2. LITERATURE REVIEW

2.1 KNITTING

2.1.1 Introduction

On a historical timescale knitting is relatively modern technique[1]. The popularity of knitting has grown tremendously within recent years. This is because of its simple production technique, low cost, the increased versatility of techniques, the adaptability of the new manmade fibers, and the growth in consumer demand for wrinkle resistant, stretchable, snug fitting properties, softer handle, bulkier nature and high extension at low tension particularly in the greatly expanding areas of sportswear, underwear and other casual wearing apparel[2]. Knits are an important part of every wardrobe because they are comfortable to wear and easy to care for. Most knits do not ravel, making them quick and easy to sew[3, 4].

In the earlier days due to non-awareness about knitwears and their poor quality, its use was very much limited to innerwears only, but modern technology has enabled high quality knitted constructions in shaped and unshaped fabric form to expand into a wide range of apparel and domestic clothing[5]. Knits are versatile and can be seen in everything from the most casual wear to the dressiest of clothing attire. They come in a variety of fabrics that vary in texture, elasticity, fiber content, weight, and design. Knitting technology meets the rapidly-changing demands of fashion and usage. With new combinations of fabrics and yarns and with developments in fabric construction, knitted fabrics appear to be the ideal base for functionally correct sportswear. Knitted garments are mainly worn next to the skin and therefore deserve particular attention. Professional athletes and also general consumers are nowadays much more conscious of the functional capabilities of the products they use for their sports activity, and this attention will become even further pronounced. People are paying more attention to sports activity and the market for sportswear continues to expand, and those engaged in developing sportswear feel encouraged to produce an adequate response to these increasingly demanding expectations[6].

Due to the three-dimensional curved shape of the basic unit – the loop, they are generally more porous and extensible than other textile structures. The appearance and performance properties of various knitted structures differ mainly due to the differences in the material composition and structural parameters[7].

2.1.2 Weft knitting

Weft knitting is more diverse, widely spread, larger and accounts for approximately one quarter of the total yardage of apparel fabric compared with about one sixth for warp knitting. Weft knitting machines, particularly of the garment length type, are attractive to small manufacturers because of their versatility, relatively low total capital costs, small floor space requirements, quick pattern and machine changing facilities, and the potential for short production runs and low stock-holding requirements of yarn and fabric.

A major part of the weft knitting industry is directly involved in the assembly of garments using operations, such as overlocking, cup seaming and linking, that have been specifically developed to produce seams with compatible properties to those of weft knitted structures. There are, however, production units that concentrate on the knitting of continuous lengths of weft knitted fabric for apparel, upholstery and furnishings, and certain industrial end-uses[8].

The flexibility provided by weft-knitting technology enables the production of a wide range of structures with different properties. In fact, the variation of material and structural parameters such as fibre, yarn, loop size, and type combined with machine parameters such as machine type, gauge, needle selection capability, yarn feeding and take down technologies, may lead to an endless number of weft-knitted fabric possibilities. An important limitation of weft-knitting technology is machine gauge, which leads to a limited range of yarns that can be used for each gauge, thus influencing the properties and dimensions of the knitted fabrics produced[9].

2.12.1 The primary structures

Four primary structures – plain, rib, interlock and purl – are the base structures from which all weft knitted fabrics and garments are derived. Each is composed of a different combination of face and reverse meshed stitches, knitted on a particular arrangement of needle beds. Each primary structure may exist alone, in a modified form with stitches other than normal cleared loops, or in combination with another primary structure in a garment-length sequence.

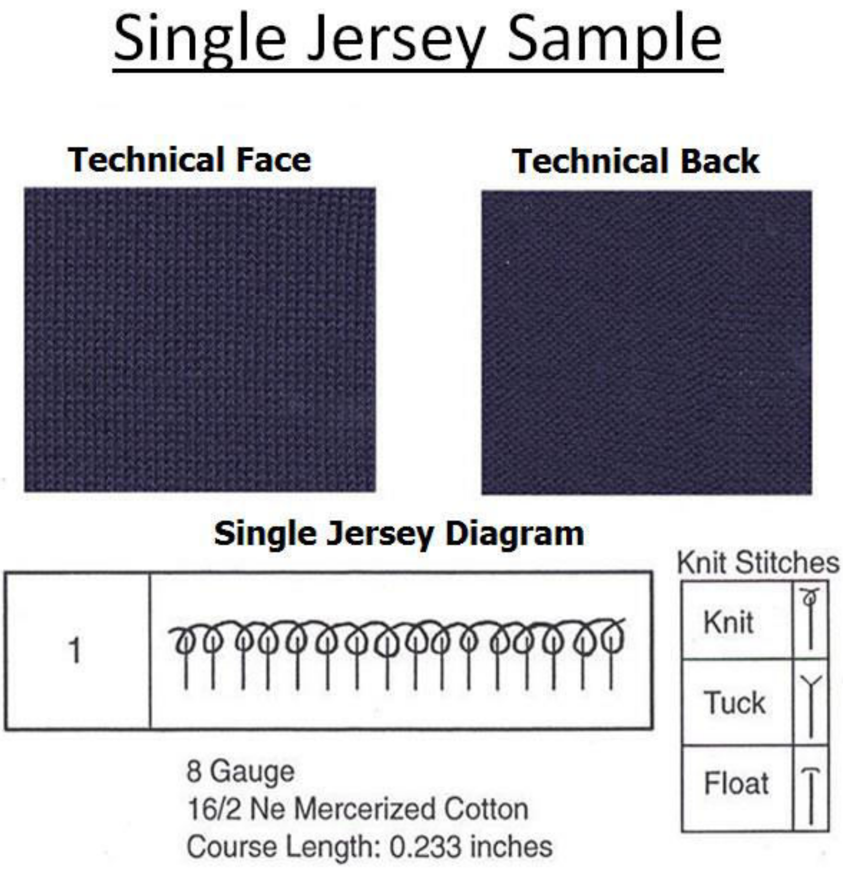


Figure 2.1

2.5.2.2 Plain structure

Today, the two basic knits are the Jersey and the Piqué. Jersey is the simplest and most economical weft knitted structure to produce and has the maximum covering power. It is the base structure of ladies' hosiery, fully fashioned knitwear and single-jersey fabrics. The jersey is a plain stitch knitted cloth made on a circular knit machine. It is produced by the needles knitting as a single set, drawing the loops away from the technical back and towards the technical face side of the fabric. It normally has a potential recovery of 40 percent in width after stretching. The jersey knit has the least amount of shrinkage of all knit stitches. It is, in fact, a very stable knit. Plain knitted fabric is illustrated in figure 2.2. W and C represent wale and course spacing, whereas w and c correspond to the number of wales per cm and number of courses per cm, respectively (see figure 2.3). Its technical face is smooth, with the side limbs of the needle loops having the appearance of columns of V's in the wales. On technical back, the heads of the needle loops and the bases of the sinker loops form columns of interlocking semi-circles, whose appearance is sometimes emphasized by knitting alternate courses in different coloured yarns.

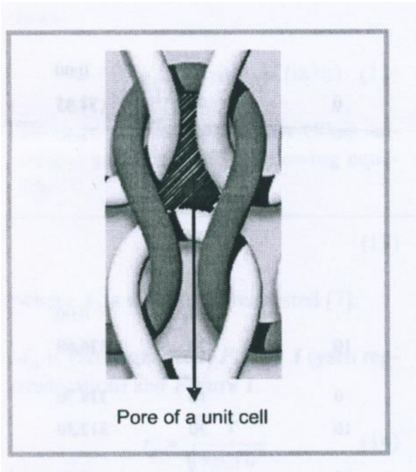


Figure 2.2: Representation of a plain knitted fabric

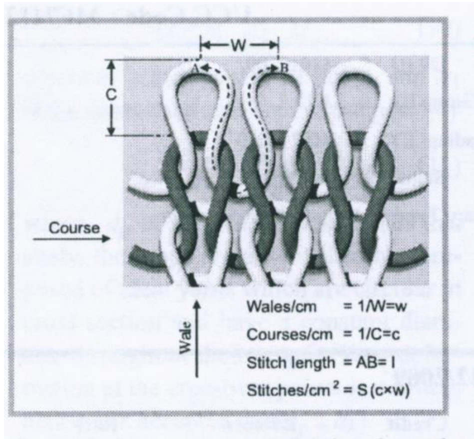


Figure 2.3: Stitch diagram of a plain knitted structure.

Characteristics of Jersey Knits

Stretch crosswise and lengthwise; stretches more in the crosswise; tend to run or ladder if stitch breaks; produced under tension; fabric less stable and curls when cut; special finishes; counteract curling. Jersey fabrics and their derivatives are single-sided structures and include fabrics such as plain jersey, feed stripe, pique, flat jacquard, fleece and plated jersey. Jersey fabric from natural and synthetic fibers is used for T-shirt, underwear, sportswear, pants, etc[10].

2.1.2.3 Pique Structure

The piqué is a medium-weight fabric with a raised dobby design. Piqué fabric can be a single piqué with high and low stitches or possess a honeycomb effect, such as a hexagon shaped stitch. There is a third variation of the piqué fabric, which is widely used in today's branded knits—the birdseye piqué, a raised dobby design that incorporates alternating two-color yarns for the surface of the fabric (A and B colors). As such, the birdseye world has this surface: ABABABABAB (two alternating colors). Thus, the pattern created appears to be a "bird's eye." Pronounced "P-K", this is the fabric that is most associated with **the original Lacoste Alligator Polo shirt**. Also sometimes called **mesh**, it is characterized by a textured fabric face with lots of tiny holes and a fabric back that is smooth. Although, it's usually a heavier fabric, its "meshy" knit provides a great deal of "breathability" (see figure 2.4).

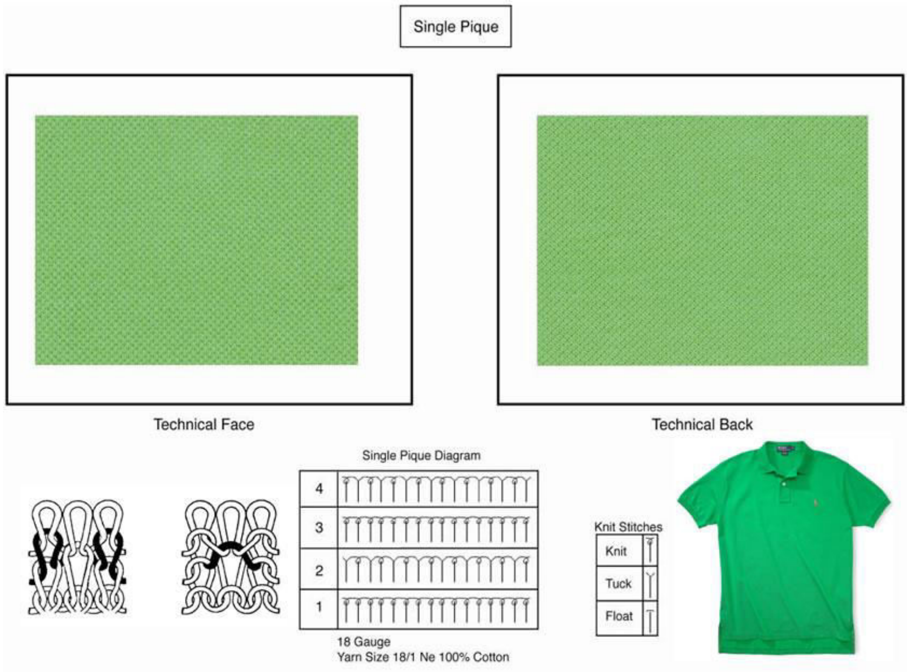


Figure 2.4: Single Pique diagram

The fabric is sometimes referred to as cross tuck. The construction is designed to pull moisture from the skin and wick it into the air, keeping the fabric, and the wearer, relatively dry and cool. Before the days of high tech and high performance Polyester yarns, Pique was **the original performance fabric.** In the 1920's, pique fabrics were an innovation that was used in the first use-specific athletic wear, particularly in the original tennis and polo shirts, as athletes began to move away from participating in sports in long sleeve button down shirts that covered up all skin! The extraordinary comfort of this fabric soon popularized it for less serious athletes, and the rest, as they say, is history! Cotton pique fabric has very good air permeability and moisture permeability, soft feel, even in the hot day, it can give a gentle and comfortable touch. They are usually be used for T-shirt, polo shirt and sportswear.

2.1.2.4 Weft knitting machines

There are two types of weft knitting machines: circular and flat. Circular machines can be classified into – 1) single jersey machines which have one set of needles and make only jersey fabrics, 2) dial and cylinder machines which have two sets of needles and are capable of making jersey and rib fabrics, and 3) double cylinder purl machines which are double-ended latch needles and make purl fabrics.

2.1.3 Circular Fabric Knitting

Weft knitted fabrics may be approximately divided into single or double jersey (double-knit) according to whether they were knitted with one or two sets of needles. Most single-jersey fabric is produced on circular machines (see figure 2.5) whose latch needle cylinder and sinker ring revolve through the stationary knitting cam systems that, together with their yarn feeders, are situated at regular intervals around the circumference of the cylinder. Fashion trends towards prints, fine gauge lightweight fabrics and leisure wear, have increased the world popularity of single jersey over double jersey.

The fabric, in tubular form, is drawn from inside the needle cylinder by tension rollers and is wound onto the fabric-batching roller of the winding-down frame (see figure 2.6). The winding-down mechanism revolves in unison with the cylinder and fabric tube and is rack-lever operated via cam-followers running on the underside of a profiled cam ring. As the sinker cam-plate is mounted outside on the needle circle, the centre of the cylinder is open and the machine is referred to as open top or sinker top machine. Compared with a rib machine, a plain machine is simpler and more economical, with a potential for more feeder, higher running speeds and knitting wider range of yarn counts. The most popular diameter is 26 inches giving an approximate finished fabric width of 60-70 inches.

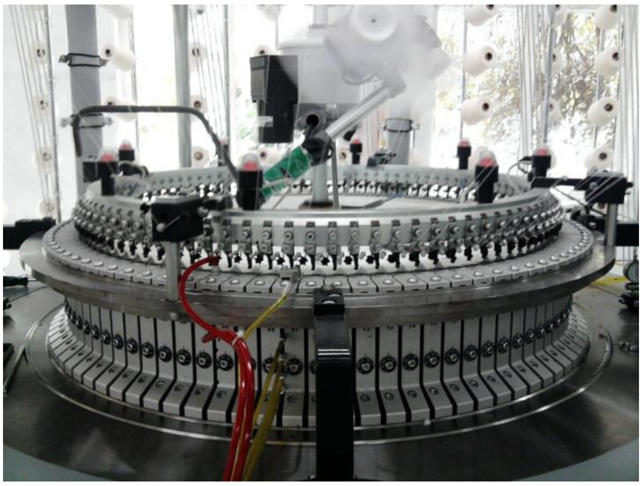


Figure 2.5: Circular Knitting Machine

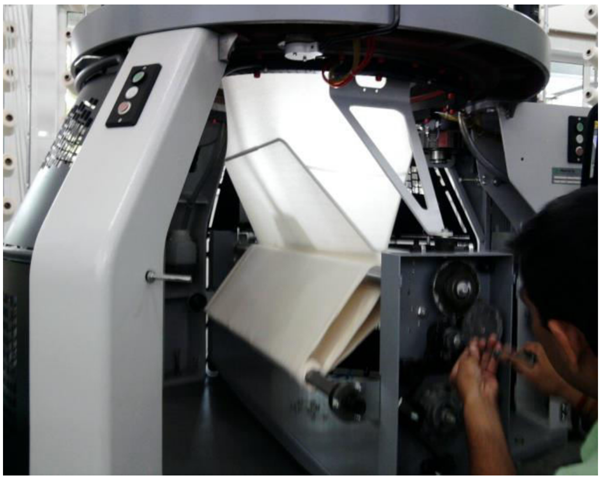


Figure 2.6: Winding-down mechanism

Flexibility in circular knitting is being achieved by providing machines with the ability to produce several products, not only in terms of patterning but also in terms of structural design. Until now, circular knitting machines have been designed and manufactured for mass production of knitted fabrics. The special properties of knitted fabrics, especially fine fabrics made by circular knitting process, makes these types of fabric suitable for application in clothing, industrial textiles, medical and orthopaedic garments, automotive textiles, hosiery, agro and geo textiles, etc[11]. In response to the trend of spinning very fine yarns, circular knitting machines are now available in very narrow gauges, which may reach 60 needles per inch. This is a remarkable development taking into account the complex systems that are involved in the knitting process. On concerns of machine speed, recent developments addressed at increasing productivity enable large diameter circular machines to run at speeds of the order of 100 rpm.

2.1.3.1 Loop shape and loop-length control

During the 1950s, HATRA (the Hosiery and Allied Trades Research Association) investigated the problems of knitted garment size variation and created a much clearer understanding of the influence of stitch length on knitted fabric dimensions, which led both to further research in this field and to the practical application of this knowledge in production. Doyle emphasized the relationship between stitch length and fabric dimensions when, in plotting stitch length against stitch density for a wide range of dry, relaxed, plain weft knitted structures, he showed that, irrespective of yarn type or count or of machine type or gauge, the points lay close to a general curve. HATRA was thus able to establish three basic laws governing the behavior of knitted structure:

1. Loop length is the fundamental unit of weft knitted structure.
2. Loop shape determines the dimensions of the fabric, and this shape depends upon the yarn used and the treatment that the fabrics has received.
3. The relationship between loop shape and loop length may be expressed in the form of simple equations.

The acceptance of these rules has encouraged the introduction of yarn loop-length measuring and yarn feed control devices, has accelerated improvements in shrink-resist and fabric relaxation treatments, and has provided a basis for the theory of knitted fabric geometry. The properties of the resultant knitted fabrics are governed by the two parameters, namely length of loop and shape of loop.

Loop length

Loop length is one of the structural parameters that determine pore size in knitted fabric. Variations in course length between one garment and another can produce size variations, whilst course length variations within structures (particularly when using continuous filament yarns) can produce horizontal barriness and impair the appearance of the fabric.

With the exacting demands of modern knitting technology, the need to maintain a constant loop length at one feed for long periods of time between one feed and another on the same machine, and between different machines knitting the same structure has become of importance in the control of fabric quality. This requirement has encouraged the development of yarn feed measuring and control devices.

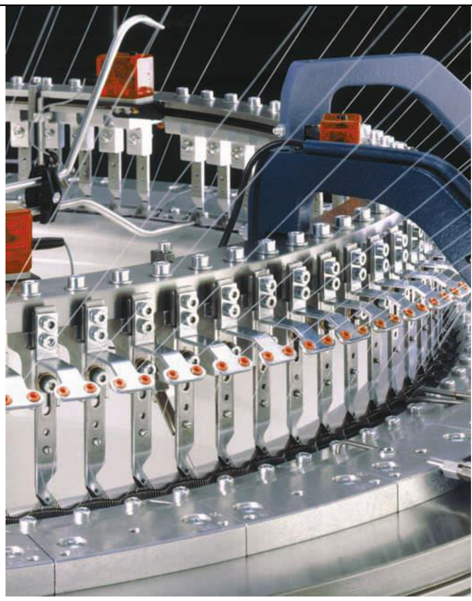
Under normal circumstances, about 15 per cent of the yarn drawn into a newly-formed loop is actually robbed from already-formed neighbouring loops. Although a machine may be set to knit a specific stitch length, fluctuations in yarn or machine variables can affect yarn surface friction or yarn tension and ultimately influence yarn input tension at the knitting point. As a result, the ratio of 'robbed back' to newly-drawn yarn changes and this alters the size of the knitted loop. Course length measurements can be obtained by unroving the yarn from a knitted fabric. This is time consuming, destructive of material, and only provides information after knitting. Two types of meter may be employed to monitor yarn feed during knitting- yarn length counters and yarn speed meter.

Yarn length counter (see figure 2.7) is simplest in construction, providing a reading of the amount of yarn fed in a certain time period. It is particularly suitable for attaching to a moving yarn feeder on a circular revolving cam-box machine. After a specific number of machine revolutions, the machine is stopped to enable the yarn length reading to be taken; this is then divided by the number of knitting machine revolutions in order to obtain the course length for that feed.

The yarn speed meter may require calibrating and provides a direct reading of the rate of yarn feed, usually in metres per minute, whilst the machine is running. The meter may be hand-held and can be used on a revolving cylinder machine without the need to stop it. To obtain the course length it is necessary to divide the reading by the number of knitting machine revolutions per minute.

Monitoring every feed of a large diameter multi-feeder machine is time-consuming and provides no guarantee that the course length will remain constant after measuring (see figure 2.8). Positive feed devices (see figure 2.9) are designed to overcome this problem by positively supplying yarn at the correct rate under low yarn tension to the knitting point instead of allowing the latch needles or loop-forming sinkers to draw loops whose length could be affected by varying yarn input tension.

Due to complicated drive linkages, complex yarn path and careful adjustments required in earlier devices, tape positive feed system developed by Isaac Rosen proved to be more acceptable. A continuous tape driven from the machine drive by a single pulley encircles the machine above the feeders and provides identical and constant feed for any yarn threaded through the nip it forms

	
Figure 2.7: Loop length counter	**Figure 2.8: Knitting head**

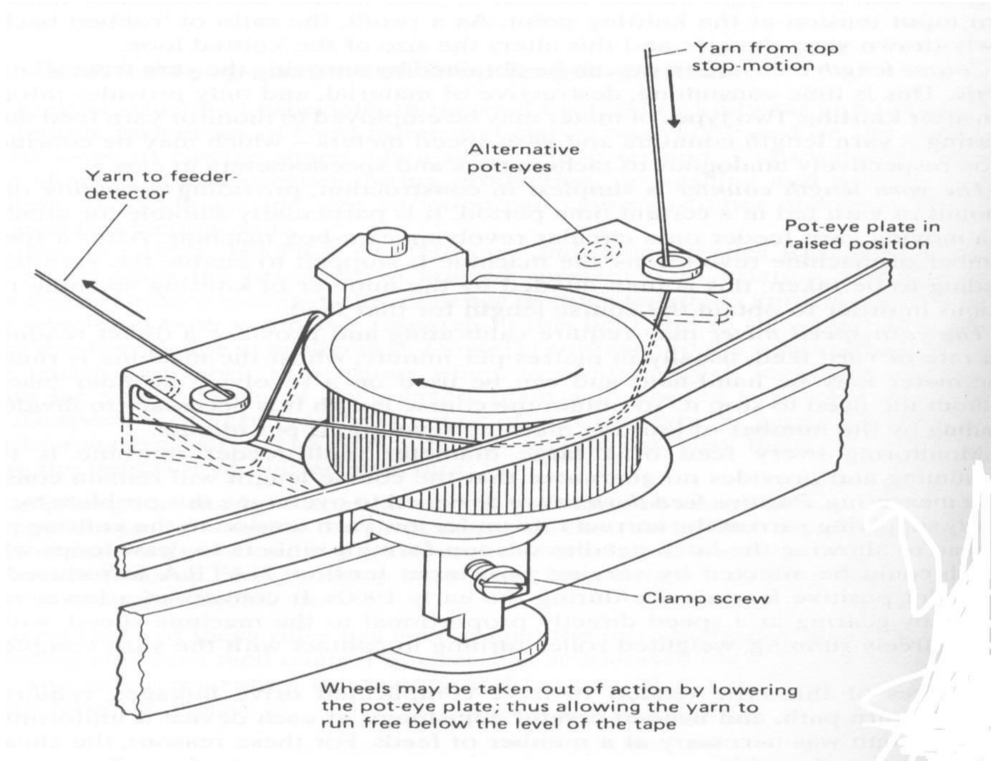


Figure 2.9: Trip-tape positive feed

with a free-running feed wheel at each feed position. On clockwise revolving machines, the yarn passes from its package into the right-hand side of the tape/wheel nip and on leaving the nip on the left it passes down through a detector to the feeder. The faster the tape speed relative to the machine speed, the faster the rate of yarn feed and the longer the resultant course length. The tape speed is altered by adjusting the scrolled segments of the drive pulley to produce a larger or smaller driving circumference.

Fabric cover factor or Tightness factor

Fabric cover factor (CF) is a factor that indicates the relative tightness or looseness of the plain weft knitted structure and is defined as the ratio of the area covered by the yarn in one loop to the area occupied by that loop[12]. This factor influences the porosity of the knitted fabrics which in turn has an effect on its moisture transport performance.

On plain knitted fabrics, Doyle has found that the stitch density depends only on the loop length, and is independent of the yarn and knitting variables[13]. Munden suggested that the knitted loop would take a natural shape when released from mechanical strains, and is independent of the yarn properties[14]. A further study by Munden has shown that the dimensions of plain knitted wool fabrics, in a state of minimum energy, are dependent only upon the length of yarn knitted into each loop. His experimental studies have indicated that in different relaxed states the following equations are applicable, giving a number of different constant values[15]:

$K_c = c \times \ell$, $K_w = w \times \ell$, $K_s = K_c \times K_w$ or $K_s = S \times \ell^2$, $K_r = R = K_c / K_w$,

Where c is the number of courses per unit fabric length and w is the number of wales per unit fabric width; S is the loop density; ℓ is the loop length in mm or cm, and K_r or R is the loop shape and has an average value of 1.3 for fabrics in both the dry relaxed and wet relaxed states. The significance of the above equations is that plain knit fabric dimensions are uniquely defined by the length of yarn in the knitting loop. All other variables influence the dimensions only by changing this variable, that is, if the fabrics are always measured in same relaxed state. Nutting and Leaf introduced a term involving the yarn diameter, and proposed a small modification to the well-known basic equations[16]. Knapton et al have shown that dimensional stability in plain jersey fabrics can be attained either by mechanical techniques or chemical treatments and suggested that the stable loop geometry is almost identical for wool and cotton plain knitted fabrics[17]. Baird and Foulds have shown that by using a factorial analysis of many combinations of factors that the most important variable influencing the shrinkage rate of plain knit in washing is the cover or tightness factor, which they have defined as:

$K = C.F. = T.F. = \sqrt{T} / \ell$

Where T is the yarn count in tex and ℓ is loop length in cm or mm[18]. The tightness factor is means of assessing knitting performance, and has been experimentally proved that its values vary from 10 to 20 when the loop length is defined in cm[19, 20, 21]. The tightness factor can be changed through alteration of the loop length or yarn linear density or through alteration of both these parameters.

Numerous other expressions for cover factor are in existence, of course. Henning used the expression:

$$T.F. = \frac{C + W}{\sqrt{Nm}}$$

Where C is the number of courses per cm, W is the number of wales per cm and Nm is the metric yarn count[22].

Varying the fabric tightness results in systematic variations in the dry relaxed values of the fabric parameters K_c and K_w for fabrics knitted on the same machine gauge. For a range of fabrics knitted on the same machine, an increase in fabric tightness causes a decrease in the length shrinkage of the fabric accompanied by an increase in its width shrinkage. Fabric tightness is important in respect of the end user's perception of the fabric quality. The fabric should not be too tight or too slack. It is difficult to quantify since that is very much a subjective assessment. It is easy to understand that the knitters will try their best to please customers and make every effort to find the fabric tightness factor to their liking.

Pierce suggested a model and derived from it certain relationships between the number of wales per inch and length of the yarn knitted into a single loop. He derived the formula,

$L = 2/c + 1/w + 5.94d$

Where 'L' is the length of yarn in one loop, 'c' is the number of courses per inch, 'w' is the number of wales per inch, and 'd' is the diameter of the yarn[23,24].

Loop shape factor

Loop shape factor is the ratio between the course density and wale density values and hence the ratio between the height and the width of the loop. The shape of the loops in the plain knit fabric can be altered and so the dimensions of the fabric can be changed. It can be said that a higher loop shape factor value possesses a lower dimensional change potential especially in the fabric length.

2.1.3.2 Intelligent yarn delivery systems

Yarn delivery systems for weft knitting are very important parts of knitting machines (see figure 2.10). The main objectives of these systems are:

- To supply the machine with processed textile material, usually yarn, in sufficient quantities, to unwind the yarns from bobbins and to guide the yarns into knitting mechanism.
- To control the quantity of the yarn supply, i.e., the lengths and tensile stresses of the yarns.
- To inspect the yarns from different viewpoints and to stop the machine if necessary.

In general, the yarn delivery system aids the stability of the knitting process by means of yarn length or stress control. The mechanisms controlling these factors can be:

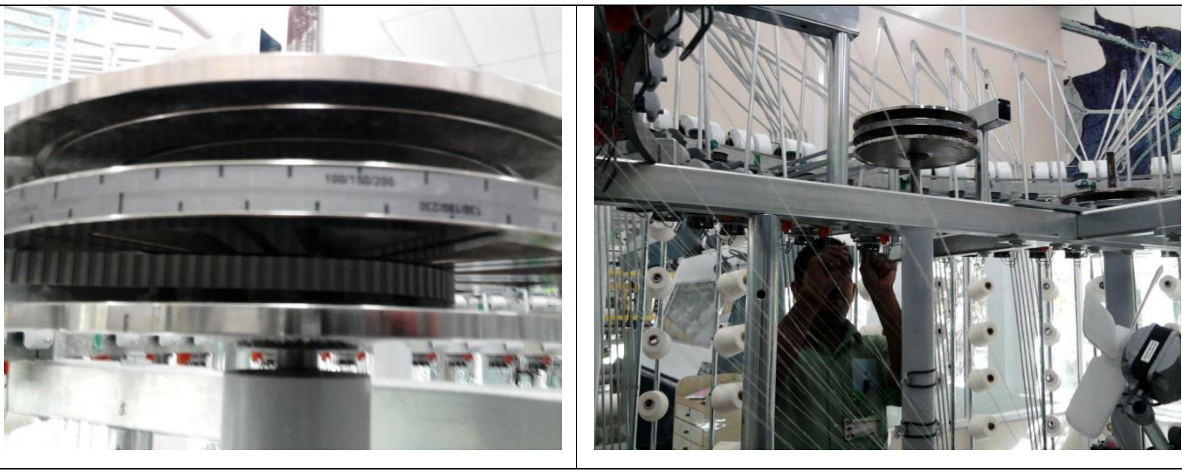


Figure 2.10: Yarn delivery system

Passive, without an energy supply and only able to increase tensile stress in yarns (so-called yarn tensioners or breaks); Active, with an energy resource that can either increase or decrease tensile stress in yarns (yarn feeders). Feeders can control and stabilize the supply of yarn length per fabric unit (positive feeding) or the yarn tensile stress (negative feeding).

2.1.3.3 Fabric range

Weft knitted fabric is one of the most important materials for the very large apparel manufacturing industry worldwide. Of all applications of the weft knitted fabrics in the apparel industry, plain knitted fabric must be the most abundantly used. In this respect, plain knitted fabric used for making garments can be knitted using a circular knitting machine or a flat knitting machine depending on the type of garment, which basically depends on the weight of the yarn for knitting[25].

The fabrics with patterns of float knit, plaited jersey, repeated stripes, pique, twill, lacoste, and the others for summer season high quality apparels from natural and synthetic fibres to be used for T-shirt, underwear, sportswear, pants, etc. are possible on this machine. Even the fabrics for bed covers and industrial linings can be produced as well. In case of knitting with lycra, then it is able to knit fabric for swimming suits and dancing tights[26, 27, 28].

2.1.3.4 Future trends

Compared with the warp – knitted fabrics, the use of weft-knitted fabrics in technical fields has been still limited. For this reason, the most important aim for weft-knitted fabrics in the future is to extend their applications to a larger range of technical fields, such as the automotive industry, functional clothing, the medical field, composite reinforcement and sports. To reach this objective, the use of new kinds of fibre material such as high performance fibres, optical fibres, biodegradable fibres and shape memory fibres, to mention a few, is becoming indispensable[29].

At a glance, the production of elegant circular knitted materials such as seamless fabric is due to advances in biotechnology, information technology, microelectronics, wearable computers, nano-coated and micro electromechanical devices. In many cases the purpose of these systems is to provide both military and civilian personnel engaged in high-risk applications with the most effective survivability technologies. Some new applications of knitted garments in circular form are being developed, such as the introduction of conformal antennas to the fabric body for integrating radio equipment into clothing, power and data transmission devices in the knitted structure, photovoltaic integrated into fabrics, smart footwear, quality knitted coating in home applications such as carpets or covers, energy-converting and protective tubular fabrics, which generate electricity from the thermal energy in people's movements, and the application of phase changing materials for heating and cooling of the individual (used in double face knitted fabrics, or spacer fabrics that are knitted in circular knitting machines). The specific features of circular knitted fabrics such as flexibility, seamless structure and contactability make the circular knitting industry the most improved quality textile sector of the future.