right in a warp twill will make the twill more prominent. If indistinct warp twill is wanted, a Z twisted warp yarn should be used. In other words, in twill fabrics the clearness and prominence of a twill line are accentuated if their direction is opposite to the surface direction of the twist of the yarn, with the reverse conditions obtaining for distinct twills. The whole relation of direction of twill to direction of twist in the warp and filling yarns is summarized in Table 1.

In practical work, of course, these conditions are greatly modified by the quality of the wool, the size, character, and turns of twist in the yarn, whether it is single or double ply, closeness of the sley or set and

also the finish of the goods. Another circumstance must be considered: If the twill runs right and left alternately and it is desired to have them equally distinct, right twist must be used for the warp yarn in the left twill and left twist in the warp yarn for the right twill.

Steep and Reclining Twills

While this variety of twill (also known as regular twill) is usually at 45° with the horizontal and advances one thread to the right or up until a full repeat has. been obtained, there are other types that depart from this method and angle of diagonal. They are the steep twills in one case and the reclining or flat twills in the other. The *steep twills,* as the name would imply, are twills that are steeper than 45° and run more toward the vertical. These twills are formed when the warp float or twill line is advanced two or more picks instead of only one above the float of the preceding thread as is the case in the common 45° twill and brings the twill line nearer the perpendicular. Steep twills are exemplified in Fig. 1 by designs 6, 7, 8, and 10.

The diagonal lines in steep twills are closer together, but frequently, owing to the filling floats on the back, are more prominent than the regular twills. They are commonly employed in whipcords, uniform fabrics, tricotines, gabardines, and other womens and mens wear fabrics. These steep twills are made by advancing the twill float by two, three, or four picks on each successive end as is clearly demonstrated by the twill angle diagram (Fig. 2). According to this figure, they are termed 63°, 70°, and 75° steep twills, advancing two, three, and four picks respectively. The 52° is a combination of one and two advances, but is not commonly employed. For instance, design 7 is a 5 up and 2 down 63° warp effect twill. Again, design 10 is a 7 up 1 down, 1 up 2 down, 1 up 2 down, and 1 up 1 down 63° fancy twill. Other 63° twills in Fig. 1 are designs 6 and 8.

If a regular twill having an even number of shafts, say ten, twelve, or sixteen, is selected for the construction of a steep twill, only one half as many threads are used and hence, only one half as many shafts are needed. On the other hand, if a regular twill has an uneven number of shafts, the resulting steep twill will have the same number of threads or shafts in the pattern. Again, a steep twill with warp floats using three picks at each succeeding thread requires only one third as many shafts as are required for the base weave, providing the base weave is divisible by 3. Where the number of shafts of the base weaves is not divisible by 3, then the resulting steep twill will require the same number of shafts as the base weave. These weaves can be made with long or short float twill lines, making them more or less prominent. The twill line, of course, is affected by the set or the sley of the cloth, that is, ends and picks per inch. If the set of the cloth is balanced the twill will run exactly as planned. If the warp is closer set than the filling, which is very common, the twill will be steeper than before. If the yarn sizes differ or are changed, the twill angle will also change to some extent. Hence, caution is required here, to prevent radical changes in the character and face of the goods when changing weaves or yarns.

The reclining twill is used only occasionally and for special purposes. These twills decline away from the 45° line and come closer to the horizontal. The same theory applies as in creating the steep twills, only in the opposite direction. When two moves or ends are skipped it becomes a 27° reclining twill when the twill line is retarded three it becomes a 20° declining twill and when a move of four is made it becomes a 15° reclining twill (see Fig. 2).

Pointed and Herringbone Twills

The term herringbone twill is applied to twills in which a sharp break occurs when the twill is reversed, especially when it runs for a considerable length before it is reversed. An illustration of such a twill is shown in design 9 of Fig. 1. Note in the design that a 2 up and 2 down 45° twill is employed, which runs one way for eight ends and is reversed for eight ends. Twills of longer floats than this, all variations and combinations can be employed here. Such weaves are common in ladies and mens suitings and coatings. The pointed twill is very similar to the herringbone in fact many mill men draw no distinction between the,

two in that the twill is reversed without making a break or that it is reversed after it is allowed to come to a point. This system forms the basis for damask diamond, zigzag, and honeycomb weaves, the latter of which is illustrated in design 18 of Fig. 1, and gives wide opportunities for matching fields, squares, and checks created by weave only. When colours are applied many interesting and vivid contrasts can be originated. The pointed herringbone effect can be created with a twill chain and a pointed drawing in draft (see designs). The twill in a herringbone weave can also be arranged to bring the points at the side of the design. The pointed twill patterns have the general defect that the float at the apex is nearly double that of the other floats. When it is important to have them short and practically uniform, risers are removed or inserted at that point. Of course, this increases the number of shafts required in the loom.

Broken or Reversed Twills

By breaking the twill line or practically reversing the direction at intervals in regular or irregular fashion, many attractive patterns can be created. The twill can be reversed in either the warp or the filling. For instance, a 2 up and 2 down twill can be reversed every two warp threads and while the warp threads still weave two up and two down, the reversing of the twill causes every alternate pick to inter lace the warp in plain weave order. If the twill is reversed in the filling, the latter becomes more prominent than the warp, which is stitched (bound) more closely. This applies to the balanced twills only. This weave shows no twill at all.

Very interesting designs can be created by rearranging the parts of a twill so that two groups of threads, with the twill running in the same direction, alternate with two groups running in the opposite direction and also, by reversing the twill in accordance with selected motifs. The latter gives ladder effect and criss cross twills, commonly employed in fancy worsteds.

Corkscrew Twills

The peculiar feature of corkscrew or double twill weaves is the combination of two or more distinct twill lines, which may be of different colours. They are also called diagonal ribs and are popular in clear finished fine mens wear worsted fabric and many interesting colour effects may be achieved by using these weaves. They are usually set closely in the warp and require manifold drawing in drafts. A typical corkscrew weave is shown in Fig. 1, design 12.

Corkscrew weaves can be made by reversing, deflecting, and waving or undulating the twill line. They may be developed with warp as well as with filling floats. The twill can be run alternately to the right and left in order to bring about an undulating effect suitable for stripes in worsted goods.

Inter locking and Offset Twills

Inter locking twills are used extensively to obtain wide diagonal effects with a relatively small number of harnesses in the loom. They also permit an unlimited variety of special designs by inter locking weaves in the warp and filling as well as by bringing a ground weave on alternate picks. They are also used to increase the filling absorbing capacity of a weave. Any change in position produces a new effect.

Offset twills are obtained without reversing the twill direction. In balanced twills, for instance, the risers of the first thread of a group are usually, but not necessarily, brought opposite the sinkers of the last thread of the preceding group. An illustration of this type of twill is shown in the design 11 (Fig. 1). They produce very attractive effects in fine worsteds and can be enhanced with colour.

Undulating Twills

This class of twills produces a wavy twill line, which is formed by an irregular offsetting of the warp and filling floats for instance, by moving the float three threads at one place and four threads at another, either vertically or horizontally. The more the twill line is offset the less distinct it becomes, hence twill with longer floats are used. For instance, a 3 up and 3 down twill, offset one pick, and a 6 up and 6 down twill, offset two picks, are combined to form an undulating or waving twill. Very attractive designs for coatings and tree

bark effects can be made with these, when these waving twill lines are broken and started again. The same effect can also be created with a regular twill weave on an irregularly reeded warp, which consists on groups of fine and coarse yarns, such as five per dent on the fine yarns and four per dent on the coarse yarns. Many combinations are possible with undulating twills and they are extensively employed in the bark effect coatings.

Diversified, Combination, and Fancy Twills

The twill weaves are just a few selected types that are commonly employed in woollen and worsted ladies and mens suitings and coatings. There are other methods of obtaining twills, such as adding or removing risers, the spotting of twills, combining basket, rib, and satin weaves to form twill lines, arranging a twill to form braided effects, etc. In all such combinations the twill line is usually worked out on design paper first and other weaves filled in to serve the purpose. Into this grouping belong the famous tricotine, gabardine, and similar weaves, shown in Fig. 1 by designs 6 and 8. They are very characteric of fine worsted ladies, suitings, producing single and double twill lines that actually rise from the surface and stand erect in fine yarn worsteds. A typical fancy twill is shown in Fig. 1 in design 10. These combination weaves can be carried to such dimensions that Jacquard looms are required to weave them. In general, all such weaves for practical purposes are, wherever possible, drafted down to less than twenty harnesses.

The twills as a group constitute the most important class of weaves for all types of woollen and worsted suitings and coatings and offer a great field for the designer to draw from continually in creating new patterns, designs, and effects. By the use of these weaves, with the aid of colour and all types of yarns, there are unlimited possibilities for application. However, a designer is forced to keep his draft and weaves in simple and easily followed form, so that matters are not unnecessarily complicated in the drawing in department and the weave room.

The Satin Weave

This is the third of three main classes of weaves, namely plain, twill, and satin. The object of the satin weave is to get away from the distinct diagonal of the twill and to produce a patternless, smooth, lustrous surface in the fabric. The satin weave is extensively used in venetians, broadcloths, doeskins, meltons, and kerseys. Satin weaves are usually constructed from a twill weave, but the inter weaving of the two sets of yarns does not follow consecutively but at definite calculated intervals.

Satin weaves are classified into two groups: those in which the warp predominates on the face, called *warp flush sateens*, and those in which the fining predominates on the face, known as *filling flush sateens*. The word *satin* originated in the silk trade, where the satin fabric is made with a *satin* weave. The word *sateen* is more of a cotton term, employed to designate any fabric in which the filling predominates on the surface of the goods. In the woollen and worsted trade the words satin and sateen are used inter changeably and promiscuously to mean the weave rather than any particular fabric as is the case in the silk and cotton trade. The word *satinet,* however, was first used to designate a union cloth in which the face shows only woollen filling, the cotton warp being covered entirely.

The principle involved in the construction of stain weaves is to determine the order of progression for the so called stitchers or points of inter lacement between warp and filling. To obtain the combination from which to design a satin is to take any number of harnesses required of the original twill weave on which it can be woven and divide it into two parts.*These must not be equal, nor must one be the multiple of the other, nor should they be divisible by a third number*. For instance: the number 5 is divisible into 2 and 3. Beginning with thread 1 and progressing two warps threads to the right at each pick, the warp threads are stitched (bound) in the following order: 1, 3, 5, 2, 4. That is, the first warp thread is stitched on the first pick, the third warp on the second pick, the fifth warp on the third pick, the second warp on the fourth pick, and fourth warp on the fifth pick. Hence it can be seen that each warp end is inter laced *with one pick only* and vice

versa and that a scattered order of this inter lacement is used so that no twill is formed at all, although a twill weave of 1 up and 4 down is used. This constitutes a filling flush and by a complete reversal a warp flush satin can be created.

The simplest satin weave, although not strictly a satin but a broken twill, is that made on four harnesses. It is shown in filling and warp effect in designs 13 and 14, respectively, of Fig. 1. The order of inter lacing warp with filling is 1, 2, 4, 3. This is generally termed a crowfoot weave and is quite effectively used in stitching of double cloths and in broadcloths of all types. The twill line is well broken and with the proper yarn will produce a smooth, lustrous surface.

A more or less pronounced twill effect will be encountered in many of the satin weaves, particularly in the even numbered harnesses such as six, eight, ten, or twelve harnesses or shafts, where no regular order of progression is possible. For instance, in a six harness satin the only move numbers available are 2 and 4 (1 is not used), in the eight harness satin 3 and 5 are available, in the ten harness satin 7 and 3, and in the twelve harness satin only 7 and 5 are available, and so on. The uneven number harness satins produce the best effects, because a choice in progression exists, one of which will suit very well, whereas some will show an undesirable twill line. This rule applies mostly to uneven number harness satins.

Table 2 gives the order of stitching satin weaves on various harnesses, which have been found satisfactory in woollen and worsted work.

This Table eliminates a lot of experiments and will serve as a guide in selecting the best progression for any satin weave between five and sixteen harnesses, which are most commonly in use.

For the warp effect satins a closer set, or, in other words, more warp yarns per inch are used, whereas the reverse is true in filling mush satins. If the weave is too loose, the result will be a spongy fabric of poor appearance, lacking handle and durability. On the other hand, if the construction of the cloth is too tight it will be difficult to weave and get the required picks into the cloth and a ribby cloth will generally result. Hence, a happy medium must be found and the filling shrinkage of the cloth carefully watched.

Another factor is the use of the satin weave in stripes of all kinds. Here it is sometimes necessary to crowd the ends in the reed at the stripe to accomplish desired density of weave formation. Checks can also be made by using one harness for the crowding of the picks, if necessary. This is done to some extent in ladies fancy worsted dress goods. The satin weave can also be employed in coloured yarn goods, where the warp is of one colour and the filling of another.

One or the other can be brought to the face independent of the other, and without the other showing through if the yarn is reeded close enough.

Owing to the minimum amount of inter lacing in these weaves, the strength of the cloth is not as good as with the plain weave, hence precautions must be taken if strength, slippage, and durability in satin weave fabrics become factors.

An important use of satin weave is in double, triple, double plain, and broche fabrics, where these weaves are employed in stitching the layers of cloth together or reversing the back with the face alternately also in figured satins, where the warp and filling satins are alternated to produce patterns, figures and motifs, in regular or irregular order. There are also irregular satins and double stitched satins, which, however, find less use in the woollen and worsted trade. Colour effects can be worked very well with satin weaves also. Of course, it will be realized that satin weaves can also be used in combination with other elementary weaves to form a variety of stripes, checks, over plaids, and colour effects which defy the imagination.

Knitting

The origin of knitting is unknown. In the *Odyssey*, there is a description by Homer of Penelope weaving a web by day, which she unweaves at night. This reference possibly means a knitting process, because the secret delaying deeds of the Queen, opening an already woven fabric would require as much time as

producing it, but a knitted fabric can be unravelled as fast as the yarn is rolled into a ball.
The earliest knitted fabrics dating from the third century before Christ were found in the Egyptian tombs. It can be assumed that the art of knitting originated around the Mediterranean and from there it spread to Europe and the rest of the world.
Jesus wore a seamless coat before his execution on the cross. The references to a wrought or fashioned garment he wore could have been knitted, because there is no loom to weave a fabric into shape without a seam.
Dating back to the fourteenth century, there are several mentions of knitting in English poetry, descriptions of garments, and acts of Parliament. The words knot and knitting are derived from the Saxon word of cnyttan, meaning a fabric produced by hand using threads in the formation of loops.
Hand knitting, using two or more pins made of wood, bones or metal became an occupation of amusement, therapy for the aged and sick, and a profitable home industry. In the fifteenth century knitted caps and coarse hosiery were accepted garments in England and fancy knitted hand embroidered ceremonial clothing and silk stockings were worn by the nobility in every court of Europe.
In 1589, the Reverend William Lee invented the hand knitting machine. Many original inventions and mechanisms of Lees, which he incorporated into his stocking frame are still used in the modern automatic knitting machines. Political, economical, and religious prejudices denied Lee the success he deserved. Skilled craftsmen added many improvements and inventions to the art of knitting. Before the start of the nineteenth century all the fundamental stitch constructions already were achieved on the original stocking frame.
The progress of knitting is best illustrated with the speed of a hand knitter forming 100 stitches per minute, Lees hand knitting machine started with 600 stitches per minute, and a modern automatic knitting machine producing over 4 million stitches per minute. Comparing a fast commercial loom, weaving a similar cloth as produced on a knitting machine, the knitted square yardage is 20 times larger than the output of the loom.
The use of knitted fabrics is constantly growing. A man, woman, and child can be dressed from the top of their head to the tip of their toe in knitted apparel. The advantages of the knitted fabric are good fit to the shape of the body, elastic to conform and move with the motions of the body, resilient to recover its original shape without wrinkles, needs no ironing, soft and comfortable to wear, ease of handling as a wash and wear garment, cheaper to produce than other comparable textile fabrics, attractive in unlimited colour and texture designs. The disadvantages of the knitted construction include the lack of perfect stability, and the need of a finer or costlier yarn to produce a similar weight fabric as made on the loom.
Knitting is the art and science of constructing a fabric by inter lacing loops. The loop forming elements of the knitting machine draw the yarn into a curved form called the *loop*. Two loops, a *needle loop* formed around the needle and a *sinker loop* formed around the sinker or some other loop forming element, combine into a *stitch*. A horizontal row of stitches Knitted across the width of the fabric is a *course*, and a vertical row of stitches knitted on the same needle is a *wale* (Fig. 1). The stitch is a basic unit, expressing the fineness of the knitted fabric. Along a ruler or under a magnifying glass the number of *courses per inch* (CPI) and *wales per inch* (WPI) are counted and their product give the *stitches per square inch* (ST/SQ. INCH), WPI × CPI = ST/SQ. INCH, therefore the increasing number of stitches in a square inch indicate a finer fabric. There is a wide range of knitted fabrics from heavy outerwear to fine underwear and hosiery with a fraction of one stitch to several thousand stitches in a square inch.
There are two types of knitting: warp and weft knitting. These terms are also used in weaving, where the parallel threads following the length of the fabric are in the warp and those going across the fabric are the weft threads. In weaving the inter lacing and inter secting of the two systems of threads form a fabric construction, but in knitting one yarn system by itself is sufficient to inter lace the stitches. *Warp knitted* fabrics are knitted from one or more warps in such a way that the individual parallel thread is lapped

around only one needle in a course. Then in the following course the thread will form the next stitch around the same or another needle and knitting progresses in the length of the fabric. *Weft knitted* fabrics are drawing all the stitches of a course from the same yarn. Up to 120 courses can be knitted with each revolution of a circular weft knitting machine, depending on the diameter of the machine, the circumferential space restrictions required for the stitch formation, and the angle of the spiral introduced into the fabric. The volume of weft knitted fabrics in use is about eight times as large as the warp knitted cloths due to the versatility of the weft knitting machines.

Principles of Stitch Formation

The parts of the knitting machine that come into contact with the yarn during the formation of the stitches are called the loop forming elements. The most important loop forming element is the needle, made from wire or sheet metal. Needles are classified in gauges according to their fineness, listed in Table 1. There are many thousands of differently shaped needles according to the type of machine, fineness of the machine, and the special stitch formation technology required. The four basic types of needles are the straight, spring bearded, latch, and compound needles. The straight needle is used for hand knitting, where the thickness of the needle determines the size of the stitch and the looseness of the fabric. The compound needle is rarely used, because it has two independently moveable parts. The disadvantage of the spring bearded needle is the need of a presser, to close the beard during the stitch formation, whereas the latch needle is self contained. The spring bearded needle can be manufactured thinner, demonstrated by the finest full fashioned knitting machine with 60 needles per inch, whereas the finest latch needles are used in 42 needles per inch seamless hosiery machines. Regardless of how freely the latch of the needle moves, it requires the yarn to do mechanical work during the stitch formation, therefore the latch needle needs a stronger yarn than its spring bearded counterpart, which also can knit a more uniform and tighter fabric. The latch needle is the more widely used needle, because its stitch formation is much simpler compared to the spring bearded needle, as they are illustrated in Figs. 4 10, using different types of knitting machines. The other important loop forming element is the sinker, deriving its name from the original stocking frame where this thin steel blade sinks the yarn into a sinker loop between two needle loops.

A weft knitting machine can form the stitches with loop wheels, loop forming sinkers, web holding sinkers, holding down sinkers, and the forecut of the needle bed trickwall between the needles can also function to form the sinker loop. The web holding sinker in Fig. 5, holds the sinker loop of the previous stitch in the throat of the sinker (X) while the needle goes up from the rest position (A) to clearing (B). As the needle starts to descend to the feeding position (C) the yarn is fed into the hook or under the beard of the needle, and then the old stitch is cast off (D), while the sinkerbelly holds the fabric up. The relative distance between the head of the needle and the top edge of the sinkerbelly is the primary determining factor to the size of the stitch and the length of the yarn forming each stitch. The type of yarn, softness of the yarn package, tension on the yarn, sinker and needle cam timing, needle spacing, and the takeup weight of the fabric contribute to the size of the stitch and the ease of the stitch formation. The increased use of yarn feeding devices incorporated into the knitting machines are the best method of eliminating some of the stitch variations and improving the uniformity of the fabric.

Rib machines have the coordinated movement of two sets of needles during the stitch formation, illustrated in Figs. 7 and 8. In a circular machine the horizontal position is taken by the dial needles and the vertical arrangement by the cylinder needles. In straight rib or V flat rib machines the front bed needles form plain stitches the same as the cylinder needles of the circular machine and the back bed needles knit rib stitches similar to the dial needles. From the rest position (A), first the dial needles move out to hold the fabric down, then the cylinder needles move up to the clearing position (B). After the yarn is fed (C), the dial and cylinder needles draw their loops at the same time for synchronized timing (D), or one needle forms its loop ahead

of the needle of the opposite needle bed (D1 and D2) for delayed timing. Synchronized timing is used for strip knitting, because it is easier to adjust on the machine and it has to be used with broad rib and fancy design fabrics. Delayed timing is often used on rib yardgoods knitting machines to knit weak yarns, very tight fabrics, and to reduce the wear on the needles and on the machine.

Purl machines, often referred to as links or links links, have one set of double headed latch needles, which are staying in their respective needle bed or they are inter changing from one of the two needle beds on the same plane to the other bed during the stitch formation. The needle tricks (slots, grooves) of the two needle beds are exactly opposite each other to allow for the free movement of the needles between needle beds and knit a stitch during the same cycle. The rest position (A) is followed by clearing (B), then the needle moves to the opposite needle bed or stays in the same needle bed for the feeding of the yarn (C), and finally the old stitch is cast off (D).

Weft Knitting Machines

It is important to get the basic impressions of a knitting machine which will help to identify its design versatility, manufacturing capacity, and suitable operating methods with available personnel. All weft knitting machinery are classified into one of the three major groups illustrated in Table 2, and then each can be subdivided into additional minor groups according to the specific mechanisms and attachments designed by the knitting machine manufacturers in the United States and abroad. Many modifications of knitting inventors have conceived exceptions to the basic principles illustrated here, but they only prove the versatility of the knitting technology.

Weft knitting machines are built with circular needle beds to produce a tubular fabric and with straight needle beds to knit an open width fabric. The production limitation of the straight needle bed in weft knitting is similar to weaving, because only one course can be produced across the fabric width for each traverse of the yarn. Regardless how fast the yarn is knitted, it has to come to a stop and accelerated in the opposite direction. Whereas circular weft knitting machines maintain a uniform revolving speed and the limitations of the number of courses knitted during each revolution are the mechanical restrictions required to knit the stitch on the circumferential arc of the needle cylinder and the diameter of the machine.

Circular rib machines are manufactured with dog or dogless drive to align the cylinder needles in the exact center between the dial needles. The dog drive of older rib machines has the dog stop on the inside of the cylinder holding the wing underneath the dial, with the fabric between them. The pressure of the dog drive frequently causes vertical lines in the fabric, which is difficult to adjust, and troublesome with cloth press off. The dogless drive of newly built rib machines hold the cylinder and the dial in a fixed relative position with gearing or with sliding pins, which move individually in and out following a cam race to allow for the yarn passage.

The essential parts of a machine to produce a weft knitted fabric are the supply of the yarn on the yarnstand with the tensioning and feeding devices, the needle bed with the needles, the cams of the cambox to activate the loop forming elements, and the fabric takeup. The selection of the basic machine parts is important in high production, large diameter circular weft knitting machines, illustrated in Table 3, because the relative movement of the knitting elements has to suit the product manufactured.

The fineness of knitting machines are expressed with one of several systems selected by the individual machine builders. The fixed needle machines use the gauge designation, which has no relation to the gauge number of knitting needles as illustrated in Table 1. The meaning of machine gauge varies according to the type of knitting machine because tricot gauge is needles/1 in., Raschel gauge is needles/2 in., full fashioned gauge is needles/1½ in., loopwheel gauge is needles/1½ in., and the gauge of foreign machines can also be expressed in centimeter, zoll, or other measurements too. The individually moveable needles require slotted needle beds expressing the fineness of the machine in cut, which is the number of tricks per

inch. Cut implies the number of needles per inch only when the needle bed is filled in every trick or slot with a needle. There can be needle arrangements with empty tricks where the cut of the machine and the needles per inch are different. Cut does not accurately express the needle spacing of small diameter machines, because there are fractional number of needles per inch, therefore the inside diameter of the cylinder and the number of tricks in it are given together, such as 3¾ in. D × 474 N.

Plain, Rib and Purl Stitches

The proper way of holding a knitted fabric for analysis, and to keep it in a record file, is with the face of the fabric towards the viewer, the edge or course knitted last is on the top, the edge knitted first is on the bottom, and then the wales will be running in the length and the courses across the width of the fabric. To remember the correct handling of the weft knitted fabric, visualize the appearance of most circular knitting machines which have the course knitted last still on the needles or on the top, the fabric coming down vertically roll up the edge knitted first underneath the machine and the technical or knitted face of the fabric is on the outside.

It requires some practice and experience to draw loop diagrams representing a stitch construction especially with the more intricate designs. Using a simplified method, most of the weft knitted fabric constructions can be recorded on graph paper. Each square of the graph paper represents a stitch, filled in according to a symbol for each type of stitch. A horizontal row of squares is a course, and a vertical row is a wale. The design paper has to show one repeat of the stitch construction, which is the least number of stitches necessary in the width and the depth of the design, or a multiple of complete repeats.

The stitch is called a plain stitch, when it appears with its needle loop coming out from the previous needle loop below it, showing the long parts of the loop, designated on design paper with in the appropriate square representing the stitch. However, the stitch, which has its needle loop going away through the needle loop below it is called a rib or purl stitch, showing the semicircular parts of the loop, designated on design paper with in the respective square. In many languages there is only one expression for this stitch, but in English it is named a purl stitch in a purl fabric and it is a rib stitch when it appears in a rib fabric.

Taking the most important fabric from each of the three major types of weft knitting machines, there is an interesting relationship among their characteristics and properties, illustrated in Table 4, which help to identify the general classification of weft knitted fabrics.

The biggest percentage of the weft knitted fabrics have the plain construction. This fabric is often referred to as a jersey fabric. Jersey is a misleading word, because it is used both for warp and weft knitted jersey fabrics, with entirely different characteristics and properties. The plain fabric has a smoother face than back, because the loops are coming through the previous loop toward the face and the lengthwise side alignment of the stitches are predominant. Viewing it on the back of the fabric all the loops are going way through the previous loop, providing a rough surface with the semicircular parts of the loops showing. The uniform quality of a plain knitted fabric is very important, because any fault of the yarn and setting up procedure will be noticeable.

The plain knitted construction is used for hosiery, underwear, outerwear, and industrial fabrics. The plain knitting machine is built in its simplest form for high production and limited design versatility that include the use of diverse fibers, a range of yarn sizes, stitch length variations, and colour arrangements. The addition of patterning mechanisms for the primary and secondary knitting elements will create unlimited colour and surface effects in the plain weft knitted fabric. The single and multifeed machines are accommodating hand regulated, fixed, semiautomatic, or automatic striping controls. Most of the plain knitting machines have fixed stripers, which require the positioning of different yarn types or colours in a preselected order according to the design. Semiautomatic and automatic striper machines have a control chain attachment which can change one yarn from the active feeding position to the inactive state or vice versa at the

alternate or all knitting feeds following the design pattern.
The colour arrangement of a plain fabric shows horizontal stripe designs, commonly used for polo shirts and dresses. The designer can create new colour combinations and attractive fabric styles on paper without the actual process of knitting endless number of samples on the machine in preparation of the fabric line. It is important to consider the mechanical limitations of the machine before the selection of the design, in addition to the stitch density and the size of the colour pattern repeat, because the type of striper and the number of knitting feeds determine the courses per design repeat and the finished courses per inch will set the depth of the colour stripe. The number of courses per design repeat should divide evenly into, equal to, or be a multiple of the number of knitting feeds.
Rib fabrics offer a wide variety of stitch constructions through needle arrangements, which create vertically spaced lines in the fabrics. Needle arrangement is the selection of needles out of action without loops, which has the same effect as removing the needle from the needle bed. The wide use of rib knitted fabrics stimulated the inception of several stitch construction designating systems. In addition of representing the rib fabric on graph paper with, for the plain stitches and for the rib stitches, a fraction can be used for one repeat of the design with the nominator expressing the plain stitches formed next to each other, and the denominator indicating the rib stitches. One fraction is used to show a regular rib construction, such as Fig. 11 and two or more fractions indicate an irregular rib design. such as Fig. 12. One or both needle beds can hold isolated needles to knit single rib fabrics, such as 1/1, 2/1,1/4 ribs. and both needle beds are arranged with needles forming similar stitches next to each other to knit broad rib fabrics, such as 2/2, 3/2, 4/4, ribs. Some broad and irregular rib constructions are designed to get pleated effects for skirt and dress fabrics.
In 1908 Scott invented a special circular rib machine to knit the fabric construction called interlock. In the regular rib machine the needles are displaced between each other, but the interlock machine has two rib machines built into one with the needles opposite each other. A double raceway cam or selecting mechanism is used to control the alternate needles in the dial and cylinder, knitting the individual needles at every other feed. This way, two 1/1 rib fabrics are knitted together locking each other at their sinker loops for the interlock construction. Both sides of the fabric resemble the face of the plain fabric, which explains its often used name of double jersey.
The construction of purl fabrics are represented .on graph paper, using, for the plain stitch and for the purl stitch. Some of the simplest purl designs, which have the same type of stitch in the individual courses, can also be designated with fractions, the number in the nominator showing the plain courses and the denominator indicating the purl courses. Basket purl designs have groups of plain and purl stitches alternating in a checkerboard arrangement.

Tuck and Miss Stitch Fabrics

Colour design effects and surface texture appearances are knitted on weft knitting machines with selected needles forming tuck and miss stitches in combination with plain, rib, and purl stitches.
The tuck stitch is formed with the needle holding its previously knitted stitch and a new yarn is also placed under the beard of the spring bearded needle or into the hook of the latch needle. Tuck stitches can be formed on a needle for several consecutive courses, depending on the size of the needle hook, the diameter of the yarn, the strength of the yarn, and the distortion of the stitches. Tuck stitches can be knitted in a course on needles next to each other, depending on the fineness of the machine, the length of the float and the intended use of the fabric. The selection of the number of tuck stitches will control the increased width, thickness, and weight of the fabric. The tuck stitch appears in fabric as, or, and it is shown on design paper by placing a dot into the square representing the stitch.
Latch needle machines can form tuck stitches, in one of several ways. Tucking in the hook, illustrated in Fig. 16. is the easiest and most common method. The needle is raised only far enough to take the new yarn

into the hook. While the old stitch does not move below the latch to the blade of the needle. Tucking with short and long latches is illustrated in Fig. 17, which can be arranged in such a way that at the clearing position B the stitch of the short latch needle will go to the needle blade to form a plain stitch, while the stitch of the long latch needle stays on the latch for a tuck stitch in the hook. During the next course the clearing cam is set high for both the short and long latch needles to clear their stitches onto the blade of the needle, and both form plain stitches. Tucking on the latch is illustrated in Fig. 18, which is necessary in machines without adjustable, moveable, or inter changeable clearing cams. The needle follows the movement of forming a knitted stitch, except at the cast, off D the new needle loop is not pulled through the previous stitch. This way, the old stitch stays on the latch, and during the subsequent clearing both the old stitch and the newly formed tuck stitch move below the latch at B1 to be cast off by the new yarn fed into the hook of the needle. Tucking behind the latch is illustrated in Fig. 19. This is commonly used to feed selected yarns which appear only on one side of the fabric. The yarn for the tuck stitch is fed behind the latch after the dial needle clears its old stitch, then the regular yarn is fed in the needle hook and the old stitch is cast off together with the new tuck stitch by the new knitted stitch. Tucking with a missing latch is used in purl machines as it is illustrated in Fig. 20. The needle forms the plain stitches with its latch the ordinary way, while the latchless hook side is held by the jack. Then the needle moves to the opposite needle bed and it cannot cast off the old stitch because the lack of the latch allows the stitch to return into the hook next to the newly fed yarn. Finally the needle moves back into its original needle bed and the new plain stitch casts off the previously formed plain and tuck stitches.

The miss stitch, also known as welt or float stitch is formed when the needle holds the previously knitted stitch and the new yarn misses the needle during clearing and feeding. Miss stitches can be formed on a needle for several consecutive courses, and in the same course on needles next to each other. The miss stitch appears in the fabric as or and it is shown on design paper by leaving the square blank () representing the stitch. Comparing tuck and miss stitch fabrics with the same general face design, the miss stitch is preferred to the tuck stitch in colour effects, but the tuck stitches make the fabric wider, thicker, and heavier. Viewing the weft knitted fabrics from their face side, the position of the tuck and miss stitches are partially hidden behind the plain stitch, but they are closer to the viewer than the rib and purl stitches, illustrated in Figs. 21 and 22.

An old fabric name has reappeared to become a collective description for many rib fabrics that have a pleasing face and back under the term of double knit. Actually all rib and purl fabrics, also some plain constructions, have reversible characteristics to use either side for the outside of a garment.

The most popular double knit construction is the Swiss Double Pique illustrated in Fig. 24. The appearance of the face and back of the fabric will change according to the ratio of the length of yarn supplied between the knitting feed where all the cylinder needles knit with every other dial needle, and the feed knitting the alternate dial needles only. Other contributing factors to the characteristics of the fabric are the timing of the dial needles relative to the cylinder needles, the height of the dial over the cylinder, the tension on the yarn, the width of the fabric spreader and the tension on the fabric takeup.

There are many variations of the double pique fabric to produce a double knit type of construction with rib or needle between needle gaiting, and interlock or needle opposite needle arrangement. In addition to the Swiss Double Pique construction, the popular fabrics include the French Double Pique, Milano Rib, Ottoman Rib, Single Pique, Punta di Roma, and many others with surface or texture effects and multi colour design appearances.

Dyeing, Bleaching and Printing

Dyeing has been practiced for thousands of years, and among the earliest peoples who dyed their garments were the Chinese and the American Indians. The dyes that were available to the ancients were

produced naturally by plants animals. There were two principal colours: blue indigo, which originated from a plant, red kermas, obtained from the dried bodies of an insect.

Probably the most interesting documents on dyeing have been recovered in Egypt, the Papyrus Graecus Homkensis, preserved at Upsala, Sweden, and the Leyden Papyrus, preserved at Leyden, Holland. The former contains seventy recipes dealing with the cleaning, mordanting, and dyeing of wool, in which the following dyes are mentioned: alkanora (red), safflower (yellow and red), kermas (red), madder (red), and woad (blue). The art of dyeing was well developed, following the same principles that underlie modern dyeing.

The discovery of America added different dyewoods such as logwood, redwood, and fustic to the available dyes. The most important of the dyewoods, and the only one still used on a large scale, is logwood. The dye is extracted from the blood red wood of the campeachy, a large tree which grows abundantly in the West Indies and Central American countries. The dye is sold today in the form of logwood extract.

In addition to dyewoods, the Spainards found in Mexico an insect, which produces cochineal, a beautiful scarlet with a tin mordant which has replaced the less attractive kermas red. There is every indication that the more cultured inhabitants among the Indians of Middle America and South America used these colours to a great extent. Garments and blankets found is the Inca graves in Peru and Chile, dating from before the Spanish Conquest, are examples of the various dyes used such as purple and indigo. The Incas were able to apply these dyes on wool as well as on cotton.

Modern Dyestuffs

The whole art and practice of dyeing was completely revolutionized in 1856 by the discovery of the artificial dye mauve (from the French name of the violet coloured mallow flower). The discovery was made accidentally by a young English chemistry student. William Henry Perkin.

When his discoveries were published, chemists all over the world began to manufacture and experiment with the new dye. Factories were started all over Europe. From the beginning, the manufacture of coal tar dyes, and more recently their allied compounds, has become one of the most important and most profitable of all chemical industries.

Since that time not a year has passed without several new dyes being put on the market by some of the great dye concerns. In more recent years whole new classes of dyes such as fiber reactive, disperse, cationic basic, neutral dyeing premetalized have been discovered and produced for the dyeing of the natural and new synthetic, hydrophobic fibers.

The large dye concerns furnish the trade with excellently madeup sample shade cards showing actual dyed wool samples in the form of loose wool, yarn, or pieces and the shades and strengths offered by the company. With the trends towards pastel shades, several dyestuff manufactures have improved their shade cards by including swatches, which show the shade produced by each dye ranging from a pastel through deep shades.

In addition to shade cards, a number of the large manufactures also supply manuals, pamphlets and technical bulletins describing improved methods of application and the fastness of each dye when subjected to a large variety of tests.

Designation of Dyes

Trade Names

In these sample cards and manuals, the dyes are grouped according to the class of application. In each class of dyes they are arranged according to the colour and their relative shades beginning with yellow, orange, red, violet, blue, green and black. For proper identification of a dye the manufacture gives each dye a trade name. The trade name usually bears a reference to the class, property, and colour of the dye, as Acid Light Red G, or to its chemical composition as Anthraquinone Blue B or Alizarine Yellow GG.

However, in many cases it is simply an arbitrary and non descriptive name assigned by the manufacturer or the jobber.

Letter Designations

The letter or letters following the name generally refer to the shade, for instance, B for blue, R for red, Y or G for yellow (German *gelb*). Methyl Violet is sold in brands running from 6B to 6R that is, from a shade very close to blue with types becoming increasingly redder to a bright reddish violet shade. Sometimes the letter refers to a fastness property such as Alkali Green 2G to indicate fastness to Alkali or Red I, where the L, is used to indicate good fastness to light milling fast where the word milling is used to indicate good fastness to fulling or milling.

In other instances the letter refers to its class such as Wool Green S or Acid Blue both of which means German *Sauer* or applied from an acid bath. Quite frequently letters have no significance and are used merely to identify a type supplied by a specific manufacturer.

Also, it should be remembered that letters used for a specific dye can be misleading since one manufacturers Yellow 3G may be redder in shade than a competitors Yellow 2G or G.

Abbreviations and Percentages

In addition to the letter designations there are such terms as *cone* and *extra cone,* which are abbreviations for the concentration of the dyes. These terms were further broadened by the addition of a percentage figure such as 100 per cent or 125 per cent, meaning in this case that the 125 per cent dye is 25 per cent stronger in its colour value than the 100 per cent. During World War II most manufacturers increased their dye concentration in order to conserve packing material. In buying dyes the concentration factor is one of the most important things to consider, because the same dye may be sold in various concentrations and the prices are based accordingly.

In more recent times concentrations and terminology have changed very greatly so that a blue called extra conc. may be weaker than one called conc. or one without any letters to indicate its strength. The true money value of a dye is dependent upon its strength and performance and not necessarily by price.

Index Numbers

The Colour Index originally prepared by Rowe and published in 1924 by the British. Society of Dyers and Colourists has been revised jointly by the Society of Dyers and Colourists and the American Association of Textile Chemists and Colourists. The new revision lists a very large number of dyes, many discovered and introduced within the past thirty years.

One of the main functions of the Colour Index is to correlate the different names for the same dye. For example, colour index number 31 refers to the dye Amido Naphthol Red G which is manufactured by most dye companies. This same product is sold under many different trade names. By this numbering system, a dyer is able to find a specific manufacturers trade name for dyes, which are on the market.

The Colour Index is today the standard reference on dyes used throughout the world and contains a vast amount of information of value to dyers and textile chemists.

Theory of Dyeing

The wool fiber has an affinity for almost all natural and synthetic colouring matters. This becomes apparent when wool is dipped into an aqueous or solvent dye solution. The affinity varies with differences in the chemical constitution of the dye and consequently many methods of application are used.

The mechanism of the process of dye adsorption and diffusion into the wool fiber is not entirely understood by the chemists. A number of different theories have been advanced to explain the process as already discussed in Volume 1 of this book, pp. 261 264, but none of the theories proposed to date completely satisfy all of the known facts about wool dyeing. A particularly exhaustive study by Delmenico and Peters suggests that the Donnan theory is the best approach. Others claim the Gilbert Rideal treatment is the

more attractive.

Wool Dyes

Wool dyeing may be carried out on loose material, slubbing, yarn and piece. Selection of dyestuffs and of the dyeing procedure to be employed is largely decided by the end use of the finished goods and the state of manufacture at which dyeing is carried out. The extensive ranges of dyestuffs available from manufacturers today make it possible to produce most shades with the fastness properties required, provided their cost is acceptable to the customer.

A new classification of dyes, which are applicable to wool, was given in the *Ciba Review* by Kehrer, each class representing a virtually complete range of colours. To the five groups listed by Kehrer a sixth has been added.

Acid dyes (applicable from a strongly, moderately, or weakly acid dyebath).

Chrome dyes (applied by the chrome mordant, afterchroming. and one bath methods).

Chrome complex dyes applied from a strongly acid dyebath.

Neutral or weakly acid dyeing chrome or other metal complex dyes.

Vat dyes.

Reactive dyes.

Acid Dyes

The acid dyes, mostly sodium salts of sulfonic acids, are dissociated to the free colour acids in an acid dyebath. In view of the amphoteric nature of wool, it is a safe assumption that the colour acids combine with the basic groups of the wool protein to form saltlike compounds. Besides this relatively simple reciprocal effect, other, considerably more involved reactions take place owing to the complex character of the wool fiber.

It is likely, for instance, that following on the process of salt formation other reactive groups in the dyestuffs combine with formation other reactive groups in the dyestuffs combine with certain further groups of atoms in the wool. The actual dyeing mechanism is no doubt seen in its true light if one regards the wool surface as a semi permeable membrane placed in a liquor. Only certain ions pass through the membrane, i.e., dyestuff ions diffuse from the dyebath into the fiber. In all probability, the size and the shape of the dyestuff molecules exert some influence on the manner in which diffusion takes place.

According to Elod, the reactions involved in dyeing wool with acid dyes may be summarized as follows:

Adsorption of the dyestuff anion onto the fiber surface.

Diffusion of the anion through the cortical layer.

Chemical reactions within the wool fiber (salt formation and other types of combination).

The affinity of water soluble acid dyes is a function of the temperature and the pH of the dye liquor. Dyes, which exhaust onto the fiber slowly are applied with strong acids such as formic or sulfuric acid for dyes which have a high rate of exhaustion the use of acetic acid (which is weaker) is preferred. Alternatively, an ammonium salt, such as ammonium acetate or ammonium sulfate, which dissociates at the boil and yields the corresponding acid, may be used. Normally Glaubers salt is added which acts as a control for the dye adsorption.

Individual acid dyes have different affinity for wool. Some exhaust completely from an acid dyebath and are fast while other dyes exhaust only in part and can be partly removed from the fiber by the Glaubers salt contained in the dyebath. The latter dyes level particularly well as the result of this two way process and are sometimes known as levelling dyestuffs on that account.

The acid dyes which exhaust rapidly and completely onto the fiber and are stable to Glaubers salt generally given unlevel dyeings when applied with strong acids. The general rule holds that dyestuffs with marked affinity for wool exhibit poor levelling properties but good fastness to water, while dyes with poor

affinity for wool level well but are not fast to water.
Acid dyes applied from a strongly acid dyebath in part have good fastness to light and are used for dyeing dress goods, carpet yarns, certain upholstery materials and the like, which do not required a high degree of wet fastness.
The use of dyes applicable from a moderately acid dyebath is indicated when a substantial degree of fastness to water and washing is demanded. Shades produced with such dyes even with stand very light milling.
The weakly acid dyeing dyes, also known as milling colours, which have correspondingly poor levelling property possess good fastness to water, seawater, and washing, and are fairly stable to moderately severe milling. The field of application of these dyes includes weaving, machine, and hand knitting yarns, swimsuits and bunting.
Dip to the present the normal dye procedure was to wet out the material in bath with the liquor ratio to the weight of the wool between 20 and 50 to 1. The starting temperature is set between to 100ºF (20 40°C). The dissolved dye is added through a filter bath the process started by running the piece goods or circulating the liquor for 10 min then adding the salt and acids then opening the steam bringing the bath to boil within an hour and boil for 1 hour. When the proper shade is reached the bath is slowly cooled down with fresh water to room temperature, rinsing off any excess dyes and cooling the material at the same time. To correct the shade the necessary amount of dye, which cools well, can be added to the boiling bath and needs an additional 20 min of boiling.
Modern methods of application call for periodic pH measurements as a means of assuring better reproducibility from batch to batch. Dyeings should actually be run by pH control rather than by percentages of acid on the weight of materials. Such procedures make it possible for the dyer to know before the lot is started that the acid has been added and the amount is correct. Thus, differences in alkaline or acid content of the wool, longer liquor ratios, variations in hardness and other variables are controlled by adjustment of dye baths to definite pH before the dyeing is started.
A second pH reading may be taken when the temperature of the dye bath reaches the boil. Such controls reduce redyes, speed up dyeing cycles, saving time and money.
Correcting acid colour dyeings. For various reasons, the dyed material may be off shade, meaning that the dyer has not properly matched the standard or desired shade. Under these conditions the lot must be worked longer in the machine, redyed or stripped and redyed without spoiling the appearance of a fabric or damaging the wool by prolonged processing.
As a general rule acid dyes will level readily at the boil under the correct dye bath conditions. If the lot is uneven due to non uniform distribution of the dye, an addition of Glaubers salt and or acid and longer time at the boil will produce the desired levelness. Occasionally a feed of ammonia may be required to cause desorption of the dye. The desorbed dye can then be exhausted uniformly by careful additions of well diluted acid.
When the shade is too dark and off shade, it is often good practice to correct the shade by boiling dyed and undyed materials together in a fresh bath containing Glaubers salt and acid. During the boiling period dye will be removed from the dyed pieces and absorbed by the undyed pieces. Dyes can be added to this bath to adjust the lot to the desired shade.
If the desired shade is bright and the shade of the lot is quite dull, there is little that can be done to produce a brighter shade. The longer such a lot is boiled the duller the shade becomes. Pastel blues and baby pinks can be brightened by the addition of optical bleach in a fresh bath.
If none of these corrective measures produce the desired result the lot should be dyed into a darker shade or black.
***Correcting milling colour dyeings*.** Milling dyes have much greater affinity for the wool than they have for

the dye bath and therefore once they are absorbed by the wool they are difficult to remove. Prolonged boiling in the dye bath rarely ever levels an uneven lot sufficiently to make it satisfactory and therefore whenever possible, the lot should be dyed black or dark shade immediately. When this is not possible, a fresh bath containing 1 2% ammonia and 20% Glaubers salt may be used. An addition of a good non ionic surface active agent sometimes causes sufficient desorption and redistribution of the dye to produce a level result.

Stripping with hydrosulfite or sulfoxylate may destroy sufficient dye and produce a level bottom so that it is possible to cover by redyeing.

Chrome dyes

As the acid dyes satisfy medium fastness requirements only, they may have to be fixed more durably on the fiber. This is accomplished by bringing about colour lake formation, that is, the dyes are converted into insoluble metal complexes.

Metal atoms can be incorporated in an azo dye if the latter exhibits a certain molecular structure. The metal introduced into the molecule can be made to combine, through primary or secondary valencies, to form an inner complex salt, five and six membered ring systems resulting in the process.

In practice, the goods are dyed and after chromed, that is, after treated with potassium dischromate or sodium dichromate and acid, or the dyebath is set with so called Synchromate (Metachrome) mordant, which decomposes during dyeing and liberates the chromic acid which has the lake forming property. This one bath method calls for dyestuffs which exhaust evenly from a neutral or weakly acid liquor and do not form an insoluble colour lake in the dyebath itself. The earliest method by which the wool was premordanted with potassium dichromate and sulfuric acid is no longer in favour owing to the prolonged boiling period required by prechroming and dyeing.

Dyeings produced by the afterchrome and one bath methods exhibit fastness properties of high order. They are distinguished by fastness to water, washing and milling, even in white styles with coloured effects and possess good to very good fastness to pressing and decatizing. This makes chrome dyes specially suited for goods that have to be subjected to milling such as uniform and coating materials, and hats.

***Correcting mordant colours*.** Because of the good fastness properties of these mordant colours, it is extremely difficult to correct shades that are too dark or streaky. For this reason it is important to start the dyeing operation at the proper pH so that the dye will exhaust slowly and be absorbed uniformly. Microscopical studies have shown that the dye is absorbed first as the acid or unchromed form in metachrome and bottom chrome dyeings. This allows the dye to redistribute itself and level as an acid colour during the time the temperature is being raised to the boil. When the boil is reached, chromation of the dye takes place more rapidly and there is less chance of levelling thereafter. Once the insoluble chromium complex of the dye is formed, little if any levelling can take place.

As a general precaution it is wise to keep the shades on the light side and to use small amounts of level dyeing acid colours for matching. When the shade is too light, the dyeing procedure has to be started over again with chrome colours as with undyed goods.

A rather large number of chromable dyes can be demetalized, (returned to their original state) and will then level as though they were acid dyes. When such fabrics are rechromed the spots do not reappear and the fabrics are generally level and satisfactory. A method of levelling by the simultaneous demetalization of the metal dye complex and the removal and sequestration of metallic impurities has been developed. The method found to give the best results for the greatest number of chromable dyes tested was a 2 hour boil in a 40:1 liquor ratio bath containing 8% oxalic acid, 20% anhydrous sodium sulfate, and 2% of a sequestering agent (tetrasodium ethylenediamine tetracetic acid) based on the weight of the material.

Experiments have shown that desorption and redistribution of dye occurs during this treatment and thus

levelling is promoted in raw stock, slubbing, yarns and piece goods.

Metal complex Dyes

Dyestuffs chemists succeeded in devising a simpler method of dyeing wool by incorporating the metal required for lake formation in the dyestuff molecule: they created premetallized azo dyes such as the Neolan and Palatine Fast dyes. In these chrome complex dyes the chrome is combined with a sulfo group to form an internal salt. The chromium atom is not completely saturated and combines with the amino groups of the wool to produce permanent fixation of the dye on the fiber. The Neolan dyes are derived from sulfonated azo dyes, one azo dye molecule containing one chrome atom. For example, see the chemical formula for C.I. Acid Blue 158.

The introduction of the chrome complex colours simplified dying procedures and eliminated the need for chrome salt, which attacks the wool molecule. A further advantage is seen in the superior fastness properties of the chrome complex dyes as compared with metal free acid wool dyes.

These dyes require a strong acid dyebath, 6 8% sulfuric acid, which has an adverse effect on the physical and chemical properties of the wools. In Table 1 are given the breaking strength, the flex abrasion and the alkali solubility data of four worsted pieces dyed with 1% Palatin Fast Tan IWP and 8% sulfuric acid, dyeing time 1½ hr to boil, 2 hr boiling. These data were obtained during the Princeton Wool Research Project and reported by Wakelin and Von Bergen.

There are no significant differences in the properties of the four pieces. The breaking strength loss is around 20%, whereas there is a decrease of over 50% in the abrasion resistance. A clear indication of the chemical damage is the three fold increase in the alkali solubility. This is probably the result of a relatively small amount of peptide hydrolysis produced under these conditions.

***Correcting chrome complex colour dyeings*.** This class of dyes can be levelled rather easily and whenever possible the lot should be levelled in the original dye bath. If the pieces appear uneven or skittery it may be due to the presence of insufficient sulfuric acid. Take a pH reading and if the bath has a higher pH than 20, a further addition of sulfuric acid should be made. The lot should be boiled 30 min and examined again. If the lot is still uneven add 1 3% of a good levelling agent and boil 30 min longer.

Redyeing, however, will reduce the tensile strength and harshen the hand.

Special Wool Finishes

Introduction

The most important developments that have occurred since 1950 are in the field of improved serviceability such as Wash and Wear Durable Creasing and Permanent Press. The advent of wool and synthetic fiber blends in fabrics which could be permanently creased and pleated was the stimulus for the research work on finding methods whereby all wool fabrics could be given similar properties.

Treatments were developed for wool such that pleating or other fabric deformation could be obtained of a stability equal to that of the thermoplastic synthetic fibers. Similar processes were applied as a flat setting procedure yielding fabrics of improved crease resistance.

In all these treatments, recognition has been given to the important role of fabric structure on the ultimate performance of the finished garment. In addition, the treatments have been utilized for special finishes, such as lustering, embossing, and permanent stretch, which have resulted in a range of fabrics not only of new design but of higher utility and beauty.

The further successful development and application of fiber utilization, fabric design, and finishing processes to the production of wool garments that are of improved wearability has become of the vital goal of the wool industry.

Another area which has proved fertile for development is that of multi purpose treatments. Sironizing is

such as process where flat setting is carried out on shrinkproofed wool fabrics. The incorporation of moth proofing agents in either aqueous or solvent bath of a shrinkproofing treatment will convey durable moth resistance to techniques very similar to those used conventionally for pressing trousers or pleating skirts. A challenge was thus presented to wool interests to devise, and introduce on a large scale, methods for producing similar effects in all wool garments.

The first industrial process for producing these effects was the Immacula finish invented by Speakman and described by Speakman. It is based on the use of sodium bisulfite, a process of presensitizing the wool fabric by treatment for 15 min in a cold solution of 2 3% sodium bisulfite and the permanent creases desired are obtained when the garment is steam pressed in tailoring.

The Si Ro Set process, an Australian development by Commonwealth Scientific and Industrial Research Organization CSIRO, was introduced in 1959. The principle of permanent creasing or pleating is the wool, while held in the required form, is given a permanent set by the simultaneous application of heat, water and a chemical reducing agent. In the Si Ro Set process, an aqueous solution of a reducing agent is sprayed on to the appropriate areas of the finished garment and steaming carried out immediately while the fabric is still wet. The reducing agent can be ammonium thioglycollate, sodium bisulfite or monoethanolamine sulfite (MEAS) and from the technical point of view, it is immaterial which reagent is used. Pardo suggested the use of MBA (*N, N* methylene bisacrylamide). In practice, the choice of chemical depends on the availability of a suitable, stable concentrate, the price, and the service given by the chemical supplier. Because of these factors, different reducing agents are used in different countries, and even in different areas within a particular country.

Other studies covering the development of methods for durable creases were made by Davidson. They found that the addition of Urea in concentration of 6 12% increased substantially the crease retentive properties imparted by the bisulfite, Cednas made a more fundamental study of different stages in the setting process using concentrated solutions of urea bisulfite. After bisulfite or MEAS (low concentration) steam setting, no careful rinsing is required. By urea bisulfite or MEAS (high conc.) setting, rinsing is necessary, and the cloth must be kept in a flat state.

The Si Ro Set process was first used on a large scale in Australia and, on a population basis, more permanent creasing and pleating of wool garments (more than 1 million annually) takes place there than in any other country. The use of the technique is however increasing continually in USA, Japan, and Europe. The details of the technique as used in the USA by manufacturers of mens slacks and suit trousers are given in the WB 4 report of the Wool Bureau Inc. In the United States in 1967, approximately 5½ million slacks and trousers have been treated.

An alternative method to the Si Ro Set process is the technique of presensitizing developed in the USA by the Wool Bureau Inc. The reducing agent is applied to the fabric in the finishing mill and the permanent creases or pleats are then produced, after the garment has been made, by adding water just before steaming. The relative merits of the two procedures are best compared by considering separately the manufacture of trousers and skirts.

For trousers, the Si Ro Set technique appears to be a more useful way of producing permanent creases than the use of presensitized fabrics. Here, the extra cost of presensitized suit fabrics is wasted for the cloth which is made into jackets, while the suggested use of damp cloths on the press as a means of adding the requisite amount of water to the trousers is very uncertain in practice. In order to obtain the best results consistently with presensitized fabric, it is necessary to spray a minimum of 20% water on to the trousers immediately before pressing. The mens clothing industry has, therefore, generally preferred the Si Ro Set process.

For permanent pleating of all wool skirts presensitized fabrics are preferred. The required pleating technique is described in WB 5A report of the Wool Bureau Inc.

The actual technique of presensitizing is very simple. Generally, the fabric is impregnated with a 2% solution of sodium bisulphite, then tentered at the usual temperatures and given a light open decating in the normal way. Other procedures used involve impregnation with monoethanolamine sulfite (MEAS) (WB 5 report of the Wool Brueau Inc.), or the treatment of cloth with either of the reducing agents in a dolly washer or winch dyeing machine, then centrifuging or squeezing before drying.

The disadvantage of these particular creasing and pleating methods is the necessity for free water to be present during steaming. To overcome this disadvantage Cook and Delmenico found a dry setting technique based on the use of a reducing agent urea combination.

Pretreatment consists in padding the otherwise finished fabric through a solution containing the reagents and a wetting agent so that the wool retains 5% urea and 2½ 4% diethanolamine as the carbonate. This is followed by tenter drying and, preferably, hydraulic pressing. At a later stage, the fabric of normal regain can be creased, pleated or otherwise set simply by steaming.

Another technique is the setting of creases or pleats in all wool fabrics by high pressure steam without the use of reducing chemicals. Davidson found that durable creases in all wool trousers can be produced by steaming the neutral fabric for 10 min at 120ºC (248ºF). The loss in breaking strength is around 4% Kopke developed a method for producing permanent pleats by steaming the dry fabrics in an autoclave at 132ºC (270ºF) for 25 min. The degree of setting is influenced only slightly by variations in cloth construction, finishing routine, pH and moisture regain. However, cockling in the pleated material is found to be dependent on the moisture regain of the cloth measured before pleating and setting. The cockling is caused by hygral expansion as higher the moisture regain, the less cockling. Most fabrics were found to be free of cockling when conditioned at 65% RH.

The high temperature setting causes a yellowing of the wool, which may change the shade of pastel and bright blue colours.

The reduction in the breaking strength found in eight panels was 11% for the dry strength, and 25% for the wet strength.

Flat Setting

The principle used for setting wool fabrics increases or pleats has been applied to the setting of full pieces of fabrics as a new finishing operation. This new finish is called flat setting and by now has been given about a dozen different trade names round the world.

Lipson in recent papers give the following details on this wool finishing procedure. Flat setting of wool fabrics with sodium bisulfite solution results in an improved wet wrinkle recovery, which helps to maintain a smooth surface appearance after wetting and air drying. Flat setting combined with shrink resist treatments therefore gives a method of producing washable, minimum iron fabrics. Flat setting also gives a luster and smooth handle to the fabric, and flat set fabrics are easier to tailor than normal fabrics. For these last named reasons, flat setting is becoming a common finishing procedure in many countries.

As with all chemical treatments of wool, flat setting must be carefully controlled for satisfactory results, free from undesirable side effects, to be obtained. The recommended method for flat setting is that the fabric is impregnated with a 0.5 1.0% solution of sodium bisulfite and streamed for 2 5 min. The pH of setting is important. Below pH 4.5, the degree of setting is usually inadequate, and, above pH 6.0, stiffening of fabrics and yellowing of the wool can occur. The pH of an aqueous extract of the fabric should be in the range 4.5 6.0 before impregnation with bisulfite takes place. This is necessary, even though the pH of the bisulfite solution is about 4.5, since a simple impregnation does not necessarily bring the pH of an aqueous extract of the fabric to this value. For example, the pH of an aqueous extract of a fabric may be lowered only from 6.8 to 6.2 by flat setting, whereas a fabric whose aqueous extract is pH 9.2 can still have an extract of pH 8.0 after setting with sodium bisulfite.

Setting with Monoethanolamine Sulfite Solutions

When monoethanolamine sulfite or bisulfite solutions are used industrially for flat setting, adjustment of fabric pH prior to impregnation is particularly important in this case, since the sulfite solutions are prepared with pH values of 6.0 7.0.

If concentrations of reagents and pH adjustments of fabric and solutions are accurately controlled, results obtained with monoethanolamine sulfite bisulfite solutions and sodium sulfite bisulfite solutions are identical.

In practice, the technique can cause difficulties unless the mill is reorganized to carry out the process on a reasonable scale, when it can become very cheap and simple. The only technical problem in industrial application is the steaming of the wet fabric, since this means that the wrappers on the blowing machines quickly become wet. Most mills carrying out a lot of flat setting have at least two wrappers available for each machine, scouring and drying them at regular intervals, while some use specially woven lightweight wrappers made from synthetic fibers.

Flat setting was first used industrially as part of the Sironizing processing. In this case, flat setting is carried out on shrinkproofed wool fabrics to give the cloth the ability to retain a smooth appearance during washing and, in Australia; this is still the main use of flat setting. Flat setting is a very effective way of crabbing and can be used to simplify and shorten finishing routines. Some European mills now flat set fabrics straight from the loom, then scour, tenter and give a light steaming. This gives fabrics that are quite acceptable for many uses and, when the necessary reorganization has been carried out, can significantly lower costs.

Flat setting is now a common finishing technique in the U.K. and Europe, being used mainly because of the luster and improved handle which is given to worsted fabrics.

Sutcliffe found that the combination of flat press characteristics with water repellency assists the resistance to wrinkling.

The padded fabric with a 70% pickup was steamed in a semi decator for 5 min (steam pressure 80 lb) and vacuum extracted for 7 min and then dried. After drying the cloth was finished normally ending up with a treatment on the semi decator for 3 min steam, 5 min vacuum.

Permanent Press

The ability of a garment to remain pressed or in other words has a lasting good appearance is a very desirable attribute. This has become an important feature. Todays concept of permanent press in garments involves the smooth pressed condition, which, together with sharp creases and pleats, last through repeated washings and tumble dryings so that the garments may be worn without ironing. Other terms used for this feature include durable press, press free, washable non iron, wash and wear, and minimum care.

Permanent pressed wool fabrics as reported by Farnworth can be produced by combining any chemical shrinkproofing treatment with a flat setting. Such fabrics were first introduced in Australia, licensed under the trade name Sironized. Today such fabrics are produced on an increasing scale worldwide based on continuous processes as described under shrinkproofing and flat setting.

Lustering of Wool Fabrics

The demand for wool fabrics that have a high luster is not new. It is well established that careful selection of raw materials, such as luster wools and specially hair fibers such as Mohair and Alpaca still play an important part in this field. Of the blends the oldest to achieve a permanent luster are the silk wool combinations. In many of the modern wool type fabrics good luster effects are obtained by the addition of lustrous man made fibers.

In recent years as brought out in the literature, there has been an increasing amount of attention devoted to the production of lustrous wool fabrics. The particular emphasis at the present time is placed on the luster produced during the wool finishing, with the requirement that these finishes should also be permanent. The

latter feature has posed, and still does, particularly tough problems for the cloth finisher. High luster finishes on woollens and worsteds have been readily attainable in a variety of ways, but to make such finishes stable to heat and steam treatments, such as they have to undergo at the hands of the spongers and garment manufacturers, has perplexed many wool manufacturers.

Luster on Pile Fabrics

Luster on pile fabrics in finishing can be obtained in two ways: Mechanical process such as teazle raising and laying the surface fibers in one direction and specific methods to flatten the cloth such as wet decating, blowing, rotary and hydraulic pressing, previously discussed, are ways to obtain appreciable luster. Chemical processes in the main, are related to mechanical processes such as raising, wet decating and blowing but combined with a pretreatment of the cloth with chemical setting agents such as sodium sulfide or monoethanolamine bisulfite.

The biggest change in the finishing of luster pile wool coating fabrics has come about through the adoption of the method and machinery developed years ago by the fur industry to convert sheep skins into the fur known as mouton, as stated by Frishman. The firm, which pioneered in the development of the machinery and a new knitted deep pile fabric of man made fibers, was the Borg Electronics Corporation. The wool finisher was very slow in adopting this method simply because of the low permanency of the pile. But today there is hardly any wool finishing plant without such a machine. The process is known under various names such as electrifying, polishing, ironing, electropolishing, glossing, or lustering.

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