Analysis of Yarn Tension Generated during Circular Weft Knitting in Case of Positive Storage Feeding

by

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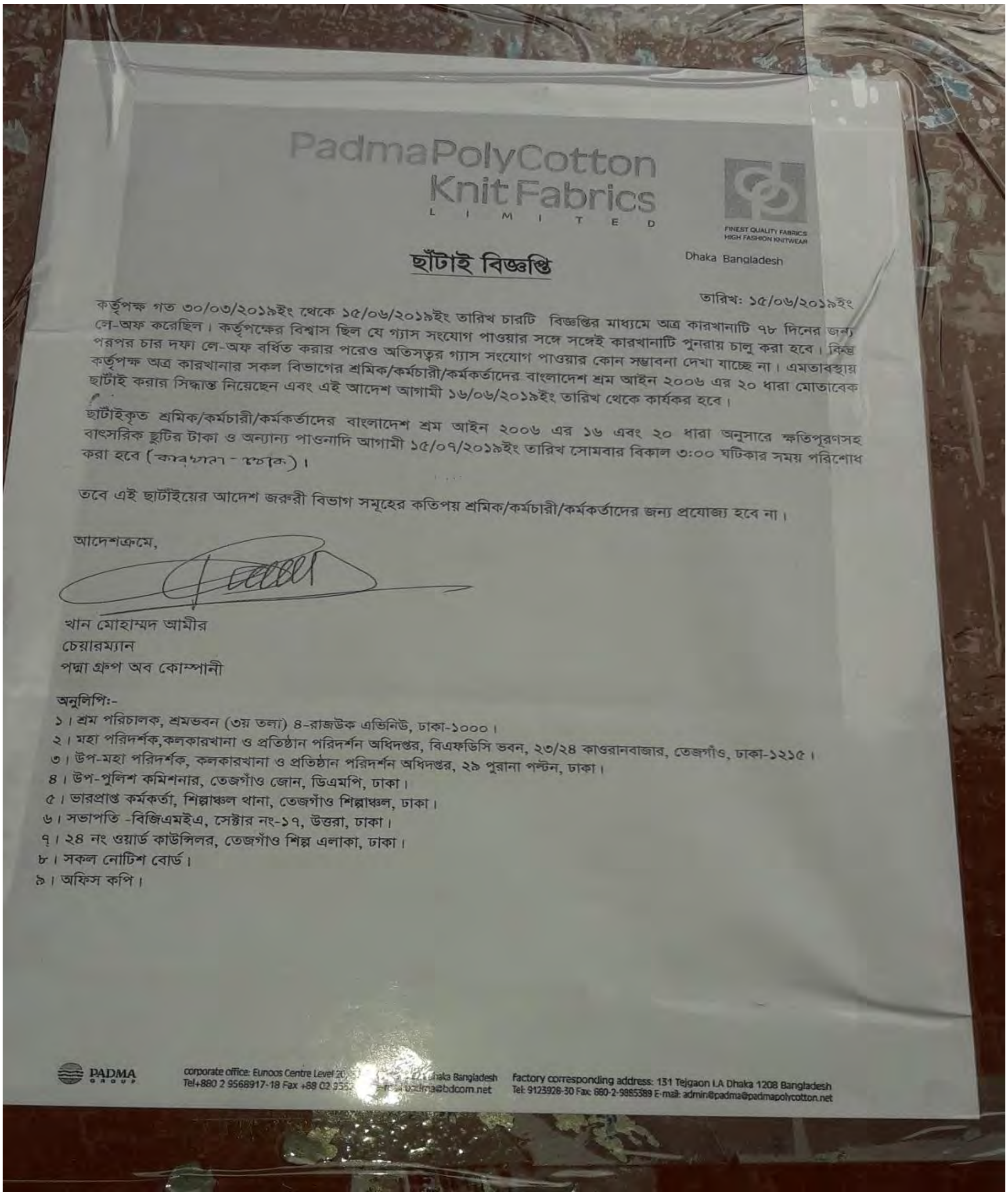
To

The ex-workers and ex-employees of recently closed **Padma PolyCotton Knit Fabrics Limited;** without their tremendous support the research works would never be accomplished. May Allah grant better provisions for them.



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তবে এই ছাঁটাইয়ের আদেশ জরুরী বিভাগ সমূহের কতিপয় শ্রমিক/কর্মচারী/কর্মকর্তাদের জন্য প্রযোজ্য হবে না।

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চেয়ারম্যান
পদ্মা গ্রুপ অব কোম্পানী

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২। মহা পরিদর্শক,কলকারখানা ও প্রতিষ্ঠান পরিদর্শন অধিদপ্তর, বিএফডিসি ভবন, ২৩/২৪ কাওরানবাজার, তেজগাঁও, ঢাকা-১২১৫।
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৮। সকল নোটিশ বোর্ড।
৯। অফিস কপি।

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List of Abbreviations

ASTM	American Society for Testing and Materials
CKM	Circular Knitting Machine/Circular Weft Knitting Machine
CL	Course Length
GDP	Gross Domestic Product
ISO	International Organization for Standardization
LL	Loop Length / Stitch Length
MS	Machine Speed
PPCKFL	Padma PolyCotton Knit Fabrics Limited
PSF	Positive Storage Feeding
QAP	Quality Adjusting Pulley
RMG	Ready-Made Garment
YIT	Yarn Input Tension
YL	Online Yarn Length / Machine Rev.

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Abstract

Knitting mechanics is highly affected by yarn tension at various points in the process. Yarn tension plays a crucial role by influencing the knittability as well as the quality of the fabric. Besides these industry practitioners always have to be aware about higher production rate as well as machine performance. Therefore analysis of yarn tension, particularly Yarn Input Tension (YIT) [Yarn feeding tension to the loop formation zone], with respect to course length (CL), machine speed (i.e. rev./min. of needle bed) and machine performance are some very important issues to be studied. To investigate these issues on a modern circular knitting machine (CKM) some theoretical and experimental works were carried out.

To relate YIT with CL a model in the form of an equation has been developed based on the mechanical consideration of yarn during dynamic circular weft knitting process that runs with positive storage feed (PSF) system. The predicted CL through this model has been compared with that found from actual fabric by a recognized apparatus, i.e. HATRA Course Length Tester. The t-test was carried out over the obtained results for statistical analysis purpose. It was observed that for cotton and spun polyester knitted fabric, as used in the experimental part, the model worked very effectively through precision prediction by showing very low average mean difference in predicted CL from that measured from the actual fabric. Moreover from the experimental works it was also observed that actual CL remains almost unaffected by machine setting (i.e. stitch cam position) and yarn fineness.

To find out the effect of machine speed on YIT, plain jersey fabric samples were knitted on an industrial CKM at different loop sinking depths through adjustment of cam settings**.** Linear regression analyses representing the relationship between the variables were evaluated. YIT and online yarn length/machine rev. were found to vary, though not so significant, positively with machine speed resulting a r-square value of more than 0.9.

To assess the performance of a modern CKM (i.e. the particular industrial machine used for the research study) through monitoring of running yarn tension, a total of 16 different production runs- each for a machine running period of 30 seconds [equivalent

to the time required for more than 05 revolutions of the needle bed or machine at 10.5 rev. /min.] were analyzed. Highest tension-peak value for each second was identified through MLT Wesco Yarn Tension and Rate Meter and associated PC software. Run charts were built-up with these selected tension values by statistical software, i.e. Minitab and the p-values were checked to identify special cause variations. It was found that most of the production runs showed no non-random pattern in the tension values based on an alpha value (significance level) of 0.05, representing absence of special cause variations and thus disclosing quite satisfactory machine performance.

Finally a noble approach has been shown to bring an improvement in the Quality Adjustment Pulley (QAP) belt cleaning system of a CKM. A compressed-air based lint removal device for the QAP belt has been developed. It has been found that the device acts as a convenient tool for lint removal from the belt. Moreover, the device is more cost-effective and shows better cleaning performance than the traditional brush-shelf type cleaning apparatus that are available in some CKM.

CHAPTER-1

INTRODUCTION

1.1 General

The subject area of this research work is analysis of yarn tension for positive storage feed based circular knitting machines-a critical issue of modern weft knitting mechanics. Knitting technology, a major branch of textile engineering, is quite popular worldwide for converting yarn into loop-structured fabrics (Figure 1.1 and Figure 1.2). It needs to be mentioned here that textile engineering has been defined as an interdisciplinary field and recognized by the US Accreditation Board of Engineering and Technology (ABET) as a derivative of mechanical engineering (El Mogahzy,2009).

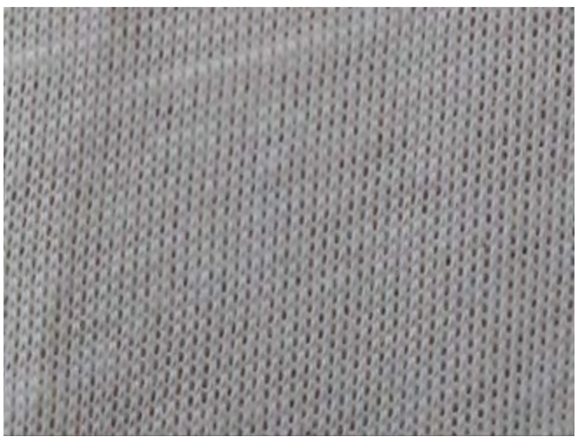


Figure **1.1**: An image of knitted fabric

Figure **1.2**: Interlooping in knitted fabric

In Bangladesh circular weft knitting machines are mostly used due to regular demand of relevant product, availability of manpower and comparatively lower machine price. An image of an industrial circular knitting machine is shown in Figure 1.3.

Figure **1.3**: A circular weft knitting machine (Courtesy: Padma Polycotton Knit Fabrics Limited)

The yarn tension of a yarn running into a circular knitting machine is an important technological parameter. During knitting operation yarn withdrawn from yarn package passes over a large number of accessories or machine parts to reach the knitting zone where it is converted into loops (Figure 1.4). Such passing over of yarn develops yarn tension which varies from zone to zone in the machine depending particularly on the frictional coefficient of yarn and angle of wrap between the yarn and the machine parts. So it is quite obvious that tension in yarn is a kind of force that is developed automatically and may be enhanced by some devices called tensioner.

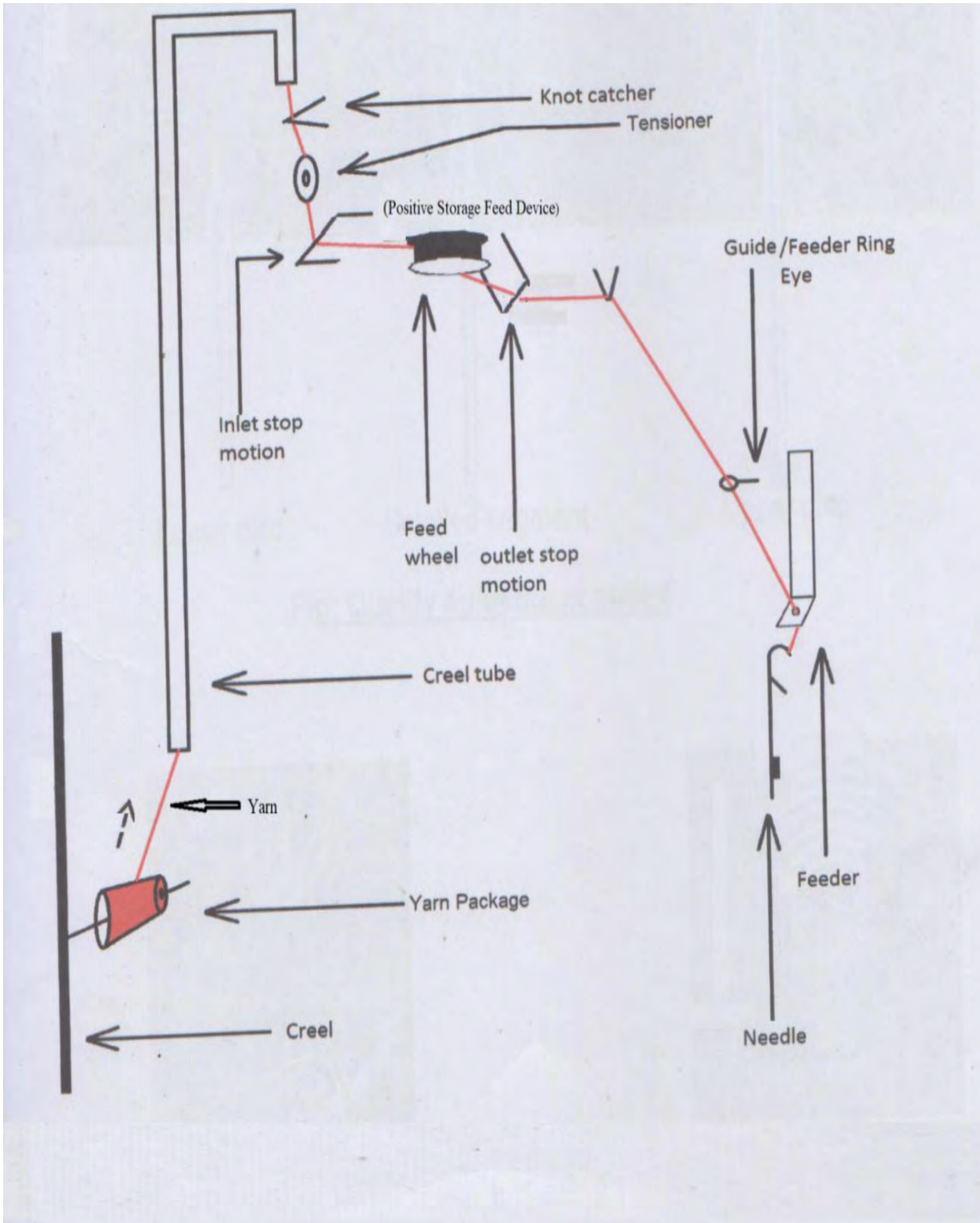


Figure **1.4**: Yarn path in a circular weft knitting machine with positive storage feeding

Acceptability of a knitted fabric to the consumer largely depends on its proper value of quality like areal density (e.g. GSM), handle, shrinkage etc. largely depends on its quality. On circular knitting machine, the fabric is improved by using the positive storage feed device which is aimed to deliver a predetermined length of yarn to the needles in order to form stitches at a constant rate. This „online" yarn length for each revolution of the machine eventually becomes course length (CL) of the fabric, which ultimately defines the loop length, LL (the length of yarn in a loop) - the most important factor influencing knitted fabric quality. Yarn tension level, yarn mechanical properties and yarn structural characteristics are some other factors that influence course length in knitted fabric (Lek-Uthai and Dias, 1999). However there is a scarcity of numerical expression showing the interrelationship among the factors influencing course length.

With the development of high speed modern circular knitting machines, great attention has been devoted to improve productivity, machine performance as well as physical quality of produced fabric. Being an important technological parameter, yarn tension has always drawn much interest of the researchers for evaluating the dynamic knitting operation. It is usual to measure the yarn tension between the area of feed wheel unit and yarn guiding eye (also known as yarn input tension or YIT) because of ease of reach and other measurement positions under production conditions are not possible (Pusch et al.,1997). YIT directly reflects the influence of the different mechanisms involved in the production of the knitted fabric (Catarino, Rocha and Monteiro, 2003).Therefore besides correlating with course length, YIT can be studied as a tool to figure out machine running speed, machine running condition or machine-cause oriented fabric defects.

1.2 An Overview of Bangladesh Knitting Industry

The ready-made garment (RMG) industry of Bangladesh, mainly comprising of knit and woven garments factories is a strategic sector. In fiscal year 2013-14, RMG industry of Bangladesh provided 4.2 million direct jobs (90% of those are to women!), 16 percent of Gross Domestic Product (GDP) and more than 75 percent of foreign exchange earnings (History of development of Knitwear in Bangladesh, n.d.).The export-oriented knitwear industry is the top -leading exporting sector in Bangladesh. The contribution of Bangladesh knitwear sector on GDP is 6.92% and the backward linkage sector has another 2% contribution on GDP to Bangladesh. In 2013-2014 the contribution of knitwear in national export earnings is 39.81%where the domestic value addition was about 75% resulting a net retention of 50%.The Direct contribution of Knitwear sector on GDP of Bangladesh is almost 7%, but the backward linkage sector of Knitwear sector has another 2% contribution on GDP (Value Addition from Knitwear Industry, n.d.)**.**

At present there are more than 2000 knitwear factories in Bangladesh, of which more than 200 are composite. Knitwear is exported to 153 countries of the world from Bangladesh (Strength of Knitwear Sector of Bangladesh, n.d.). So far the EU is the largest destination for Bangladesh knitwear, worth of value $8.7 billion with share of 72.03% exported in the year 2013-14 followed by the USA with $1.2 billion and a share of 9.93 %(History of development of Knitwear in Bangladesh, n.d.).Bangladesh being the second largest apparel exporter in global apparel market has recently become the world‟s second largest knitwear exporter after China, replacing India (Strength of Knitwear Sector Bangladesh, n.d.). A good number of high-end brands like H&M, Walmart, JC Penny, Zara, Gap, M&S, Uniqlo, C&A, Tesco, Hugo Boss and Adidas have been sourcing billion worth of knitted garment items from Bangladesh every year (Note for Importers, n.d.). Bangladesh Export Basket contains mainly basic products like T-shirt, Tank top, Vests etc. Table 1.1 shows the dominating contents of which are mostly of knit items (Note for Importers, n.d.).

Table **1.1** Major Export Bundle (Product wise) of Bangladesh

Product type	**Examples**
T-shirt, Tank Top and Singlet‟s	

Product type	Examples
Polo-shirt	 Full sleeve poloshirt for women/girls  Short sleeve Poloshirt for women/girls
Knitted Jacket, Cardigans	 Cardigan for women/girls  Cardigan for men/boys
Briefs, Underwear"s and Panties	 Briefs/Panties for women/girls
Pullover and Sweatshirt	 Pullover for men/boys  Pullover for women/girls

Product type	Examples
Babies Item	 

The knitwear sector of Bangladesh has the unique structure as well as the competitive advantage not only in terms of price but also the product quality. However, the core strength of the knitwear sector is its backward linkage. Over the period of time, knitwear sector gradually became almost self-sufficient in fabric and yarn development. Currently the sector is supplying 90% of knit fabric requirements where local yarn suppliers provide a large sum of yarn demand for the industry (Strength of Knitwear Sector Bangladesh, n.d.). Moreover duty-free and quota-free access to several developed nations, transformation to socially and environmentally compliant factories, adopting the green factory mechanism and overall the cheap labor force provides comparative advantages of Bangladesh knitwear industry over its global competitors.

Despite all positive signs, knitwear industry of Bangladesh have some weaknesses too, particularly long lead time to complete buyer‟s order and very few value-added items in the product mix. Moreover, increasing cost of production and reducing price-offer from the buying brands are also threatening the profitability of this sector as many least-developed nations like sub-Saharan countries are also entering into apparel business. So producing quality products with shortest possible lead time, product diversification and managing the production cost efficiently have become key challenges for the Bangladesh knitwear sector in present buyer-dominated apparel business.

1.3 Fabric Manufacturing through Circular Knitting

1.3.1 Circular knitting machines

Circular knitting machines (CKM) [Figure1.5] are widely used throughout the knitting industry for mass production of fabric. These machines having „circular" needle beds offer the greatest potential for high-speed production, because knitting can take place continuously in the same direction. No time is lost in continually changing the direction of yarn feed, and the rotary motion minimizes problems of vibration and wear at high speeds.

Figure **1.5**: Single jersey circular knitting machine (*Courtesy:* Knitting laboratory, Department of Textile Engineering, Ahsanullah University of Science and Technology)

The process flow chart for such type of knitting is shown below.

Process Flow Chart for CKM

Yarn in the form of package

↓

Placing the yarn package in the creel

↓

Feeding the yarn

↓

Setting the machine as per stitch length & design

↓

Knitting(looped structure forming by needles)

↓

Withdrawal of the roll fabric and weighing

↓

Roll marking process

↓

Checking or inspection

↓

Delivery to batch section for dyeing and finishing

Renowned machinery companies are still carrying out researches to improve the productivity of modern CKM with the ability to ensure finest quality of the fabric.

1.3.2 Positive storage feeding:

Positive Storage Feeding has become the common standard for high production large diameter circular knitting machines. Here the technology of adjusting the yarn delivery rate is based on a diameter-adjustable pulley called a “Quality Adjusting Pulley” (QAP).The QAP is driven by the main drive of the knitting machine and drives a toothed/punched belt. The belt, in turn, drives a series of pin wheels/toothed pulleys of positive storage yarn feed units. Each yarn delivery unit consists of two wheels/toothed pulleys fixed to a shaft. One of them acts as a yarn delivery wheel (also known as feed wheel), and the other (the pin wheel or toothed pulley) drives the unit (Dias and Lanarolle, 2002). A typical figure of QAP-based positive storage feeding is shown in Figure 1.6 and a diagram of the positive feed unit for such type of feeding is shown on Figure 1.7.

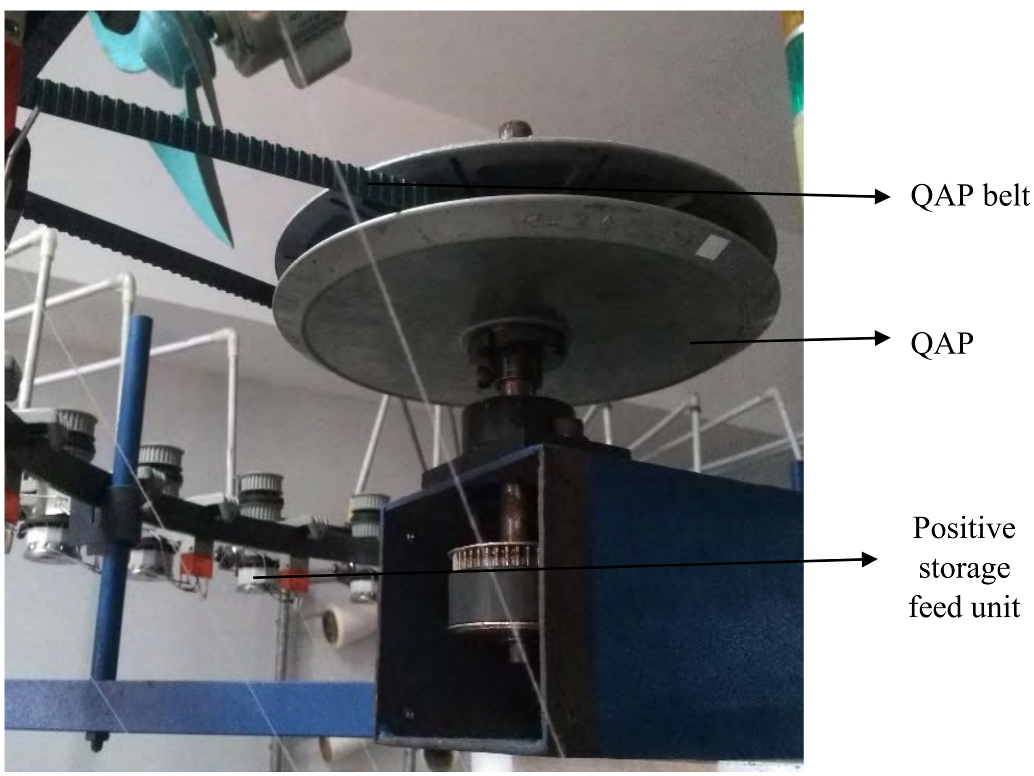


Figure **1.6**: QAP-based positive storage feeding

The feed wheel also creates a temporary yarn reserve, i.e. storage, immediately before the needles, therefore, building a safety margin against empty yarn package or yarn breakage before the yarn end reaches the knitting zone.

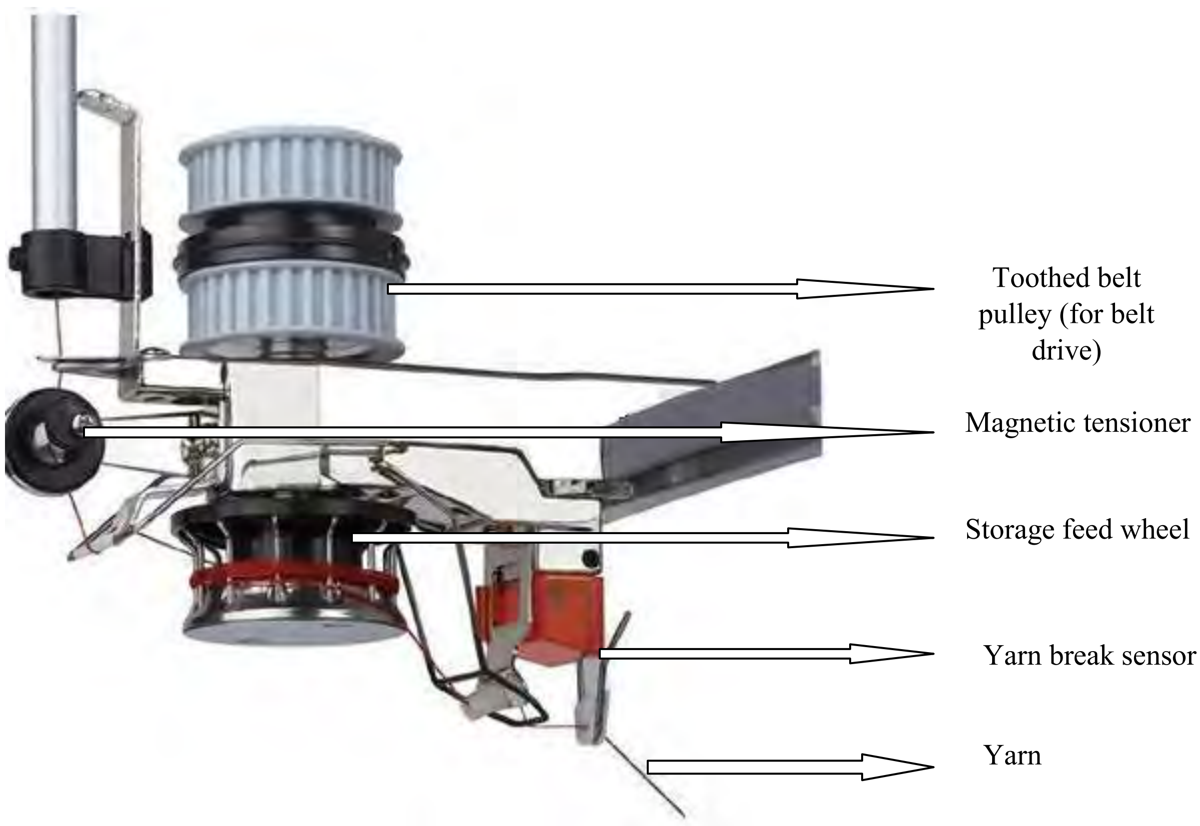


Figure **1.7**: Positive Storage Yarn Feeding Device

1.3.3 Yarn tension and yarn input tension:

Yarn tension is a kind of force either applied by some devices called tensioner or developed automatically during the process due to inherent characteristics of the same (Figure 1.8).

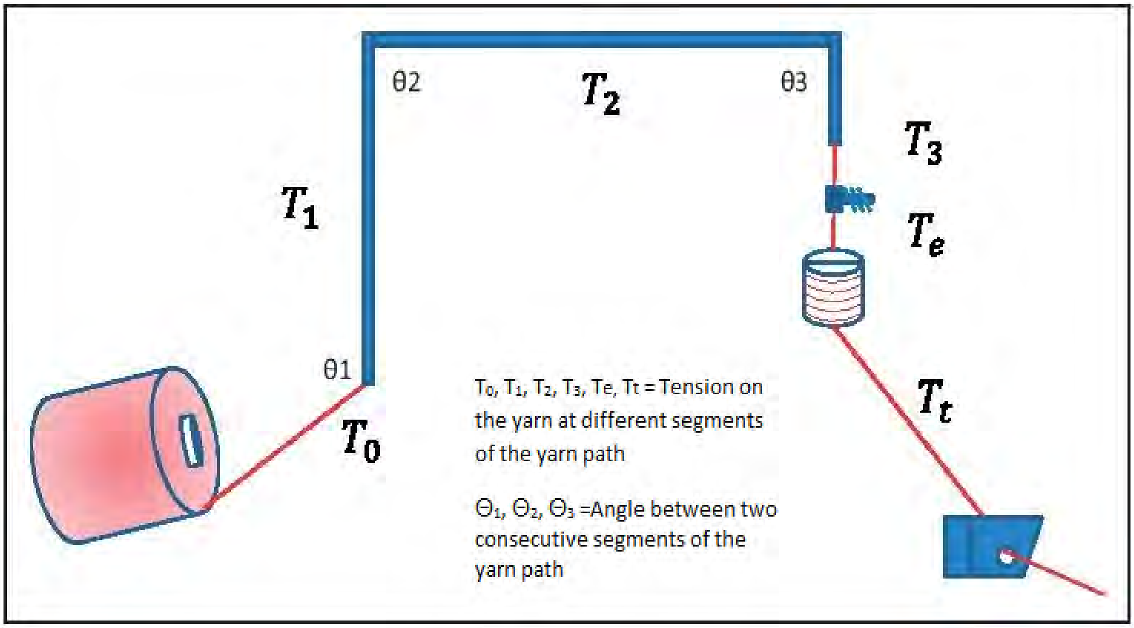


Figure **1.8** : Yarn tension in different segments of the yarn path during circular knitting(Vasconcelos,Marcicano and Sanches,2015)

The tension under which the yarn is delivered into the knitting zone is known as Yarn Input Tension (also known as Run-in Yarn Tension).

On a circular knitting machine with storage positive feeding the run-in yarn tension is influenced by the difference in the length of yarn delivered to the needles by the feed wheel and the length of yarn used by the needles to form stitches. The yarn input tension, therefore, on a circular knitting machine with PSF, is regulated by the knitter by adjusting the machine setting (i.e. stitch cam setting) for a particular feed velocity (set in the quality wheel) (Lek-Uthai and Dias,1999)

Without YIT yarn cannot flow into the knitting zone. However an excessive value in YIT results in yarn breaks along with other knitting elements. Moreover, high tension causes permanent deformation of the yarn, i.e. inherent characteristics of the yarn is lost (Ray,2012).

YIT is measured by a mechanical or electronic instrument in the zone between the feeding device and the knitting feeder (Figure 1.9).The optimal YIT ranges from around

2 to 5 grams for most basic fabrics (Au, 2011 and Cotton Technology International, 1992).

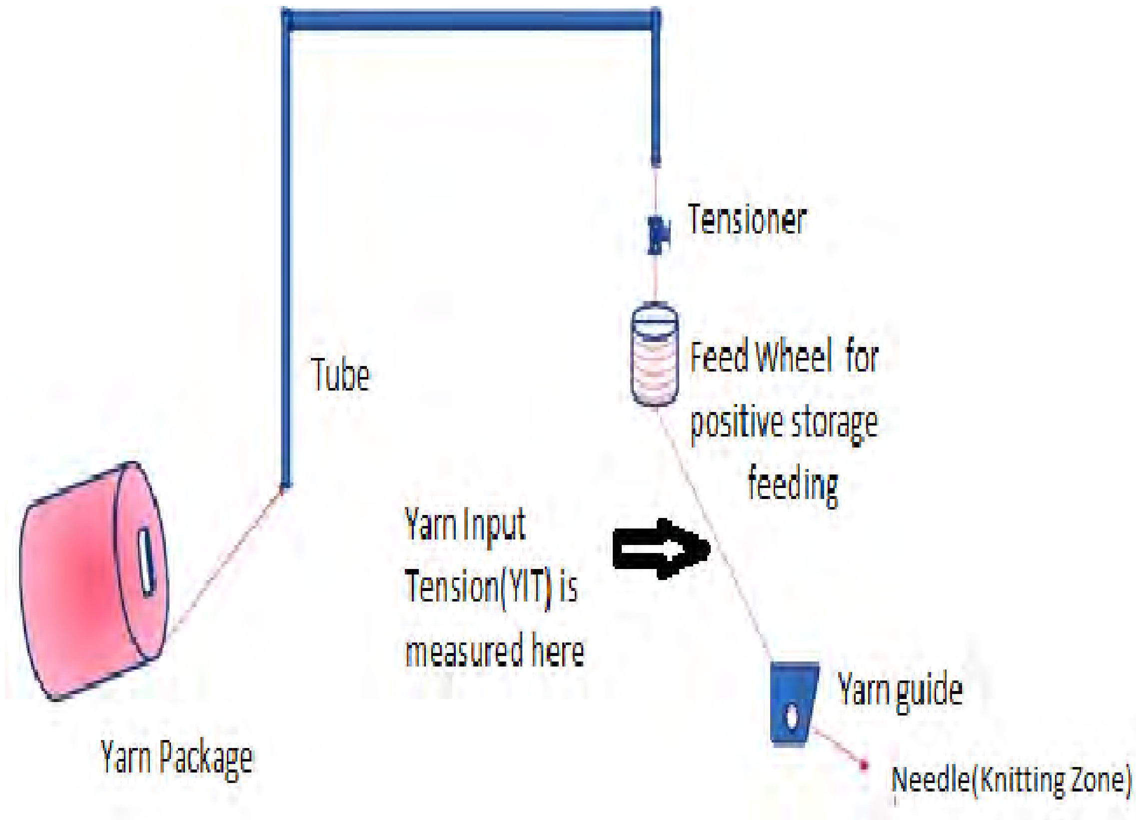


Figure **1.9**: Yarn Input Tension (YIT) generation zone in the yarn path

It must be noted that measurement of yarn tension inside the region of the knitting needles (also known as knitting tension) is quite impossible (Aisaka, 1971 and Pusch,Wunsch and Offermann,2000).However, through a model apparatus, Aishaka, Kawakami and Shindo (1969) showed that knitting tension is positively correlated with YIT.

1.4 Motivation for this Study

Yarn tension is an important parameter for various textile processes including fabric formation by knitting. Besides steadying the yarn throughout its running path, i.e. from the package to the needles, yarn tension reflects a valuable source of information concerning the knitting process. Particularly yarn input tension mirrorizes the influence of different mechanisms including actions inside knitting zone during knitting (Catarino et al., 2005). Therefore exploring such critical parameters is very much crucial for quality knitting through modern technology.

While studying knitting process for a positive-feed based modern circular knitting machine it may be found that the generated and/or maintained yarn tension is associated with a series of consecutive quality and machine related issues. The first major concern here is the length of yarn consumed during knitting process. This yarn length delivered to needles for each revolution of the machine is often wrongly interpreted as course length by the practical knitters, even by some scholars as 'on-machine' measurement of course length (Ray, 2012.However the subsequent relaxation of the elongated yarn makes the loop size smaller (Dias and lanarolle,2002) and ultimately brings some changes in basic fabric quality like GSM, porosity etc as well as fabric consumption. Obviously, it will be highly well-comed if the original loop size can be correlated with the tension and related on-machine parameters. Therefore present study on tension analysis aims to focus a theoretical model as its first step.

Secondly, it‟s a very common practice for a knitter to adjust machine speed for optimum production speed as well as quality. However this operational parameter is said to have s impact on yarn tension (Productivity of knitting machine, June 18, 2012). So there is a scope of correlating yarn tension with machine speed through statistical analysis as there is no such study available till now. Even this analysis may also help to generate some acceptable values of yarn tension through adjusting machine speed, which may be used in the model for predicting loop size, as mentioned earlier.

Again, besides controlling the produced fabric quality and productivity, the machine itself needs to be monitored for operational performance.YIT waveform analysis may help to detect abnormalities (Catarino et al., 2004); some of which may be reflections of machine performance. Such analysis is also essential to validate the experimental results that accompany the theoretical model as stated earlier.

A further expansion of the study regarding YIT analysis for performance evaluation may lead to think for possible machine modification/development.YIT waveform may show sign of incipient defects which can be further analyzed to find out the machine-related root causes. Encouraged by the above fact an attempt is taken in this dissertation to bring some modification/development in circular knitting machine for better performance.

1.5. Objectives

The main objective of this study is to analyze the generated yarn tension in the form of correlating the measurable and adjustable yarn input tension with course length of the fabric as well as connecting yarn input tension with the speed and performance of the machine during circular weft knitting with positive storage feeding. The specific objectives may be stated as:

1. To produce knitted fabric of acceptable quality at different input tension values and measure the related course length values through online reading and also from offline (i.e. measuring experimentally the actual course length values).

2. To develop a model for correlating yarn tension at different points of the yarn path with fabric quality, i.e. course length or loop length.

3. To compare both experimental and predicted outputs for justifying the influence of major factors like machine setting (particularly stitch cam position), yarn fineness (yarn linear density), yarn elasticity etc. over yarn tension and course length.

4. To verify the effect of machine rotational speed over yarn input tension and apparent loop length (obtained through „on-machine" yarn length per machine revolution) keeping different parameters constant.

5. To evaluate the performance of the circular weft knitting machine (which will be used in this present research work) for identifying possible machine flaws, if any, that is responsible for unacceptable variation in yarn tension during the knitting process.
6. To identify and pinpoint the causes of different flaws/faults in the knitted fabric. Accordingly, to suggest modification/development of the said knitting machine in order to minimize faults/flaws in knitted fabric.

1.6 Brief Outline of Methodology

Yarn tension analysis for any knitting machine has a very broader aspect. As can be seen from the objectives the analysis of yarn tension for this research work is more oriented with produced fabric and machine rather than its own analytical description. Major steps of methodology are briefly stated below.

1. A circular weft knitting machine with positive storage feeding will be used to produce passable basic knitted fabric like plain jersey at different yarn input tension values adjusted through machine setting, i.e. cam setting. The primary aim here is to observe the influence of yarn tension by justifying the difference between fabric course length (as measured by a course length tester) and online yarn length/ machine revolution (as measured by a portable yarn tension and rate meter). Simultaneously a model will be developed to correlate yarn tension (particularly yarn input tension) with fabric quality using Hooke‟s law and true specific stress-strain concept for yarn. The developed model will be justified later.

2. Samples will be knitted again at different machine rpm to check the effect of machine speed over yarn input tension and corresponding yarn delivery to needles for knitting action. A predictive analysis through linear regression will be carried out here.

3. The performance of the test knitting machine will be interpreted in the form of YIT. Run charts will be built by some specific values of YIT, obtained from the YIT

waveforms, for some production runs, as stated earlier. These run charts will be evaluated to find out the special cause variations and thus assess the performance of the said knitting machine.

4. After discovering the facts that are responsible for non-random pattern in YIT waveform during performance evaluation, as mentioned earlier, a thorough investigation on knitted fabric defects will be carried out through root cause analysis. The particular defects and the corresponding responsible causes which synchronize with the ones responsible for negative impact on machine performance will be targeted for rectification. Final suggestion will be proposed through machine modification/development.

1.7 Significance of the Study

The possible major outcome of this research work will relate yarn tension with fabric quality by enabling a knitter to predict course length precisely from on-machine measurements of some parameters including yarn input tension saving a lot of material and time. It is also expected that the outcome of this research will provide valuable information for optimizing machine speed and improving machine performance on the basis of yarn tension analysis. Additionally based on performance evaluation and subsequent root cause analysis of fabric defects, some ideas of machine modification/development may be proposed as an advanced outcome of tension analysis.

CHAPTER-2
LITERATURE REVIEW

Knitting operation undertakes a series of mechanical consideration where yarn tension plays a significant role by influencing the knittability of the machine. The primary role of yarn tension is to ensure smooth flow of yarn from the packages to the needles (Ray, 2012). Yarn tension also plays a vital role by influencing the length of delivered yarn (which becomes fabric courses later) and hence it is considered as a crucial operational parameter in the production of knit fabric. Consequently feed tension of the yarn (yarn input tension) of the yarn and its variation over time are the most important technological factors in weft knitting (De Vasconcelos, Marcicano and Sanches, 2015). Yarn input tension may vary due to change in machine setting like cam setting and yarn property like yarn frictional coefficient (Lek-Uthai,1999) or other factors (Catarino et al.,2004). Though improved yarn delivery system like positive storage feed device has been developed over the time to regulate the course length (the most important fabric parameter that influences basic quality characteristics) monitoring yarn tension still remains feasible to judge process performance, fabric quality and productivity.
Extensive studies on the different perspectives of yarn tension are available on literature.

Yarn tension analysis with respect to ‗fabric quality'

As already mentioned earlier, Course Length (the length of yarn for a row of loops around the fabric tube) plays the basic role for determining knitted fabric quality. Loop lengths (length of yarn in a knitted loop) combine in the form of course length (CL) and, the variation in course length or loop length will grow non-quality characteristics in a knitted structure (Spencer, 2001). Early research works showed that loop length influences dimensional (like GSM, tightness etc.), comfort (like air permeability) and mechanical properties (like bursting strength, bending rigidity etc) of fabric (Kane,Patil& Sudhakar,2007 and Degirmenci&Coruh,2017). Hence Course Length or Loop length is sometimes symbolized as „Fabric Quality" (Semnai& Sheikhzadeh, 2007)

Course length is measured by unroving the yarn from a knitted fabric or can be measured at a yarn feed during knitting through yarn speed meter (Spencer, 2001).However the measurement of course length at before knitting stage (during knitting) is quite questionable due to the influence of yarn input tension mainly. Although a machine may be set to maintain controlled yarn delivery through positive storage feeding, yarn input tension, which is mainly the result of the equilibrium between yarn feeding and yarn drawing (Pusch et al.1997), may result deviation between the online and off-line (actual) readings. Therefore while knitting a specific type of fabric, correlating yarn input tension with course length is absolute necessity if online measurement is to be used. Though early research work by Lek-Uthai (1999) showed no influence on course length for change of yarn input tension during positive storage feeding, a need for numerical connectivity is still felt to cope with dynamic knitting environment.

Attempts have been taken over time for developing mathematical expression for yarn tension in positive feeding. The first of its kind was shown by Crabbe (1965), which is applicable for a simple positive feed system like nip roller positive feed system. Lek-uthai and Dias (1999) derived an equation for delivered yarn length to needles with an aim to use it as a tool for identifying the reasons of yarn tension variation. Dias, Cooke and Fernando (2003) showed a mathematical model for yarn input tension when they incorporated positive feeding in flat knitting machines. However few research works are available where course length values of fabric have been unified with yarn tension, particularly for knitting machines with positive storage feeding.

Dias and Lanarolle (2002) made an analysis of the tension build-up of the yarn on its way from the yarn package to the storage yarn feed wheel. They found that course length in the fabric becomes shorter when the yarn is wound onto the storage yarn feed wheel at higher winding tension despite the yarn being delivered positively at the same rate and at the same input tension to the needles at same cam setting.

Eltahan, Sultan and Mito (2016) developed equations of loop length for different compactness of fabric from loop geometry. Jovani, Roberto, Edgar A. and Laura (2018) deployed different linear regression methods to predict the loop length in knitted fabric from the stitch cam setting of rectilinear type (non-circular) knitting machines. However these researchers did not incorporate yarn tension in their developed models.

Very recently, Berenguer, Diaz-Garcia and Martinez (2021) developed an alternative procedure to find the value of loop length from fabric instead of unraveling yarn from it. They built-up some models through linear regression to predict loop length from some fabric constructional parameters like courses per unit length, wales per unit width and stitch density (i.e., no. of loops per unit area).Though this approach of loop length determination saves material destruction but it‟s still time consuming and works only at „off-machine‟ state and therefore, not suitable for the dynamic production environment.

Yarn Tension and Machine Speed

The speed of a circular knitting machine is the speed of its needle cylinder and it may be expressed by machine revolutions per minute (rpm), circumferential speed or speed factor (Spencer,2001). Machine rpm and circumferential speed (surface speed of the needle cylinder) are the most common expressions for machine speed whereas speed factor is used to compare the production speed of different knitting machines.

Although it has been pointed out that machine speed should be restricted to a certain limit to avoid yarn –tension oriented defects (Koo, 2002), the analysis of yarn tension with corresponding course length for different machine running speed is quite scant. Among the notable works related to this particular study, Hensaw (1968) and Oinuman (1986)found almost no change in course length or loop length due to change in machine speed, by experimental studies on circular knitting machines. Aishaka, Kawakami and Shindo (1969) demonstrated knitting tension (yarn tension inside the knitting zone) through a model apparatus and showed that machine speed has hardly any effect on the yarn force in knitting zone. Koo (2004) investigated on yarn feeding speed rather than machine speed through a sample test rig and found no distinct correlation of yarn tension with the feeding speed. The most recent study oriented with machine speed and yarn tension was carried out by Duru, Candan and Mugan (2015). The researchers evaluated the effect of machine speed and yarn tension independently on needle displacement behavior for an industrial circular knitting machine. They observed that the needle displacement in both x and y co-ordination tended to increase as the yarn tension increased, irrespective of machine speed. However in this research work neither any observation was made for course length due to change in knitting parameters or needle displacement or any relation was shown between machine speed and yarn tension.

Yarn tension and machine performance

The knowledge of how well a knitting machine is working during production is very important for a knitter. This information allows scheduling all plans and necessary actions required for improved productivity and quality in a manufacturing plant (Catarino et al., 2004).Early research works on performance evaluation of circular knitting machine was based on product quality (Rozett,1976) or productivity (Reza and Hossain,2015).However, judging machine performance through analysis of process parameter like yarn tension is quite hard to find. A close approach to such objective was first shown by De Araujo, Catarino and Hong (1999) where they presented a measuring system to study the waveform resulting from the yarn input tension, in order to evaluate the possibilities of detecting defects and malfunctions produced during the knitting process. This system was further redesigned by Catarino et al. (2002) to be used with industrial knitting machines. However no clear idea regarding machine performance evaluation was highlighted there.

From the above literature review it may be summarized that yarn tension has not been evaluated to practically determine the value of CL or LL in the produced fabric from working yarn tension and associated yarn delivery for modern circular knitting machines till now. Besides, there is lack of sufficient relevant literature to relate yarn tension with machine operating speed and performance. Therefore the current research will focus on the determination of course length or loop length that may be found in the produced fabric during dynamic knitting operation. Moreover the impact on yarn tension for change in machine speed will be quantitatively analyzed. Additionally machine performance will be examined through the pattern of run-in yarn tension. Consequently a search for the scope of machine modification/development will be carried out.

CHAPTER-3

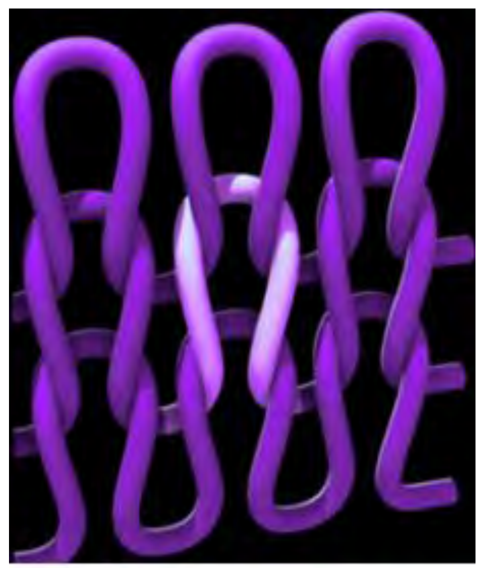
RESEARCH TERMS AND RELATED TECHNOLOGY

3.1 Knitted Garments Production Related Terms

3.1.1 A glimpse on knitted fabric

Knitted fabric, in its simplest form, consists of successive rows of „running‟ open loops, each loop engaging the corresponding one in the previous row and being in turn engaged by the corresponding one in the following row (Figure 3.1). It is one of the most versatile methods of producing a textile fabric. The loop structure provides the fabric with outstanding elasticity (i. e. stretch and recovery), quite distinct from the elastic properties of the constituent fibers and yarns. Besides elasticity, the high degree of comfort coupled with excellent wrinkle resistance makes them eminently suitable for the modern consumers‟ clothing like sportswear, underwear, leisurewear etc.

A typical knitted fabric



A typical interlooping of yarns to form knitted fabric; A knitted loop is shown in contrast colour

Figure **3.1**: Understanding knitted fabric construction [Left - A typical knitted fabric (Jersey lurex ribbed knitted fabric, n.d.) and Right- Interlooping form on knitted fabric (Basic weft knitting loops, n.d.)]

When the term „Knitting" comes to knitwear there are basically two ways for generating the shape of the garment from knitted fabric. These two processes are commonly referred to as „fully fashioned" and „cut and sew"(Introduction to knitting: „Cut & Sew Knitwear" and „Fully Fashioned Knitwear",n.d.).

3.1.2 'Fully fashioned' knitwear

Here Individual fabric pieces (which will be used as a garment panels) are engineered to be shaped at the point of knitting (Figure 3.2).The garment panels are assembled using „cup seaming" and „linking". The knitwear can be easily identifiable by the very distinctive „fashioning mark". Such type of manufacturing generates little or no cutting waste with flatter seam. However it is very slower and expensive process.

3. 1. 3 'Cut and sew' knitwear

Here knit fabrics are cut based on required pattern of different garment pieces and then sewn together to form a complete garment (Figure 3.2). The cut and sew technique is by far the simplest method of garment construction whereby individual panel shapes are cut to size from panels (produced on v- bed or flatbed) or from a long length of fabric or cloth (produced on circular knitting machine).Commercially the fabric for this process is invariably knitted on circular knitting machines. Despite higher fabric waste generation, this method is favored for relatively higher production rate & low labor input.

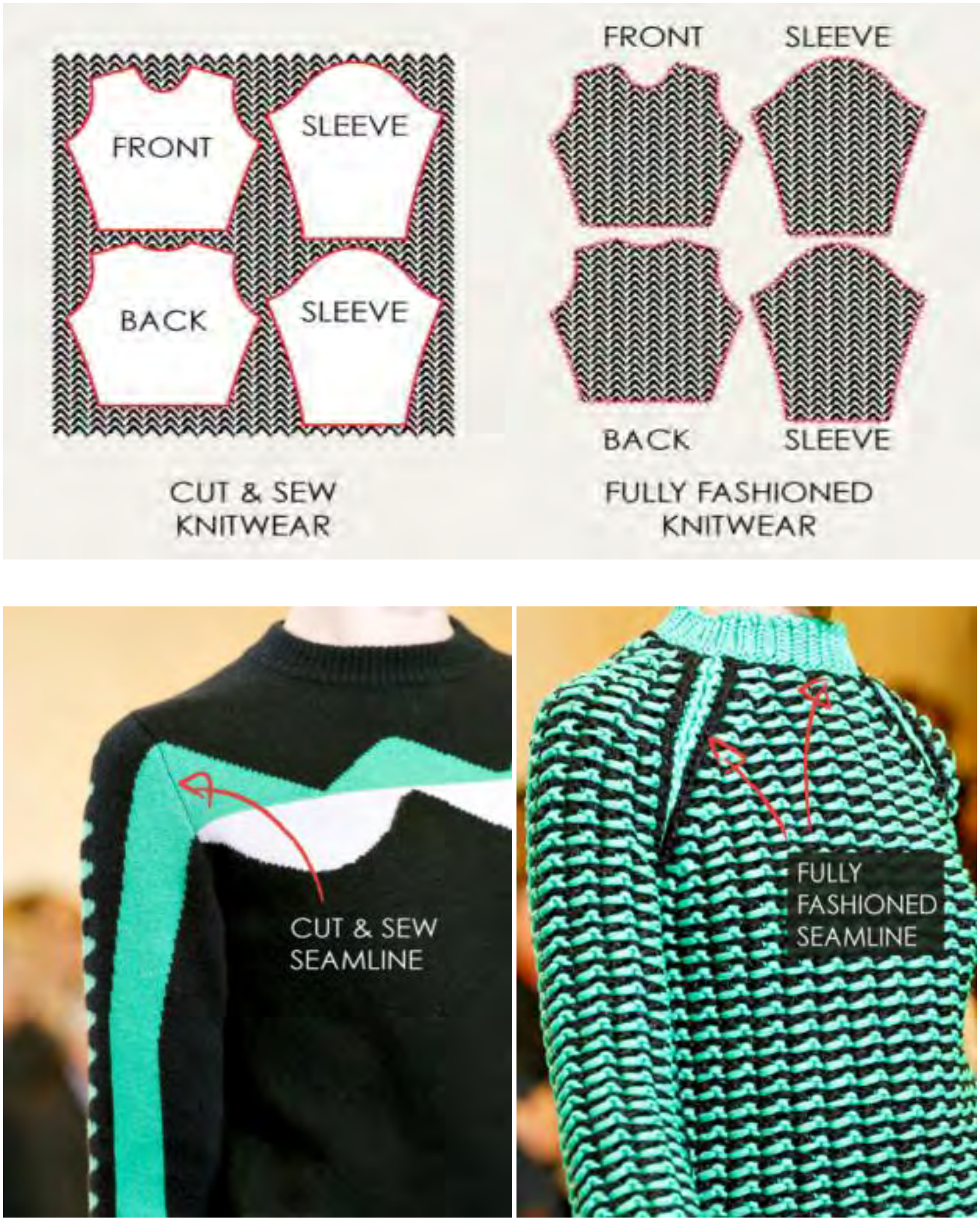


Figure **3.2**: Differences between „Cut and sew‟ knitwear and „Fully fashioned‟ knitwear (Fully Fashioned and Cut and Sew Knitwear at Jil Sander,,n.d.) (Top: Garment panels for „cut and sew‟ knitwear and fully fashioned knitwear; Bottom left: Seam line in a „Cut and sew‟ knitwear; Bottom right: Fully-fashioned seamline in a „Fully-fashioned‟ knitwear)

The production sequence of „Cut and sew‟ garments may be shown as:

Circular knitting of fabric

Scouring, bleaching and /or dyeing (Coloration of fabric)

Pressing, calendaring, decatizing or stentering(Finishing of colored fabric)

Laying - up (spreading) of fabric

Marking and cutting

Assemblying

Examining and mending

Finish pressing

3.2 Yarn Related Terms

3.2.1 Textile fibres

A substance characterized by its flexibility, fineness and high ratio of length to cross-section, suitable for textile applications (ISO 8159:1987) An example of a particular natural fibre and its Scanning Electron Microscope **(**SEM) photograph are shown in Figure 3.3 and Figure 3.4 respectively.

Figure **3.3**:Natural Cotton Fibre
(Textile Fibre,n.d.)

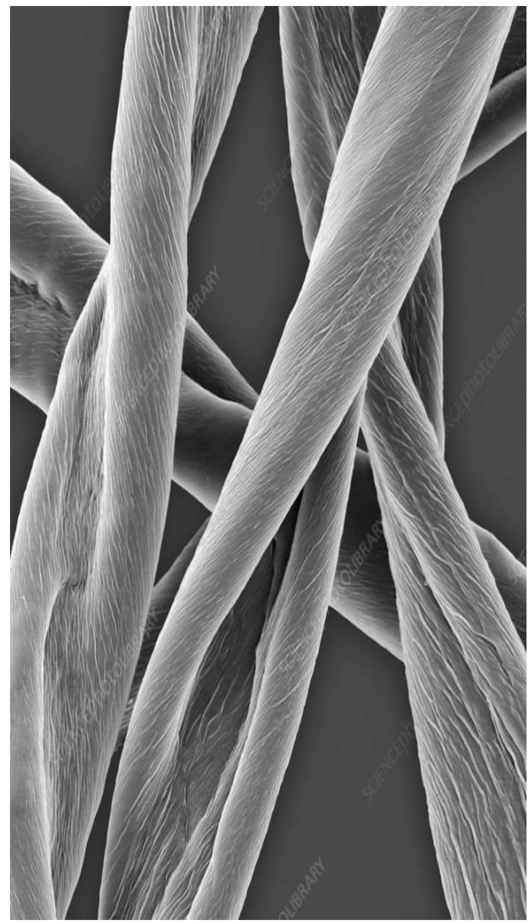


Figure **3.4** : Raw Cotton Fibres,SEM
(Raw Cotton Fibre,n.d.)

3.2.1.1 Staple fiber

A textile fibre of limited length (ISO 8159:1987) as shown in Figure 3.5

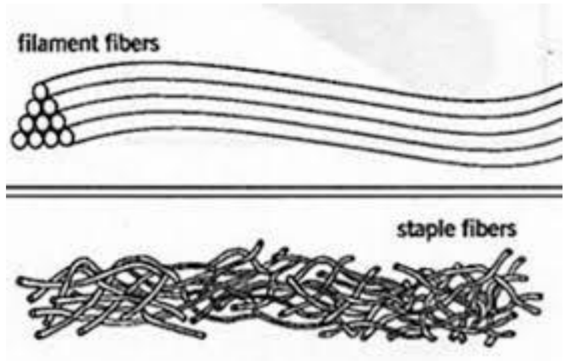


Figure **3.5**: Staple versus filament fibres (Staple Fibre,n.d.)

3.2.1.2 Filament

A textile fibre of very great length considered as continuous (ISO 8159:1987), shown in Figure 3.5.

3.2.2 Textile yarn

A textile product of substantial length and relatively small cross-section of fibers and/or filaments with or without twist (ISO 8159:1987).

The bending stiffness of yarn is strongly lower than that of a continuous beam as the constituent fibres have the capability to slide one with respect to the others. Depending on the nature of the friction at the fibre level and, depending on the characteristic time of interest, the bending behaviour can be considered either elastic-plastic or visco-elastic.

The behavior of the yarn is governed by the longitudinal (fibre) direction. Normally the fibre density of a yarn is about 90%.Consequently, when subjected to compaction loading, the apparent section of the yarn can change in a large amount. Again due to the fibre displacement inside the yarn, the resistance to expansion loading (in the direction perpendicular to fibre direction) is nearly zero (Emmanuelle et al., 2014).

Figure 3.6 shows some yarn fragments and Figure 3.7 shows a yarn package.

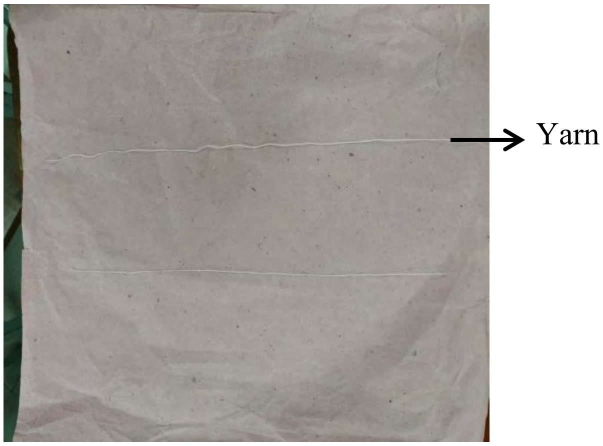


Figure **3.6**: Fragments of yarns

Figure **3.7**: Yarn Package

3.2.2.1 Spun yarn

A yarn made of staple fibres usually bound together by twist (ISO 8159:1987)

3.2.2.2 Filament yarn / Continuous-filament yarn

A yarn composed of one or more filaments that run essentially the whole length of the yarn. Yarns of one or more filaments are usually referred to as „monofilament“ or „multifilament“, respectively (Denton and Daniels, 2002).

3.2.3 Cotton

Cotton fibre is the seed hair of a wide variety of plants of the *Gossypium* family (Denton and Daniels, 2002)

The chemical composition of cotton is almost pure cellulose, and a distinct feature of the mature fibre is its spirality or convolutions.

Cotton-spun yarn, briefly Cotton yarn (as shown in figure 3.8), is a term applied to staple yarn produced on machinery originally developed for processing cotton into yarn. Cotton is known for its versatility, performance and natural comfort. It‟s used to make all kinds of clothes including underwear, socks, t-shirts etc.

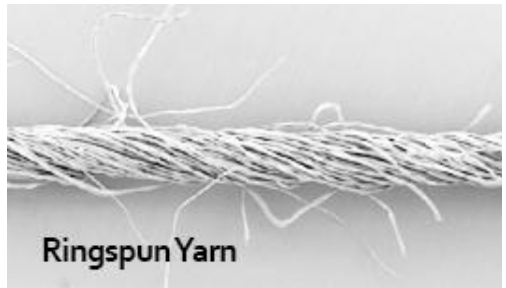


Figure **3. 8**: Cotton ring-spun yarn (The Difference Between Regular Cotton or Polyester Vs. Ring Spun , n.d.)

3.2.4 Polyester

Polyester is a manmade fibre generally originated from petroleum from which the constituent acids and alcohols are derived (Science Fair Project, n.d.).As a specific material, it most commonly refers to a type called polyethylene terephthalate (PET).Polyethylene terephthalate (sometimes written polyethylene terephthalate), commonly abbreviated PET, PETE, or the obsolete PETP or PET-P, may also be referred to by the brand names Terylene in the UK and Dacron in the US.

Polyester yarns are constituted from polyester fibres. Basically there are two different types of polyester yarns: filament yarns and spun yarns.

Polyester filament yarns are composed of filaments (textile fibres of very great length considered as continuous) assembled with or without twist.

Spun polyester or polyester–spun yarns are made by spinning or twisting together shorter lengths of polyester fibers. This is similar to the way cotton yarns are made. These short fibers are then twisted together to produce a yarn of the desired size.

Fabrics knitted with polyester yarns are used extensively in apparel and home furnishings, from shirts and pants to jackets and hats, bed sheets, blankets, upholstered furniture and computer mouse mats. Some Spun-polyester yarn packages are shown in Figure 3.9.

Figure 3.9: Spun-polyester yarn packages (Spun Polyester Yarn,n.d.)

3.2.5 Yarn count /Count of yarn/ Yarn number / Yarn size/ Yarn linear density

Methods for variously expressing the mass per unit length or the length per unit mass of a yarn. A common indirect yarn numbering system is cotton count (Ne) which is equal to the number of 840-yd lengths of yarn per pound.

The preferred unit is Tex, which is the mass in grams of one kilometer of the product. The conversion factor from Tex to Ne or Ne to Tex is 590.5(Denton and Daniels, 2002) Nominal count indicates the value that serves as a name whereas actual count may be a decimal number.

3.2.6 Yarn twist

The helical vertically or spiral configurations induced in yarn (ASTM D4849-02).Twist is usually expressed as the number of turns about the axis that are observed in a specified length, commonly indicated as turns per inch, or TPI. Twist is described as S or Z (as shown in Figure 3.10) according to which of these letters has its centre inclined in the same direction as the surface elements of a given twisted yarn, when the yarn is viewed.

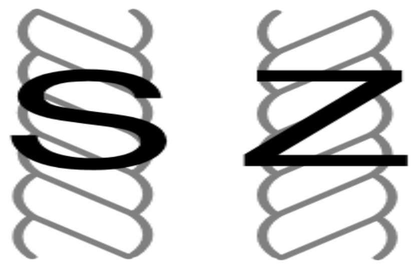


Figure **3.10**: S-twist and Z-twist (ISO 2, n.d.)

3.2.7 Lint

Loose, short fibres(shorter than 5 millimeters), fine ravelings, or fluff from yarn or fabric (Tortora and Merkel,2005).

3.2.8 Knittability

Knittability can be defined as the ability of yarns to run on knitting machines without problems (Fouda,El-Hadidy and El-Deeb,2014).

3.3 Fabric Related Terms

3.3.1 Fabric

A flexible sheet material that is assembled of textile fibres and/or yarns to give the material mechanical strength (Tortora and Merkel,2005).

3.3.1.1 Woven fabric

A woven fabric is composed of two basic series of yarn: warp and filling/weft, through interlacement (Tortora and Merkel, 2005)-as shown in Figure 3.11. Weaving, currently, is the major method of fabric production (Textile, n.d.)

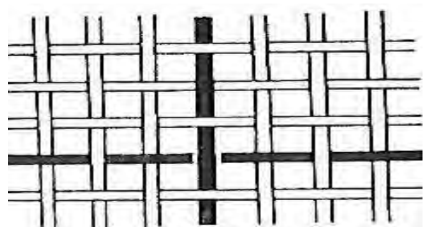


Figure **3.11**: Yarn path in basic woven fabric (Smirfitt, 1975)

3.3.1.2 Knitted fabric / Knit fabric

A structure produced by interlooping one or more ends of yarn or comparable material (ASTM D123-03). A typical knitted outerwear and some knit fabrics are shown in Figure 3.12 and Figure 3.13 respectively

Figure **3.12**: A Knitted t-shirt (What types of Wash Applied on Knit Garments?,n.d.)

Figure **3.13**: Some Knitted Fabrics (Knitted Wool Fabric, n.d.)

Weft knitted / Weft knit Fabric:

Here interlocking of loops is done by horizontal movement of yarn (Tortora and Merkel, 2005) as shown in Figure 3.14

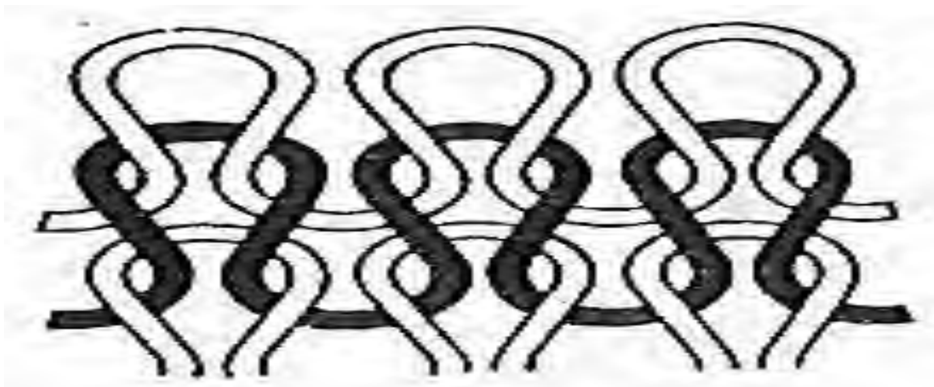


Figure **3.14**: Yarn path in basic weft knitted fabric (Smirfitt, 1975)

Warp knitted/Warp knit fabric:

Here yarns interlock in the lengthwise or vertical direction (Tortora and Merkel,2005) as shown in Figure 3.15

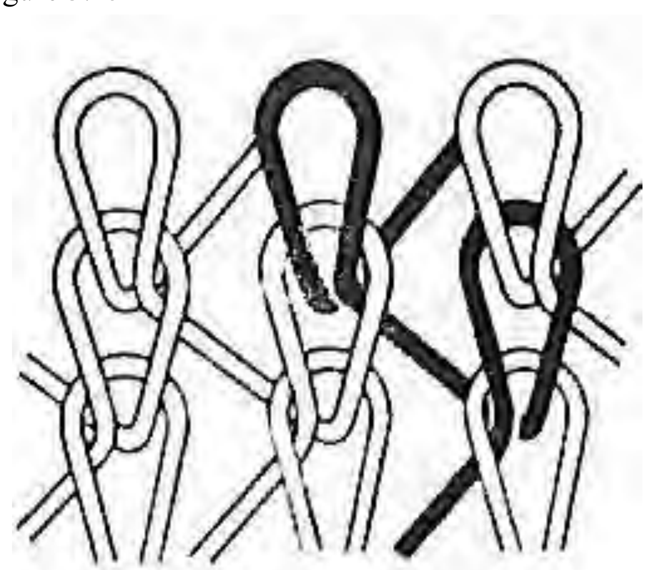


Figure **3.15**: Yarn path in basic warp knitted fabric (Smurfit, 1975)

3.3.2 Knitted loop

A kink of yarn that is intermeshed at its base (ISO 4921:2000) as shown in Figure 3.16

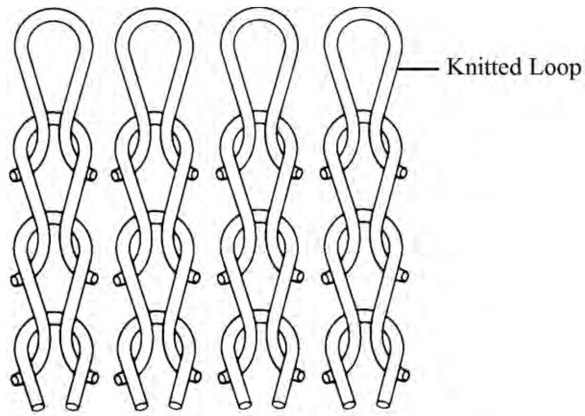


Figure **3.16**: Knitted loops at interlooping (Spencer, 2001)

3.3.3 Wale

A column of stitches along the length of at knitted fabric (ISO 4921:2000) as shown in Figure 3.17.

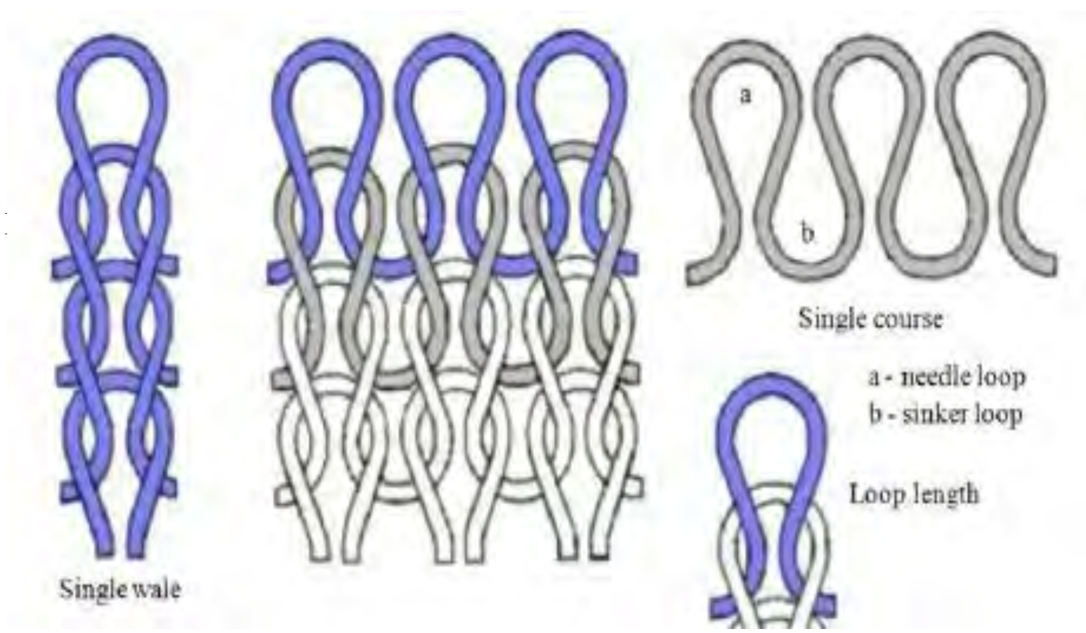


Figure **3.17**: Elements of weft-knitted structure (Chapter 2, n.d.)

3.3.4 Course

A row of knitted loops produced across the width of the fabric by the knitting elements (ISO 4921:2000) as shown in Figure 3.17.

3.3.4.1 Course length

The length of yarn knitted into one course of a weft-knitted fabric (ISO 4921:2000).It may be measured at a yarn feed during knitting or after unroving the yarn from a knitted fabric (Spencer,2001) as shown in Figure 3.18.

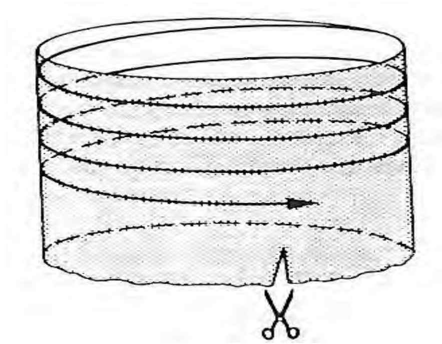


Figure **3.18**: Tubular fabric from circular weft knitting machine with yarn path from a particular feeder (Smirfitt, 1975) {a cut is required to separate a complete course from such fabric}

3.3.4.2 Loop length

The length of yarn knitted into one loop during the knitting process (ISO 4921:2000) as shown in Figure 3.17. It is also termed as stitch length (Denton and Daniels, 2002).

Mathematically it can be obtained by dividing the course length by the number of loops knitted,i.e. Loop length/Stitch length=Course length/ No. of needles knitting

The loop length is an important quality control factor in the production of knitted fabric. It has influential impacts on stitch density, fabric weight, panel size, tightness, fabric width and dimensional stability (Au,2011).

3.3.4.3 Measurement of course length/ loop length

The simplest way of checking loop length in a knitted fabric is by measuring the uncrimped length of yarn unroved from a knitted fabric of known number of stitches (wales).The measurement of straightened length of yarn can be carried out by using any simple apparatus like HATRA course length tester. Such type of measurement is carried out after knitting of the fabric and popularly known as „Off-machine" Measurement". The most recently developed technique of image analysis can also be used in „Off-machine" state for the determination of loop length (Ray,2012) but this has not yet been adopted for practical purpose commercially.

Sometimes loop length is calculated through measuring delivered yarn to needles for each revoloution of the machine and this is described as „On-machine" Measurement, which is quite confusing. However this popular technique is generally carried out by a portable hand-held instrument on running yarn. A variety of yarn speed metres and yarn length counters are available, which are used to measure yarn consumption rates in relation to the speed or number of machine revolutions in circular knitting (Spencer, 2001).

The measured loop length is expressed in millimeters correct to 02 (two) decimal places (International Institute for Cotton, 1988).

3.3.5 Areal density

Also known as Area Density or Mass Thickness. It is the measure of mass per unit area of the fabric. It is also called grammage and expressed in grams per square meter in the fabric industries. Sometimes it is also specified in ounces per square yard (Area density, n. d.)

GSM is broadly dependent on stitch density (no. of loops per unit area), loop length and

yarn count. In general, if the stitch density is high or if the yarn is heavy, the GSM will increase proportionally. However, if the loop length is high then the GSM will decrease, as stitch density decreases at a higher rate to the increase in loop length (Ray, 2013).
In case of no special requirements, normally +/- 5% is tolerable for the GSM of finished knitted fabric.

3.3.6 Fabric quality

From consumers‟ point of view, important quality aspects of fabrics generally includeareal density, dimensional stability, visibility of defects etc. (Ray,2013).However the general trade interpretation of the term „Fabric Quality‟ is the evenness in four properties,i.e., Weight per unit area, Courses per unit length and Wales per unit width, Handles and Elasticity (Au,2011).

Loop density is the most important element in defining knitted fabric quality and is directly related to fabric appearance, areal density, dimensional stability and many other factors (Brackenbury,1992 and Au,2011).

As loop density is directly dependent on loop length (Booth,1977), most scientific studies regarding quality control of knitting and knitted fabrics are based on loop length (Ray,2013), which may be calculated from course length as stated earlier.

3.4 Machine and Mechanism Related

3.4.1 Knitting machine

A knitting machine is an apparatus (complete assembly) for applying mechanical movement, either hand or power derived, to knitting elements, in order to convert yarn into knitted loop structures (Spencer,2001).

3.4.1.1 Weft knitting machine

Machine for the production of weft knitted fabrics by stitch formation from yarn fed crosswise to the length of the fabric (ISO 7839:2005).

Flat Knitting machine

Machine (Figure 2.17) for the production of knitted fabrics with independent needles, longitudinally movable, in flat arrangement, with stitches formed one after the other.

Figure **3.19**: A flat knitting machine (Spencer, 2001)

within every course from yarn fed crosswise to the length of the fabric (ISO 7839:2005).

Circular Knitting machine

Machine for the production of knitted fabrics with independent needles, longitudinally movable, in circular arrangement, with stitches formed one after the other within every course from yarn fed crosswise to the length of the fabric (ISO 7839:2005)

Circular weft knitting machine offers the greatest potential for high speed production, because knitting can take place continuously in the same direction of yarn feed and the rotary motion minimizes problems of vibration and wear and tear at high speed.

3.4.1.2 Warp knitting machine

Machine for the production of warp knitted fabrics by stitch formation from yarn running in the longitudinal direction. Machines are generally flat type; circular warp knitting machines are rare.

3.4.2 Features of a modern circular weft knitting machine

A modern circular fabric-producing weft knitting machine (as shown in Figure 3.20) incorporates and co-ordinates the action of a number of mechanisms and devices, each performing specific functions that contribute towards the efficiency of the knitting action The main features of such type of machine are as follows(Spencer,2001).

1. *The frame* or *carcass*, normally free standing and either circular or rectilinear according to needle bed shape, provides the support for the majority of the machine‟s mechanisms.

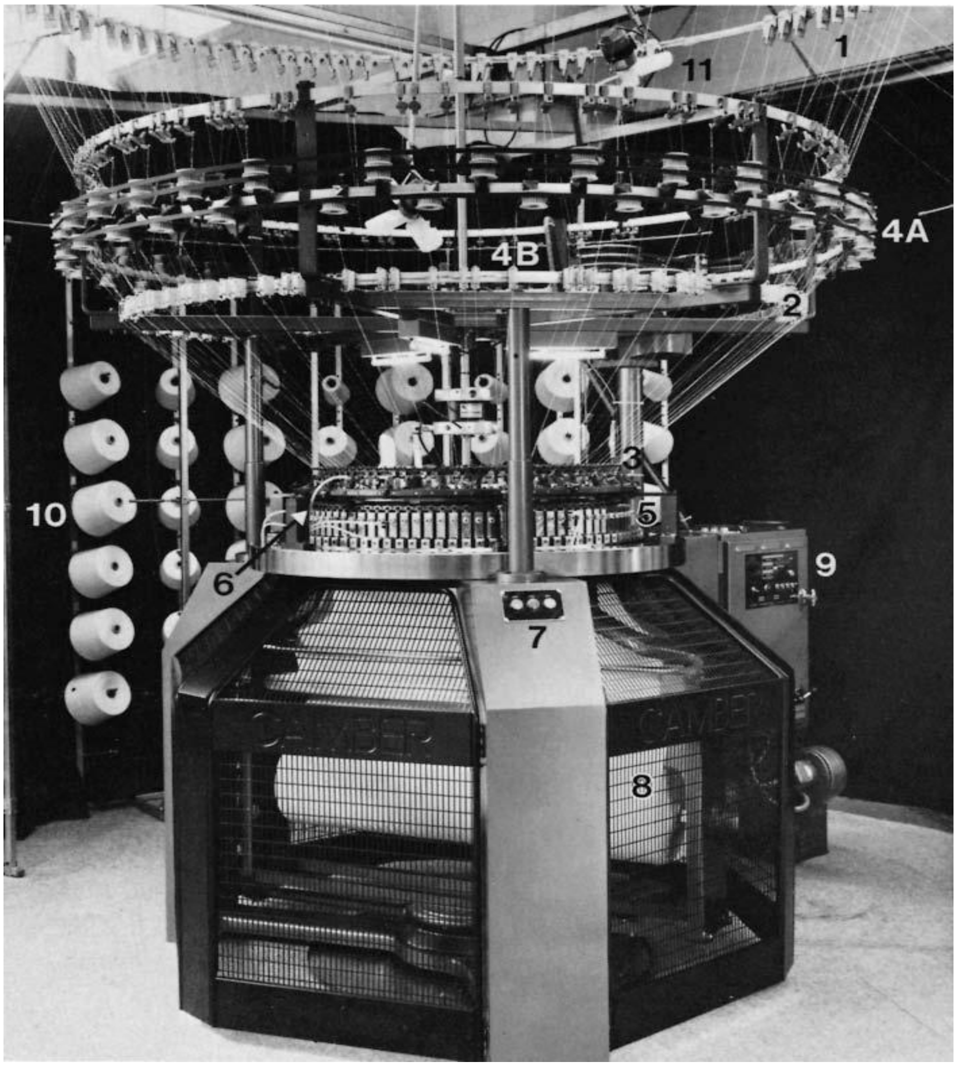
2. *The machine control* and *drive system* co-ordinates the power for the drive of the devices and mechanisms.

3. *The yarn supply* consists of the yarn package or beam accommodation, tensioning devices, yarn feed control and yarn feed carriers or guides.

4. *The knitting system* includes the knitting elements, their housing, drive and control, as well as associated pattern selection and garment-length control device (if equipped).

5. *The fabric take-away mechanism* includes fabric tensioning, wind-up and accommodation devices.

6. *The quality control system* includes stop motions, fault detectors, automatic oilers and lint removal systems.



1=Top stop motion
2= Bottom stop motion
3=Various Detector points
4A,4B= Positive Feed
5=The cylinder needle cam system
6=The automatic lubrication system
7=Start, stop and inching buttons
8=Fabric winding down mechanism
9=The revolution counters
10= Side creel
11= Lint blower

Figure **3.20**: The modern circular single jersey fabric machine (Spencer, 2001)

3.4.3 Major loop Forming Elements

3.4.3.1 Needle

The main element used in knitting is the needle which actually makes the loop. The three types of needles commonly used in knitting machines are (a) latch needle,

(b) bearded needle and (c) compound or bi-partite needle.

The latch needle is the best and most widely used in the knitting industry.

The major parts of a latch needle, as shown in Figure 3.21, are as follows:

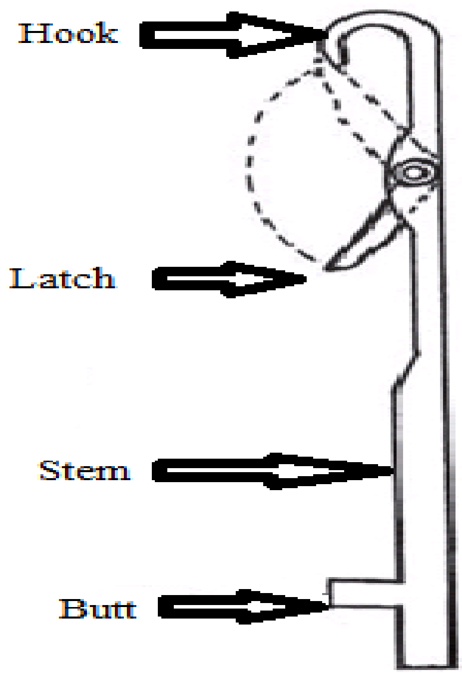


Figure **3.21**: Main parts of a latch needle

Hook, which draws the yarn, makes the loop and retains the same.

Latch, which moves around its fulcrum for opening and closing of the hook

Stem, which is the main body of the needle

Butt, which receives the motion from cam system needed for loop formation

Needle bed

Needle bed is the place where the needles are located or mounted in a knitting machine. Needle moves up and down in the trick of a needle bed. Needle beds are of two types, i.e. of flat or circular. On a circular single jersey knitting machine, the needle cylinder is a circular steel bed having grooves / tricks /cuts on its outer periphery into which the needles are mounted (Figure 3.22 and Figure 3.23) .With reference to the tricks, the needles move vertically up and down by their butt being in contact with the cam track.

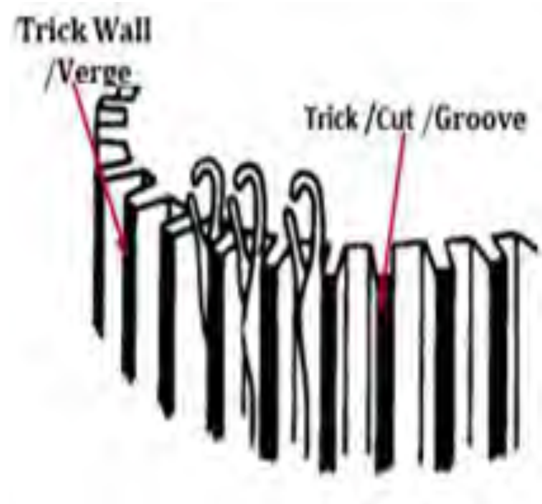


Figure **3.22**: Needle Cylinder   Figure **3.23**: Needles inside cylinder groove

Gauge / Machine Gauge / Needle Gauge

A term giving a notational indication of the number of needles per unit length, along a needle bed or needle bar, of a knitting machine. For circular knitting machines, the length referred to is measured along the circumference of the needle cylinder. A machine gauge of 10 may be written as E10 or 10G instead of 10 needles/inch. (Denton and Daniels, 2002)

3.4.3.2 Sinker

The primary knitting element next to the needle is sinker. The needle takes the help of sinker during loop formation, which applies necessary support to the yarn for loop formation. Relative positioning of needle and sinker during loop formation is shown in Figure 3.24.

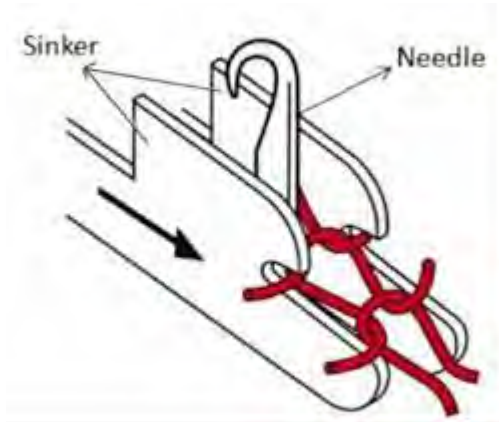


Figure **3.24**: Sinkers with needle (Knitting elements, n.d.)

3.4.3.3 Cams, Knitting

Cams are the devices which convert the rotary machine drive into a suitable reciprocating action. In weft knitting the formation of a course of loops involves the movement of each needle in turn to the various positions. This movement is achieved by means of cams acting on the needle butts.

Knitting cams are attached either individually (Figure 3.25) or in unit form (Figure 3.26) to a cam plate and depending upon the machine design, are fixed, exchangeable or adjustable. Usually four main types of knitting cams are used.

Clearing Cam: The clearing cam forces the needle to rise up for clearing of the old loop
Stitch cam: The stitch cam controls the depth to which the needle descends thus controlling the amount of yarn drawn in to the needle loop.
Up-throw cam: The up-throw cam takes the needles back to the rest position and allows the formed loops to relax.
Guard Cam: The guard cam is often placed on the butt of the needle and controls its rising motion and prevents it from jumping

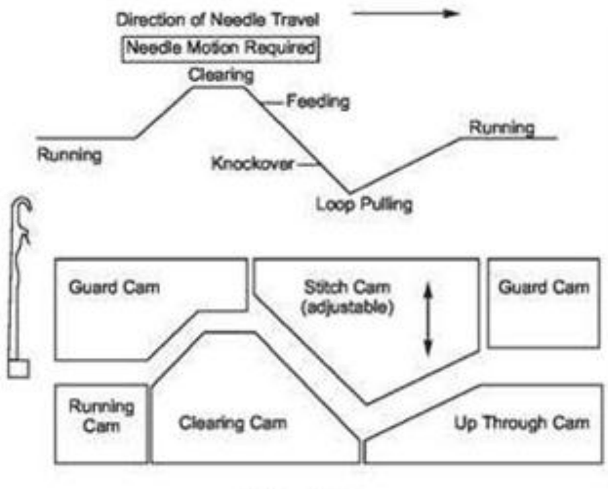


Figure **3.25**: Knitting cams (individually attached) (Cams,n.d.)

Figure **3.26**: Knitting cams (in unit form) (Knitting Cam,n.d.)

Figure 3.27 shows the inside view of some cam boxes attached on a multifeeder circular knitting machine.

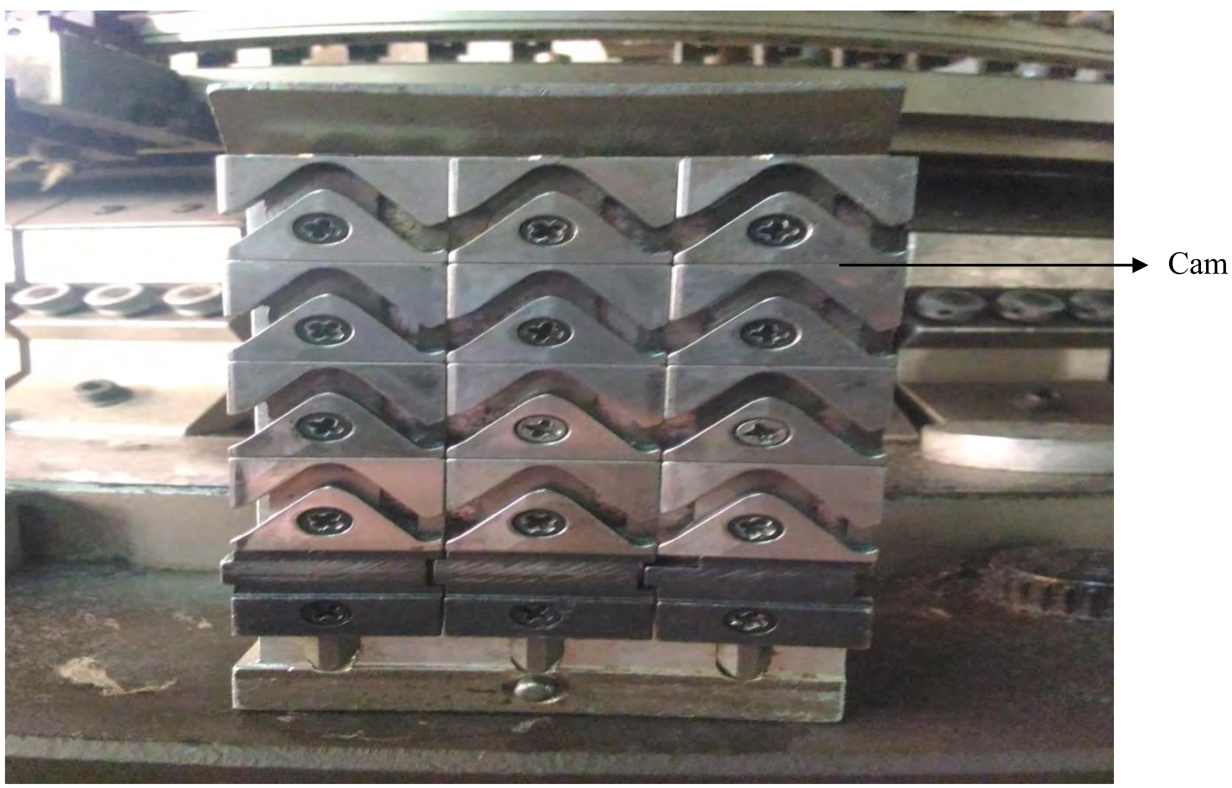


Figure **3.27**: Cams inside camboxes of a circular knitting machine

3.4.4 Basic knitting action on a knitting machine

The hooked metal needle is the principal knitting element of the knitting machine. Prior to yarn feeding, the needle is raised to clear the old loop from the hook and to receive the new loop above it on the needle stem. The new loop is then enclosed in the needle hook as the needle starts to descend. The hook then draws the new loop down through the old loop as the latter slides over the outside of the descending bridge of the closed hook (Spencer, 2001). A very simplified diagram of these steps is shown in Figure 3.28.

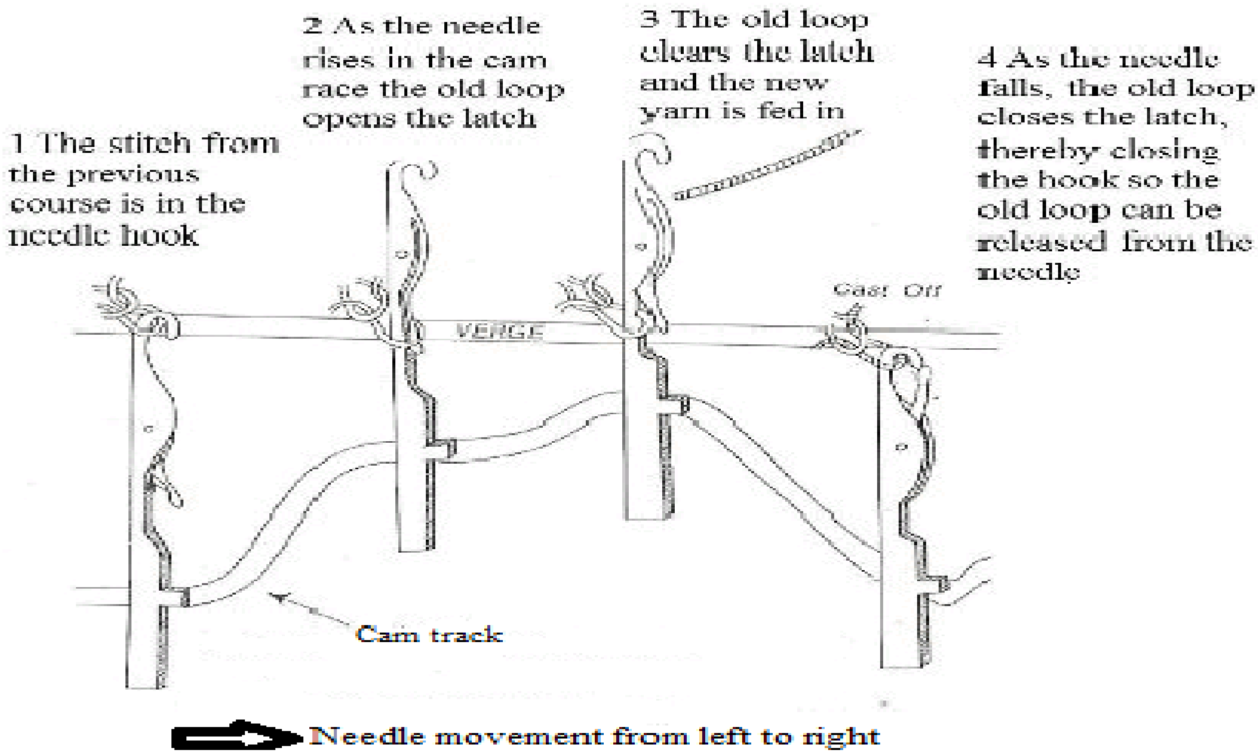


Figure **3.28**: Knitting action of latch needle on a knitting machine (General terms and principles of knitting technology, n.d.)

3.4.5 'Couliering' /Stitch size and stitch cam adjustment

The term „Couliering", particularly used in Europe, is used to describe the presentation of a yarn, the kinking of it in to a needle loop and the knock-over of the old loop (Spencer, 2001). Couliering depth is defined by machine cam setting (Pavko-Cuden and Sluga, 2015) which provides a means of adjusting the size of the knitted loop. The primary way of doing this is to adjust the vertical position of the needle or stitch cam to pull a longer or shorter loop. This is generally carried out through the adjustment of graduated knob attached with the outer surface of the cambox. However markings on the knob are supplied by the manufacturers as only guidelines for adjusting the couliering depth rather than providing any technical quantitative description of cam setting. Figure 3.29 and Figure 3.30 represent inside and outside views of a cambox and Figure 3.31 explains vertical couliering through graduated knob.

Figure **3.29**: Outside view of a cambox

Figure **3.30**: Inside view of a cambox

Minimum gap (Cam setting point is lowest,i.e. Couliering depth is minimum)

Maximum Gap (Cam setting point is highest,i.e. Couliering depth is maximum)

Figure **3.31**: Couliering through vertical shifting of cam (Left-Minimum, Right-Maximum)

It is possible to make theoretical estimation of stitch size or loop length from couliering Ignoring other factors (Control of loop length, n.d.).However in case of positive feeding yarn delivery rate is predetermined through the feed system and couliering is done mainly to adjust run-in yarn tension for maintaining the knittability rather than focusing on loop length.

3.4.6. Yarn feeding

For continuous knitting, yarn is to be supplied or fed to the needles or to the knitting zone continuously. In weft knitting, yarn is generally supplied or fed from cones or other suitable yarn packages positioned in a creel (Ray, 2012).

3.4.6.1. Negative feeding

Yarn is pulled by the needles directly from the package through guides, tensioners etc. This is a very simple technique of yarn feeding. It does not require any extra attachment as yarn is drawn automatically due to the knitting process. This technique does not maintain uniform yarn tension (Ray, 2012).

3.4.6.2 Positive feeding

Positive yarn feeding (PSF) is a system often fitted on circular knitting machines to positively drive the yarn at a fixed rate relative to the surface speed of the needle cylinder. It is currently being considered as a standard quality control installation in all modern circular knitting machines. These feeders aim to control the fabric quality by making the course length align with the desired yarn delivery speed (Au, 2011)

3.4.7 Robbing back

Robbing back is a fundamental phenomenon which occurs in the knitting zone. It is based on pulling yarns from the knitted loops suspended on needles which are raised up to the loops formed on the descending needles (Figure 3.32). Simulations and experimental investigations fully confirm the proposition that controlled robbing-back ensures low yarn tensions in the knitting zone (Klonowska and Kowalski, 2006)(Peat and Spicer,1974).

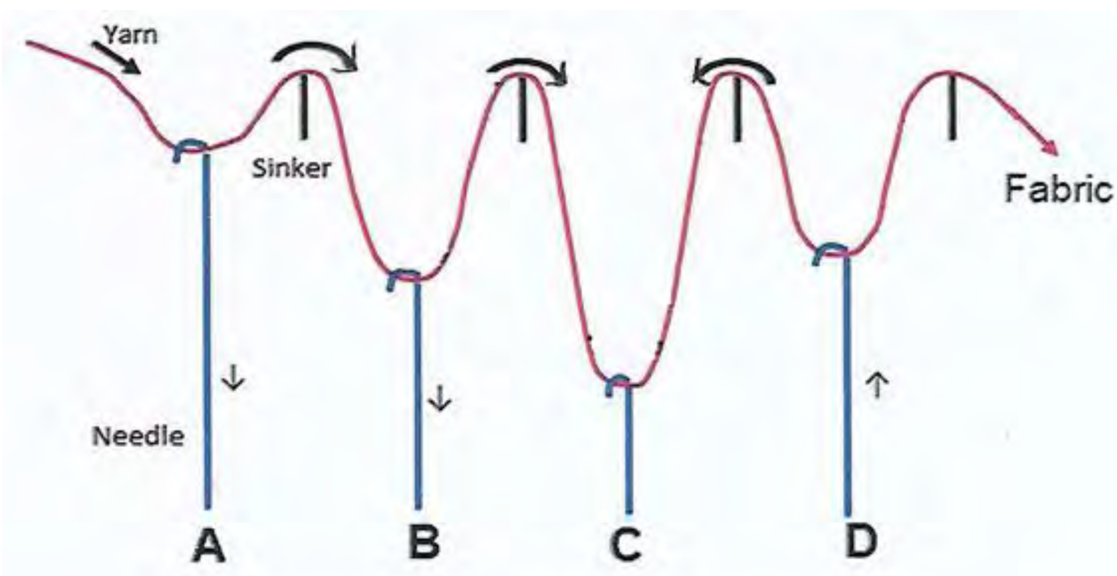


Figure **3.32**: A simplified diagram to show Robbing back phenomena in knitting

3.4.8 Rotational speed

Rotational speed (or speed of revolution) of an object rotating around an axis is the number of turns of the object divided by time, specified as revolutions per minute (rpm), cycles per second (cps), radians per second (rad/s), etc.

3.5 Mechanical/ Elastic Properties Related Terms

3.5.1 Specific/Mass stress

The ratio of the tensile force applied to a fiber, yarn or other textile assembly, to the linear density of the undeformed sample. Therefore, Specific Stress= Force/Linear Density (Initial)(Denton and Daniels,2002).

Cross section of yarns and fabrics, due to unknown packing characteristics, is very difficult to measure exactly. Also the cross-sections of yarns, fibres or fabrics are irregular. Therefore, in case of textile material the linear density is used instead of the cross-sectional area and the term „specific / mass stress" is used. It may be expressed in mN/tex,N/tex.gf/dtex or similar units (Denton and Daniels, 2002).

3.5.2 True specific stress

It is defined as the ratio of tensile force to the actual linear density of the extended fibre or yarn. It takes into account the reduction of linear density resulting from the extension (Denton and Daniels, 2002)

3.5.3 Tenacity

The tensile force per unit linear density (i.e. the specific stress) corresponding to the maximum force on a force/extension curve of a fibre, yarn, etc. (Figure 3.33); hence, the level of specific stress which is reached in order to cause a break (Denton and Daniels, 2002).

$$\text{Tenacity} = \frac{\text{Maximum tensile force}}{\text{Linear density}}$$

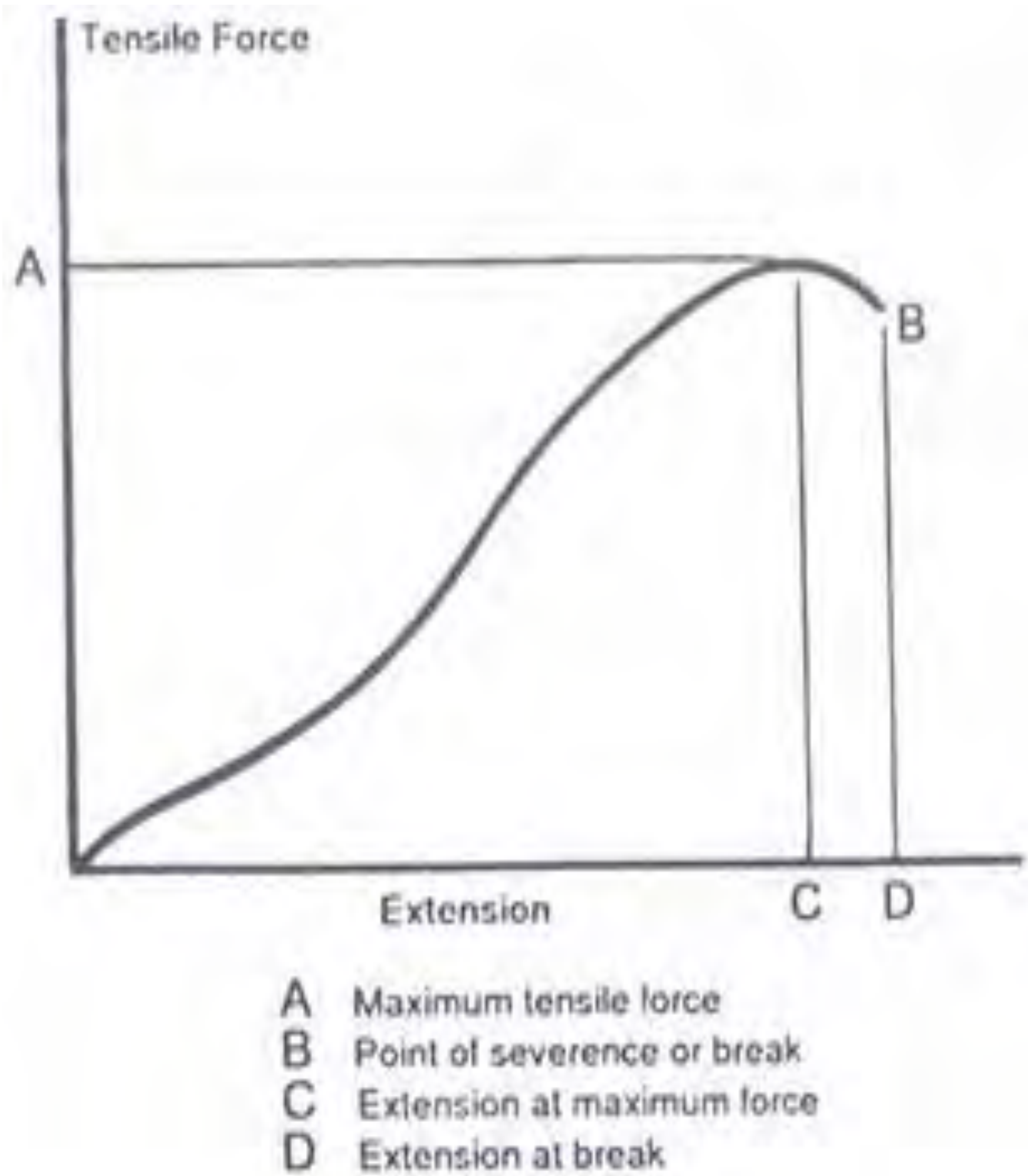


Figure **3.33**: Yarn elasticity curve (Force-Extension curve)

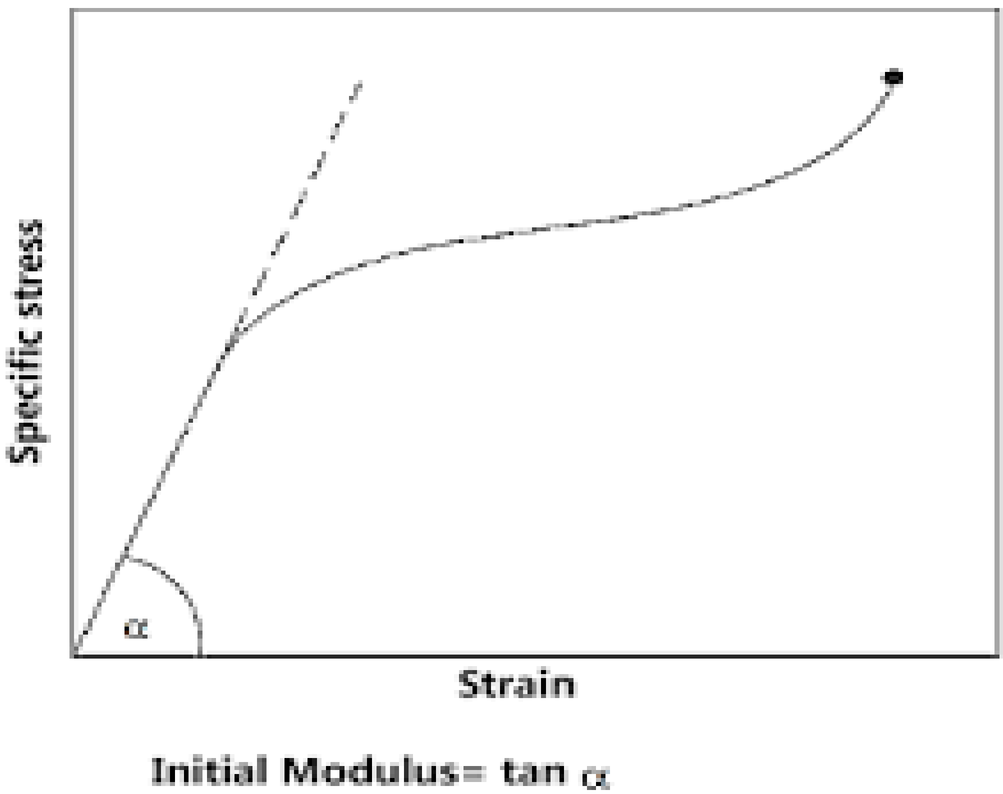


Figure **3.34**: Yarn elasticity curve (Specific stress-Specific strain curve)

3. 5.4. Yarn modulus

Modulus refers to the ratio of stress (force per unit area) along an axis to strain (ratio of deformation over initial length) along that axis. The elastic modulus measures a material‟s stiffness which is the resistance to elastic deformation. Depending on the character of the applied load, there are three types of stiffness in yarn: stiffness under extension, under bending and under twisting (Podorvan, Shovkun and Ovdak, 2019).

3.5.5 Initial modulus

The ratio of stress to corresponding strain below the proportional limit (Denton and Daniels, 2002) (Figure 3.34)

CHAPTER-4

YARN INPUT TENSION AND COURSE LENGTH –A MODEL FORMATION

4.1 Research Drive

Though a number of research works are available on yarn tension and its influence on different fabric properties, a gap is still visible in the form of mathematical relation (particularly between yarn input tension and course length). So a model is need to be formed and afterwards it need to be verified for practical application.

4.2 A Review on Knitted Fabric Course Length and Loop Length

Knitting may be considered as a mechanical process in which yarn loops are interlocked to form fabric. A knitted fabric manufacturer has to ensure some quality parameters like areal density usually expressed as gram per square meter (GSM), shrinkage etc. at desired level through controlling of some knitting variables. Among these variables loop length (Length of yarn in a single loop) acts as the single most important construction variable.

Loop length or Stitch length (LL) may be controlled in a number of ways. On machines without positive feed mechanism, it is controlled mainly by the distance the needle descends below the sinker belly. When a positive feed device is used, the length of yarn fed to the needles at a particular feed is the factor that decides the stitch length which is generally measured from course length as shown in the following equation

$$l = \frac{C}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where l is the loop length (Figure 4.1), C indicates course length and N stands for number of needles knitting.

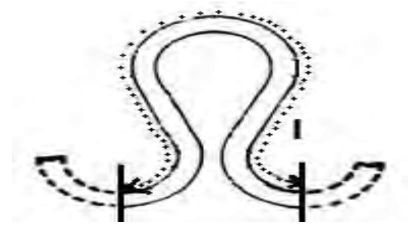


Figure **4.1**: An ideal loop

Course length is generally measured by some online monitoring tool like yarn length meter during the machine running state. To maintain uniform and predetermined amount of yarn consumption per cylinder revolution, i.e. course length, positive storage feed systems are generally integrated with modern circular weft knitting machines. However, the actual stitch length found in the relaxed fabric through off-machine measurement by Course Length Tester or Crimp Tester generally deviates from that measured through online. Tensile force in running yarn causing yarn extension is the key reason for such deviation if the feed system functions flawlessly (Dias and Lanarolle,2002). Due to some practical limitations like fabric destruction (Ray,2013) and high time consumption, off-machine measurement of course length is generally not preferred by a knitter during the dynamic knitting process. But still precision measurement of loop length is highly desired by the manufacturer to meet buyer"s quality requirement at marginal tolerance as well as to save production cost. It was observed that a positive change in stitch length by 0.01 mm results in a negative change in areal density by approximately 1.00 g/m^2 in the cotton knitted fabric (Hossain and Hoque, 2013). Consequently fabric consumption and other properties also change. A typical example of such change in fabric consumption is shown under APPENDIX A.

4.3 Mechanical Considerations

4.3.1 Yarn

Yarn may be defined as linear assemblage of fibers or filaments formed into a one dimensional continuous strand having good tensile strength and high flexibility (Goswami, Martindale and Scardino,1977). Generally yarn shows viscoelastic behavior which may be considered as linear type. During selected periods of progressive loading yarn shows spring-like behavior. During other periods of loading a creep type of deformation occurs (Adanur,1995). As shown in Figure 4.2, for a typical polyester fibre or yarn, A is the proportional limit, OA is the elastic region, AB is the viscoelastic region, BC is the stiffening region, CD is the second flow region and D is the breaking point. A viscoelastic yarn is thus generally assumed to show linear elastic behavior if the applied force does not exceed the proportional limit.

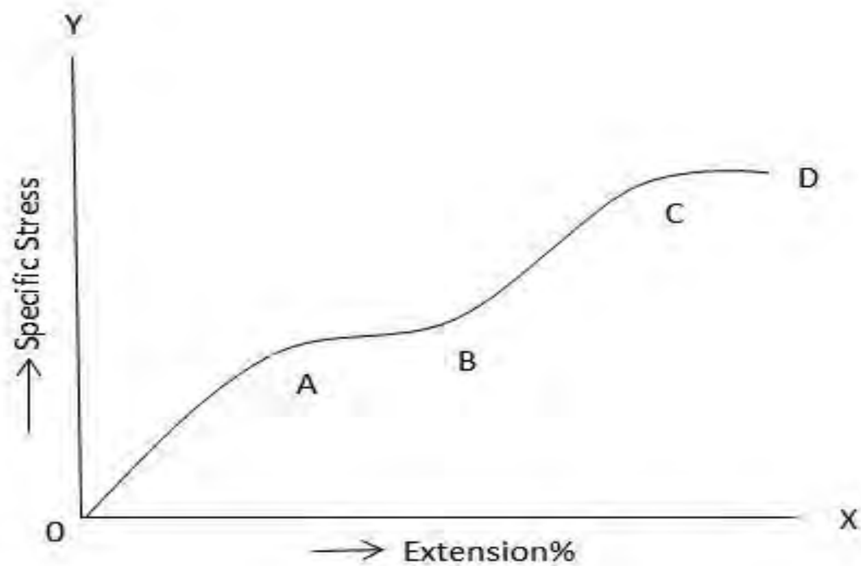


Figure **4.2:** A typical polyester specific stress-extension% diagram (Adanur, 1995).)

4.3.2 Fine structure of yarn input tension during dynamic knitting

Tension zones are found throughout the yarn path as the yarn passes from package to creel, then to feed system and afterwards into the knitting needles. Yarn input tension (YIT) is the key concern to a knitter as yarn is delivered from the feed device to the knitting zone under this tension. As the loop formation procedure results increase and decrease of the yarn tensile force due to the knitting action of needles, YIT resembles a sinusoidal waveform that can be obtained through production monitoring system like Knitlab (Catarino,Rocha and Monteiro,2003) or MLT Wesco PC Software as shown in Figure 4.3.

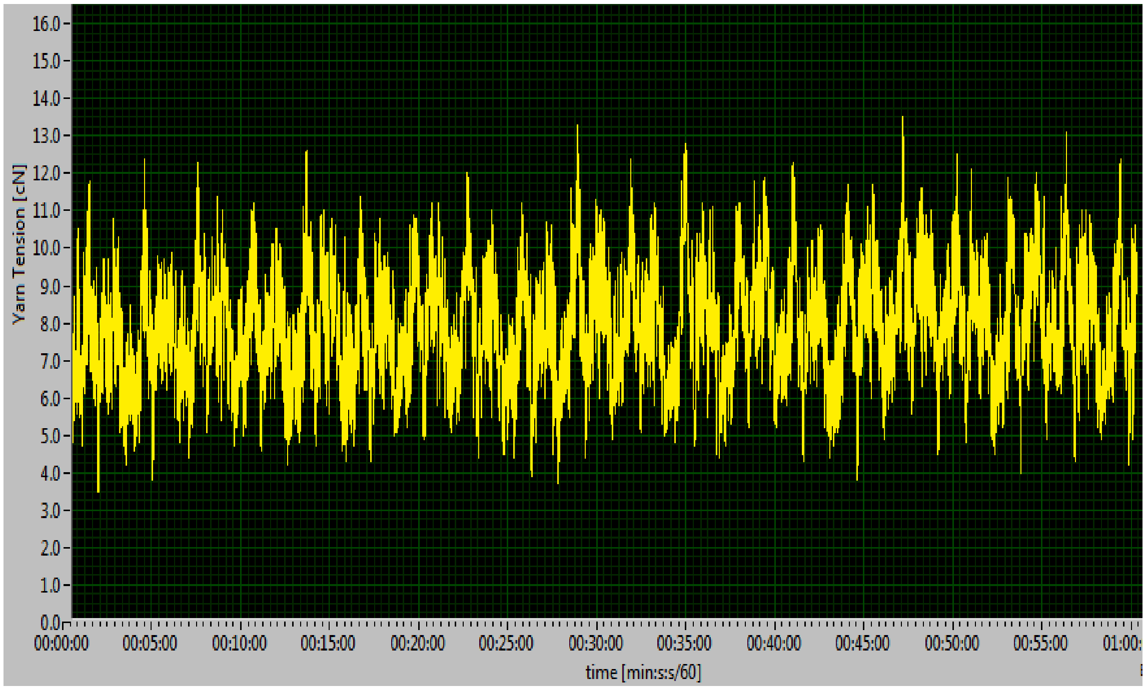


Figure **4.3**: A typical YIT waveform during knitting

The corresponding stress, when a needle proceeds through the knitting cycle to form a loop, can be written as

$$\sigma(t) = \sigma_0 \sin(\omega t)\text{..........}(2)$$

Where σ is the stress at time t, σ_0 is the maximum stress and ω is the circular frequency of stress change. As yarn input tension is maintained as low as possible for smooth knitting process, generally σ and corresponding strain,ε, lie in the linear region of yarn"s stress-strain curve. So strain can be written as

$$\varepsilon(t) = E\varepsilon_0 \sin(\omega t)\text{..........}(3)$$

Where E is the initial modulus (Young"s modulus) of yarn and ε_0 is the corresponding strain for σ_0.Thus ignoring any loss of modulus at dynamic knitting condition and taking into account other marginal tension influencing factors it may be understood that average YIT measured online may be applied to calculate corresponding yarn elongation using basic law of elasticity.

4.3.3 Actual course length measurement from fabric by the application of preload

Course length measurement is done by determining the length of an unroved course slightly tensioned by a small load. The role of this tension is to straighten the yarn without stretching. Precision selection of the tension load is quite difficult as it is rarely possible to remove all the kinks before the yarn itself begins to stretch (Booth,1968). Researchers used different regulatory preloads for course length or loop length measurements, either dependent on yarn linear density or fixed, as discussed by Pavko-Cuden and Sluga(Pavko-Cuden and Sluga,2015).

HATRA Course Length Tester is the most widely used equipment for off-machine measurement of course length. The equipment generally works with a preload of 10cN (for staple/spun yarn of up to 65 Tex) in accordance with BS 5441:1988 and has been recommended by many authors and researchers (Pavko-Cuden and Sluga,2015).

4.4 Model Development

Textile yarns generally have good extensibility but most of them exhibit lower strain% on the initial straight–line portion of a corresponding stress-strain diagram. Therefore both engineering and true stress-strain diagrams are applicable here to identify elastic properties. However for the model purpose true stress- true strain relation has been considered as it undertakes more meaningful values. Again the idea of correlating yarn tension at different points of yarn path with fabric quality or course length has to be modified as, except YIT, it is quite impossible to take actual tension values from different zones of yarn path as the probes or sensors of available tension/yarn length meters are either inaccessible or cause interference in the yarn path of the running yarn while taking practical measurements. However this constraint has been overcome by considering more than one value of YIT and associated yarn delivery. Accordingly, as YIT is the easily measurable and adjustable parameter for monitoring a yarn‟s response to external force during knitting, justification of the model has been designed based on measured

4.4.1 Assumptions

In order to formulate a mathematical model for actual course length the following assumptions are set up.

1. Yarn stiffness under extension is considered.
2. Linear density and elastic performance coefficient of yarn remain constant throughout the yarn path during knitting operation.
3. Tension peak observed during yarn feeding does not exceed the proportional limit.
4. High build-up of knitting tension (tension of yarn inside the knitting zone) is compensated by the robbing-back so that any permanent deformation in yarn may be ignored.
5. Influence of yarn unwinding tension from package and fabric takedown tension on yarn mechanical property, are all ignored.
6. The effect of inter-yarn friction during loop relaxation may be considered as negligible and therefore can be overlooked.
7. Feeder ring eye and Feeder eye impose marginal influence on yarn input tension.

4.4.2 Mathematical derivation

A simplified diagram of Yarn withdrawal and delivery through positive storage feed system in circular weft knitting has been shown in Figure 4.4

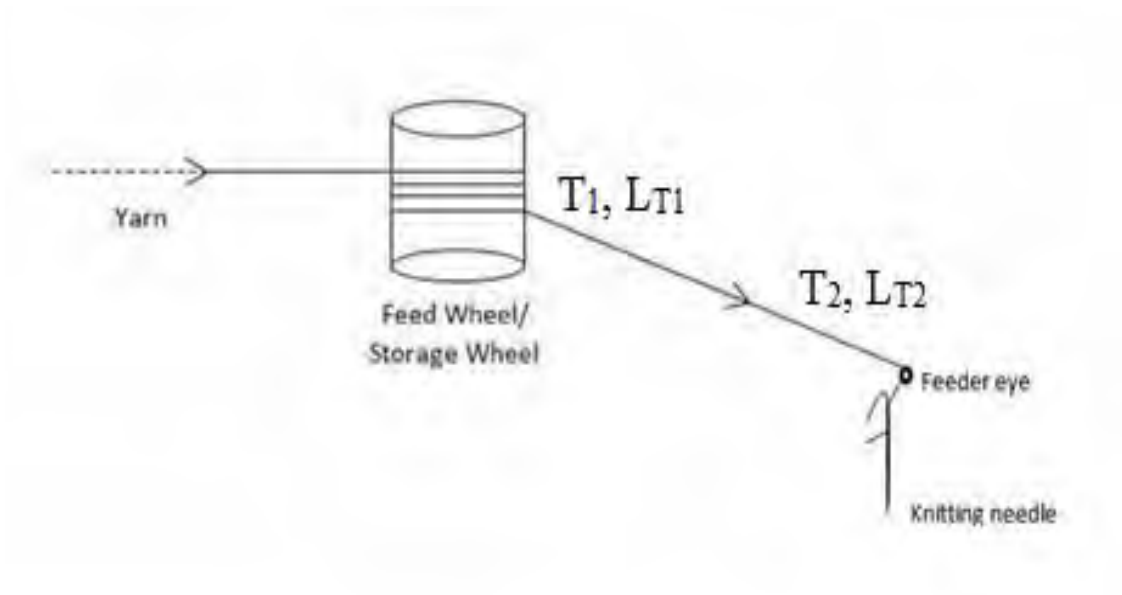


Figure **4.4**: Two random values of yarn input tension with corresponding „on-machine" course length during positive storage feeding

Let,

T_1 = A particular value of average yarn input tension measured on the yarn path during the dynamic knitting process

L_{T1}= Length of yarn delivered to the knitting zone per cylinder revolution at tension T1

T_2= Yarn tension (other than T_1) measured on the yarn path during the dynamic knitting process

L_{T2} = Length of yarn delivered to the knitting zone per cylinder revolution at tension T_2

L_0 = Course length = Actual length of yarn in a course on a relaxed fabric = Relaxed form (in length) of L_{T1} or L_{T2}.

t = Yarn linear density, i.e. mass per unit length

Textile materials like yarns and fabrics contain unknown amount of space as well as fibres in their cross-sections. Therefore cross-sectional area of a yarn is not clearly defined and more useful measurement of stress is specific stress which is defined as the ratio of force to the linear density (Saville, 1999)

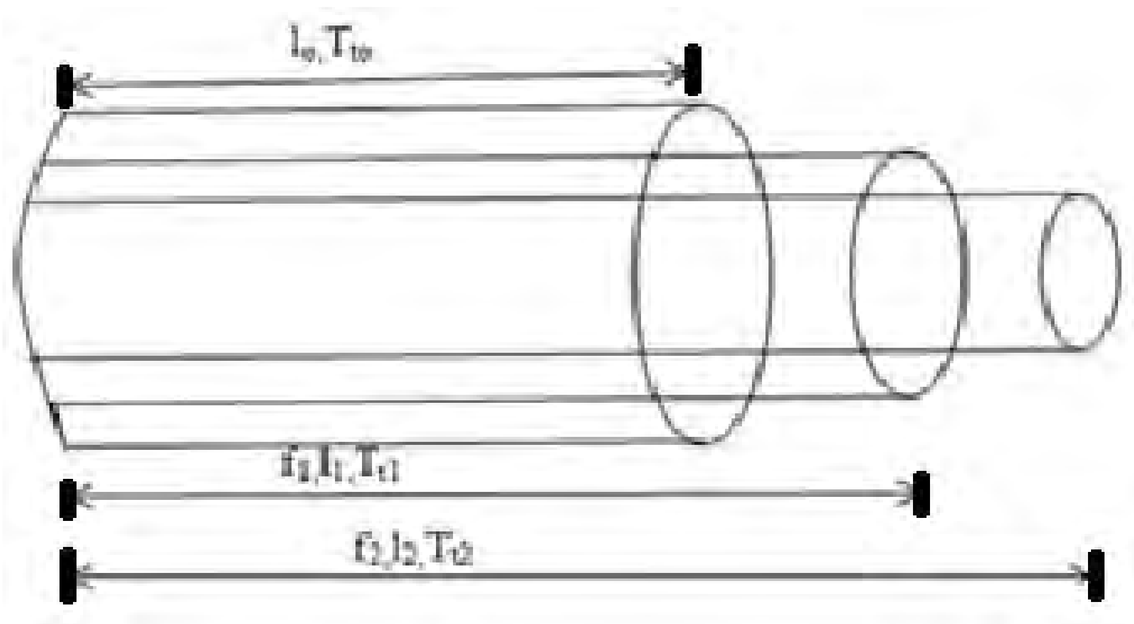
$$\text{specific stress}, \sigma = \frac{T}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Thus considering yarn as a one-dimensional element it may be found that,

$$\sigma_{T1} = \frac{T_1}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

$$\sigma_{T2} = \frac{T_2}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

True specific stress and true specific strain can be deduced from specific stress and specific strain considering mass invariance of yarn, as shown in Figure 4.5.



Mass of yarn segment (unstretched or stretched), m = $l_o T_{to} = l_1 T_{t1} = l_2 T_{t2}$

Here,
l_o = Unstretched length of a yarn segment
T_{to} = Mass per unit length for l_o
T_{t1} = Mass per unit length for stretched yarn segment l_1 at axial force f_1
T_{t2} = Mass per unit length for stretched yarn segment l_2 at axial force f_2

Figure **4.5**: Mass invariance of yarn (Matthes,Pusch and Cherif,2012) to deduce equations for true specific stress and true specific strain

Now,

True specific stress at tension T_1, $\sigma'_{T1} = \sigma_{T1}(1+\varepsilon_{T1})$…..(7)

True specific stress at tension T_2, $\sigma'_{T2} = \sigma_{T2}(1+\varepsilon_{T2})$…..(8)

Also

True specific strain at tension T_1, $\varepsilon'_{T1} = \ln(1+\varepsilon_{T1})$……..(9)

True specific strain at tension T_1, $\varepsilon'_{T2} = \ln(1+\varepsilon_{T2})$…......(10)

Considering Hooke‟s law it may be shown that

$$\frac{\sigma'_{T1}}{\varepsilon'_{T1}} = \frac{\sigma'_{T2}}{\varepsilon'_{T2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

$$\Rightarrow \frac{\sigma_{T1}(1+\varepsilon_{T1})}{\ln(1+\varepsilon_{T1})} = \frac{\sigma_{T2}(1+\varepsilon_{T2})}{\ln(1+\varepsilon_{T2})}$$

$$\Rightarrow \frac{\sigma_{T1}\left(1+\frac{L_{T1}-L_0}{L_0}\right)}{\ln\left(1+\frac{L_{T1}-L_0}{L_0}\right)} = \frac{\sigma_{T2}\left(1+\frac{L_{T2}-L_0}{L_0}\right)}{\ln\left(1+\frac{L_{T2}-L_0}{L_0}\right)}$$

$$\Rightarrow \frac{\frac{T_1}{t}\times\frac{L_{T1}}{L_0}}{ln\frac{L_{T1}}{L_0}} = \frac{\frac{T_2}{t}\times\frac{L_{T2}}{L_0}}{ln\frac{L_{T2}}{L_0}} \quad [\text{ As } L_{T1} \neq L_0 \text{ , } L_{T2} \neq L_0]$$

$$\Rightarrow \frac{T_1 L_{T1}}{tL_0} \times \ln\left(\frac{L_{T2}}{L_0}\right) = \frac{T_2 L_{T2}}{tL_0} \times \ln\left(\frac{L_{T1}}{L_0}\right)$$

$$\Rightarrow \frac{T_1 L_{T1}}{tL_0} \times \ln\left(\frac{L_{T2}}{L_0}\right) - \frac{T_2 L_{T2}}{tL_0} \times \ln\left(\frac{L_{T1}}{L_0}\right) = 0$$

$$\Rightarrow \frac{1}{tL_0}\left\{ T_1 L_{T1}\, ln\left(\frac{L_{T2}}{L_0}\right) - T_2 L_{T2}\, ln\left(\frac{L_{T1}}{L_0}\right)\right\} = 0$$

$$\Rightarrow T_1 L_{T1} ln\left(\frac{L_{T2}}{L_0}\right) - T_2 L_{T2} ln\left(\frac{L_{T1}}{L_0}\right) = 0 \qquad [\text{ As } t \neq 0 \ \& L_0 \neq 0]$$

$$\Rightarrow ln\left(\frac{L_{T2}}{L_0}\right)^{T_1 L_{T1}} - ln\left(\frac{L_{T1}}{L_0}\right)^{T_2 L_{T2}} = 0$$

$$\Rightarrow ln\frac{\left(\frac{L_{T2}}{L_0}\right)^{T_1 L_{T1}}}{\left(\frac{L_{T1}}{L_0}\right)^{T_2 L_{T2}}} = 0$$

$$\Rightarrow ln\left\{\left(\frac{L_{T2}}{L_0}\right)^{T_1 L_{T1}}\left(\frac{L_0}{L_{T1}}\right)^{T_2 L_{T2}}\right\} = 0$$

⇨ $(\frac{L_{T2}}{L_0})^{T_1\,L_{T1}}(\frac{L_0}{L_{T1}})^{T_2\,L_{T2}} = 1$ [As $L_0 \neq 0$]

⇨ $\frac{{L_{T2}}^{T_1\,L_{T1}}}{{L_0}^{T_1\,L_{T1}}} \times \frac{{L_0}^{T_2\,L_{T2}}}{{L_{T1}}^{T_2\,L_{T2}}} = 1$

⇨ ${L_0}^{T_2\,L_{T2} - T_1\,L_{T1}} = \frac{{L_{T1}}^{T_2 L_{T2}}}{{L_{T2}}^{T_1 L_{T1}}}$ [$As\ T_2 L_{T2} \neq T_1 L_{T1}$]

⇨ $L_0 = (\frac{{L_{T1}}^{T_2 L_{T2}}}{{L_{T2}}^{T_1 L_{T1}}})^{1/T_2\,L_{T2} - T_1\,L_{T1}}$ …………………(12)

By putting the values of T_1, T_2 and corresponding L_{T1} and L_{T2} in Eqn.12 one can calculate actual CL that is expected in the produced fabric.

4.5 Experimental work with background data analysis

In order to examine the validity of the model practical knitting outputs were compared with those predicted by the derived equation.

4.5.1 Production of fabric samples of acceptable quality at different YIT values

Plain jersey fabric samples were knitted with same positive feed setting on a large diameter single jersey circular knitting machine (Orizio, Johnan).To avoid slippage a fresh QAP and a new timing belt was used for the feed mechanism. The machine was of 24 gauge and 26-inch Diameter with 1920 needles and 78 feeders. However a total of 39 feeders were deployed during knitting and a particular feeder (feeder no.51) was selected to carry out the experimental works related with yarn input tension.

Polyester single (spun) yarns of 2 (two) linear densities and Cotton single yarns of 4(four) linear densities were used (Figure 4.6) to produce fabric samples. The yarn notations according to ISO 1139 (ISO 1139 :1973) are shown in Table 4.1 where actual yarn count and twist were experimentally determined (Figures 4.7 and 4.8 with APPENDIX B& C respectively) following ISO 2060 (ISO 2060:1994) and ISO 2061(ISO 2061 :2015) respectively.

Figure **4.6**: Some yarn packages used for the experimental purpose (Left-Spun Polyester; Right-Cotton)

The quality reports of these yarns provided by the supplier, i.e., Square Textiles Limited are attached at APPENDIX D.

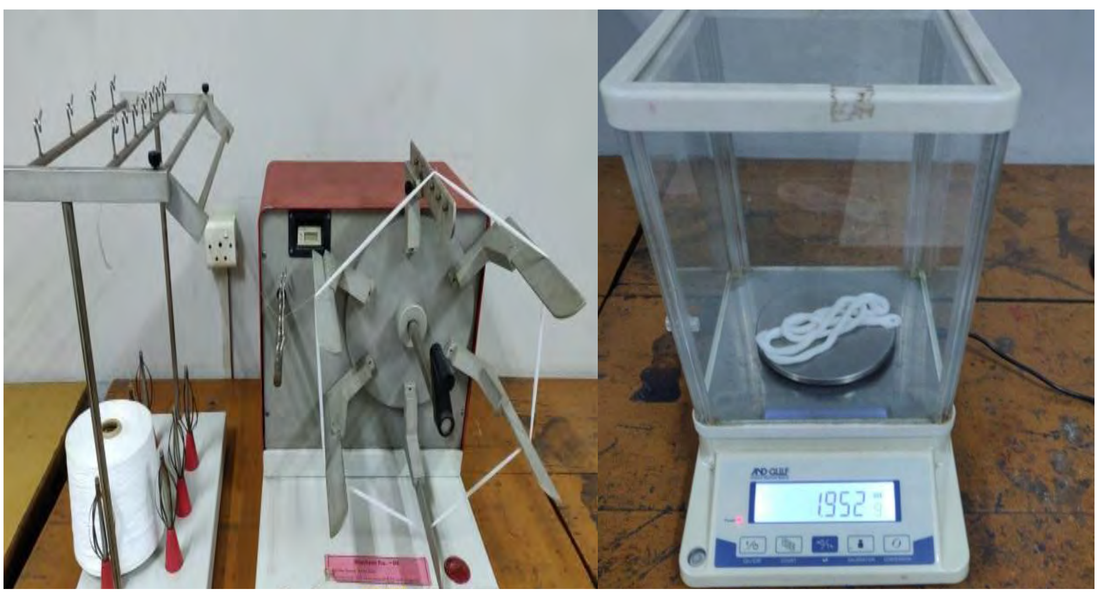


Figure **4.7**: Actual yarn count determination [Left: Hand Wrap Reel for yarn skein(120 yards) formation, Right :AND GULF precision Electronic Balance to find out the mass of the prepared skein] {*Courtesy :*Textile Testing and Quality Control laboratory, Department of Textile Engineering, Ahsanullah University of Science and Technology}

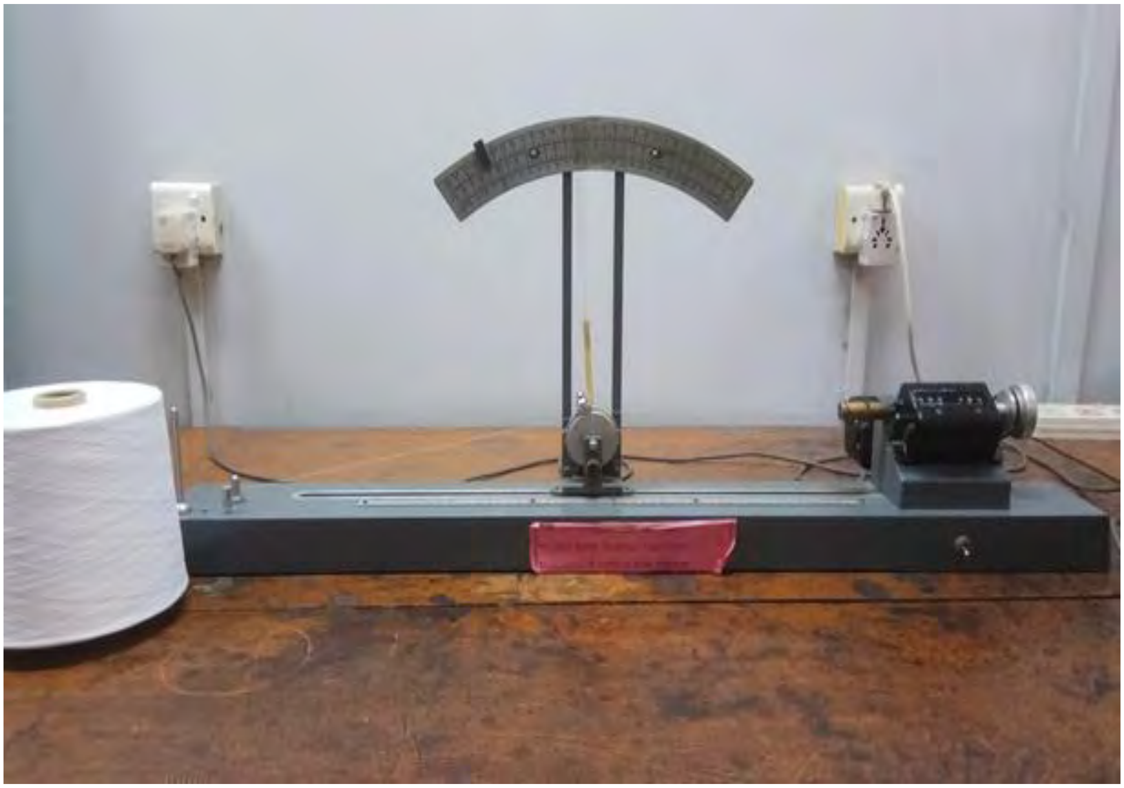


Figure **4.8**: Measurement of yarn twist by Quadrant Twist Tester{*Courtesy :* Textile Testing and Quality Control laboratory, Department of Textile Engineering, Ahsanullah University of Science and Technology

Table **4.1**: Notations for experimental yarns

Technical Description		**Yarn**					
Fiber Content		Cotton				Spun Polyester	
Count	Nominal (in Ne)	20	26	30	40	26	34
	Actual (in Tex)	29.98	23.38	19.92	15.22	23.62	17.90
Twist per inch (T.P.I)		17.37	20.04	21.97	25.41	20.59	23.95
Direction of Twist		Z	Z	Z	Z	Z	Z

Some mechanical properties of these yarns obtained through a CRE-type tester (Figure 4.9), following a standard method (ASTM D2256-10), are shown in Table 4.2 and Table 4.3; details can be found from APPENDIX E and APPENDIX F.

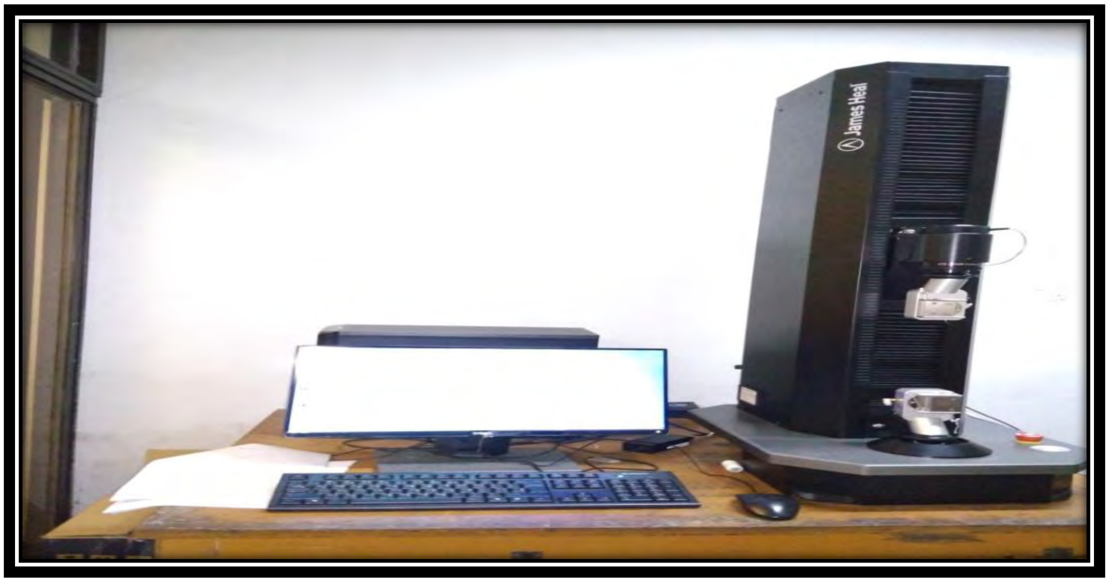


Figure **4.9**: Titan Universal Strength Tester; Model 1410 {*Courtesy :* Textile Testing and Quality Control laboratory, Department of Textile Engineering, Ahsanullah University of Science and Technology}

Table **4.2**: Mechanical properties of the experimental spun polyester yarns obtained through TITAN universal strength tester

Yarn → **Mechanical Property ↓**	**Spun Polyester , 23.62Tex**	**Spun Polyester , 17.90 Tex**
Initial Modulus (cN/Tex)	140.71	152.15
Tenacity(cN/Tex)	13.77	13.69
Extension at break (%)	12.12	11.47
Proportional Limit(cN/Tex)	1.96	1.72

Table **4.3**: Mechanical properties of the experimental cotton yarns obtained through TITAN universal strength tester

Yarn → **Mechanical Property ↓**	**Cotton, 29.98 Tex**	**Cotton, 23.38 Tex**	**Cotton, 19.92 Tex**	**Cotton, 15.22 Tex**
Initial Modulus (cN/Tex)	148.08	143.99	151.85	193.49
Tenacity(cN/Tex)	7.12	7.02	5.33	7.04
Extension at break (%)	5.77	6.17	4.58	4.36
Proportional Limit(cN/Tex)	1.48	1.69	1.43	1.90

It is also mentionable that, for the experimental yarns, if the engineering elasticity curve is converted to a true specific stress- strain curve, linear relationship between stress and strain could also be found up to the proportional limit which is almost same to that of an engineering specific stress and strain curve. Examples are shown on APPENDIX G.

Knitting was performed at different couliering depths (cam settings) to obtain different yarn input tensions within the boundary of yarn‟s proportional limit keeping all other settings unchanged in identical environmental condition. The stitch cam setting was considered within graduated knob values of 0.4 to 0.7– the safe operating range suggested by the production management of Padma Poly Cotton Knit Fabrics Limited (PPCKFL), the particular factory, where the experimental machine (Figure 4.10) was located.

Figure **4.10**: The experimental circular knitting machine (Orizio, Johnan) at Padma Polycotton Knit Fabrics Limited

A brand new MLT Wesco yarn tension and rate meter (Figure 4.11) was used to get online reading for different tensions and corresponding yarn length/revolution of machine cylinder. The accuracy of the equipment was (+/-) 0.5% (according to the manufacturer‟s guarantee). The operating manual of this equipment was only followed for taking readings due to lack of any available standard. Measurements were taken only when the knitting machine had reached its normal operating temperature.

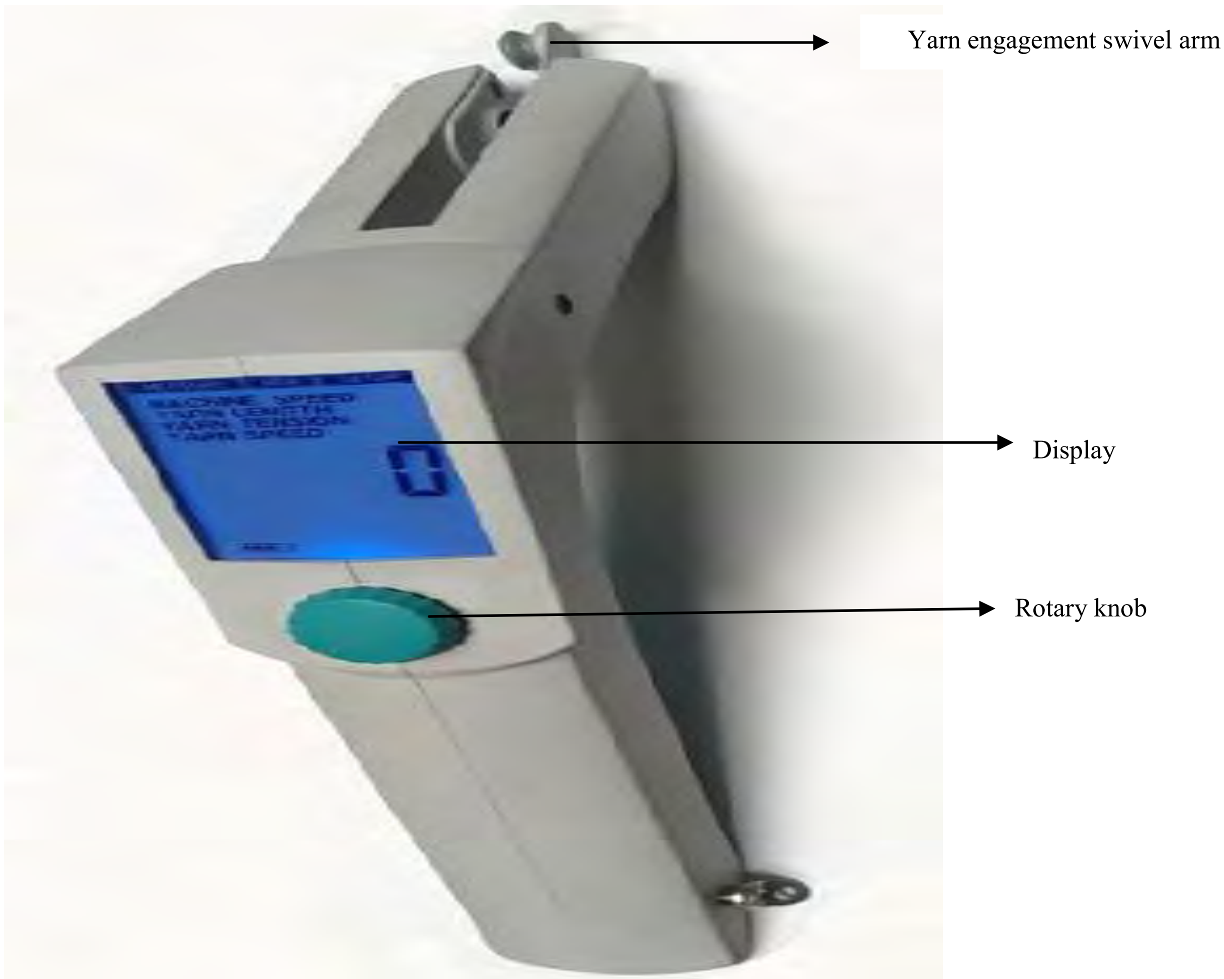


Figure **4.11** : MLT Wesco Yarn Meter

Though the machine was kept running to produce a reasonable quantity of each sample, each reading for „on-machine" measurement was taken for a machine running period of around 60 seconds (APPENDIX H). The machine was running at a rpm of 10.5 with a QAP setting of 130 indicating feeding unit driving belt theoretical speed of 5.34 m/sec. (Orizio Paolo S.p.A.,n.d.).Selected data for the analysis purpose have been gathered in Table 4.4.

Table **4.4**: Experimental data obtained for online yarn length per machine revolution and yarn input tension

Yarn	Propor-tional Limit	Reading No.	Cam Setting Point	Average Yarn Input Tension(cN)	Tension Peak (cN)	Average Yarn Length / Rev. (m)
23.62 Tex Spun Polyester	1.96 cN/Tex or 46.29cN	1	0.4	2.60 (σ=0.015)	7.1	5.164(σ=0.013)
		2	0.5	7.80(σ=0.013)	13.5	5.199(σ=0.012)
		3	0.6	11.00(σ=0.015)	19.1	5.231(σ=0.011)
		4	0.65	20.33(σ=0.012)	30.5	5.260(σ=0.011)
		5	0.7	27.58(σ=0.013)	40.8	5.285(σ=0.016)
17.90Tex Spun Polyester	1.72 cN/Tex or 30.79cN	1	0.4	1.53(σ=0.014)	4.5	5.180(σ=0.014)
		2	0.5	5.48(σ=0.017)	9.5	5.200(σ=0.022)
		3	0.6	11.02(σ=0.018)	17.3	5.235(σ=0.016)
		4	0.65	16.40(σ=0.014)	25.2	5.252(σ=0.015)
		5	0.7	20.30(σ=0.021)	30.2	5.283(σ=0.015)
29.98 Tex Cotton	1.48 cN/Tex or 44.37cN	1	0.4	8.3 (σ=0.016)	14.3	5.174(σ=0.015)
		2	0.5	15.48(σ=0.017)	22.6	5.203(σ=0.022)
		3	0.6	25.7(σ=0.02)	38.2	5.222(σ=0.022)
		4	0.7	41.87(σ=0.019)	57.8	5.253(σ=0.015)
23.38 Tex Cotton	1.69 cN/Tex or 39.51	1	0.4	4.58(σ=0.02)	8.5	5.187(σ=0.018)
		2	0.5	11.07(σ=0.017)	17	5.214(σ=0. 017)
		3	0.6	19.24(σ=0.016)	28.7	5.242(σ=0.015)
		4	0.7	26.07(σ=0.017)	36.1	5.272(σ=0.015)
19.92 Tex Cotton	1.43cN/Tex or 28.48 cN	1	0.4	3.7(σ=0.014)	8.1	5.181(σ=0.017)
		2	0.5	9.91(σ=0.017)	16.5	5.203(σ=0.018)
		3	0.6	15.54(σ=0.016)	23.8	5.226(σ=0.017)
		4	0.7	27.65(σ=0.019)	38.1	5.262(σ=0.013)
15.22 Tex Cotton	1.90 cN/Tex or 28.92 cN	1	0.4	4.41(σ=0.018)	9.3	5.186(σ=0.019)
		2	0.5	10.2(σ=0.021)	16.4	5.219(σ=0.018)
		3	0.6	17(σ=0.013)	24.7	5.229(σ=0.013)
		4	0.7	27.66(σ=0.016)	38.7	5.266(σ=0.015)

During experimental hours the temperature and relative humidity of the knitting floor ranged from around 26°C to 30°C and 41% to 47% respectively.

The experimental fabric roll was confirmed for acceptability through 4 point inspection system following a standard test method (ASTM D5430-13). The defect level for acceptability, commonly practiced in knitting factories of Bangladesh, was followed here. Only yarn tension related defects like Hole, Press-off, Drop Stitch and Run were identified as major for quality evaluation purpose. The inspection was done through a UZu Fabric Inspection Machine (Model: UZ 900). A summary of the fabric inspection is shown in table 4.5 and an image of the grey fabric inspection report with corresponding breakdown are shown under APPENDIX I and APPENDIX J.

Table **4.5**: Summarized Quality report for produced fabric samples at different YIT values

Roll Weight (Kg)	**Areal Density (GSM)**	**Roll Width (inch)**	**Roll Length-Calculated (meter)**	**Assigned points for defects**	**Points/100 sq .meter**	**Quality Call**	**Grading Scale for defect points**
10.75	155-160	53	50.5	4	6	OK	< 20=A, 20-30=B, >30 (upto 40)=C, >40=Reject

4.5.2 Course length measurement through HATRA equipment

The produced knit fabric samples were dry relaxed statically. Course lengths were then measured by unraveling yarns from fabric samples and then working on a HATRA Course Length Tester (Figure 4.12). Here, to determine fabric course length for a particular yarn type and count, courses were randomly selected from each tension-wise knitted sample considering both sides (course knitted last and course knitted first)of the fabric ignoring particular tension-wise selection as variations in yarn input tension (unless they become excessive) do not significantly affect the knitted stitch length in case of positive feeding(Cotton Technology International,1992). Table 4.6 and Table 4.7 show the accumulated data for course length determination for spun polyester and cotton knitted fabrics sequentially. Some examples of comparative course lengths for different yarn input tension values for same type of yarn are shown on APPENDIX K

Figure **4.12**: HATRA Course Length Tester {*Courtesy :* Knitting laboratory, Department of Textile Engineering, Ahsanullah University of Science and Technology}

Table **4.6**: Course length determination by HATRA Course Length Tester from fabrics knitted with Spun Polyester yarns

Reading No	**Course length measured from fabrics knitted with 17.90 Tex Spun Polyester (m)**	**Course length measured from fabrics knitted with 23.62 Tex Spun Polyester (m)**
1	5.200	5.190
2	5.205	5.190
3	5.210	5.195
4	5.230	5.230
5	5.220	5.205
6	5.230	5.210
7	5.225	5.215
8	5.225	5.200
9	5.220	5.210
10	5.210	5.185
Average	5.2175	5.203
CV (%)	0.20	0.26

Table **4.7**: Course length determination by HATRA Course Length Tester from fabrics knitted with Cotton yarns

Reading No	**Course length measured from fabrics knitted with 29.98 Tex Cotton (m)**	**Course length measured from fabrics knitted with 23.38 Tex Cotton (m)**	**Course length measured from fabrics knitted with 19.92 Tex Cotton (m)**	**Course length measured from fabrics knitted with 15.22Tex Cotton (m)**
1	5.205	5.205	5.200	5.190
2	5.190	5.185	5.190	5.185
3	5.210	5.220	5.205	5.180
4	5.200	5.215	5.200	5.205
5	5.205	5.225	5.210	5.200
6	5.190	5.215	5.205	5.180
7	5.190	5.200	5.205	5.200

Reading No	Course length measured from fabrics knitted with 29.98 Tex Cotton (m)	Course length measured from fabrics knitted with 23.38 Tex Cotton (m)	Course length measured from fabrics knitted with 19.92 Tex Cotton (m)	Course length measured from fabrics knitted with 15.22Tex Cotton (m)
8	5.220	5.200	5.210	5.215
9	5.205	5.210	5.190	5.210
10	5.220	5.205	5.210	5.210
Average	5.2035	5.208	5.2025	5.1975
CV (%)	0.22	0.22	0.14	0.25

4.6 Result and Discussion

4.6.1 Justifying the Inadequacy of On-line Yarn Length / Machine Rev. to be used as Course Length

To verify whether online yarn length can be used as course length or not, values of online yarn length/machine revolution for different yarn input tension values were compared with course length values obtained for different fabrics. Two examples for the experimental fabrics are shown in Figure 4.13 and Figure 4.14.

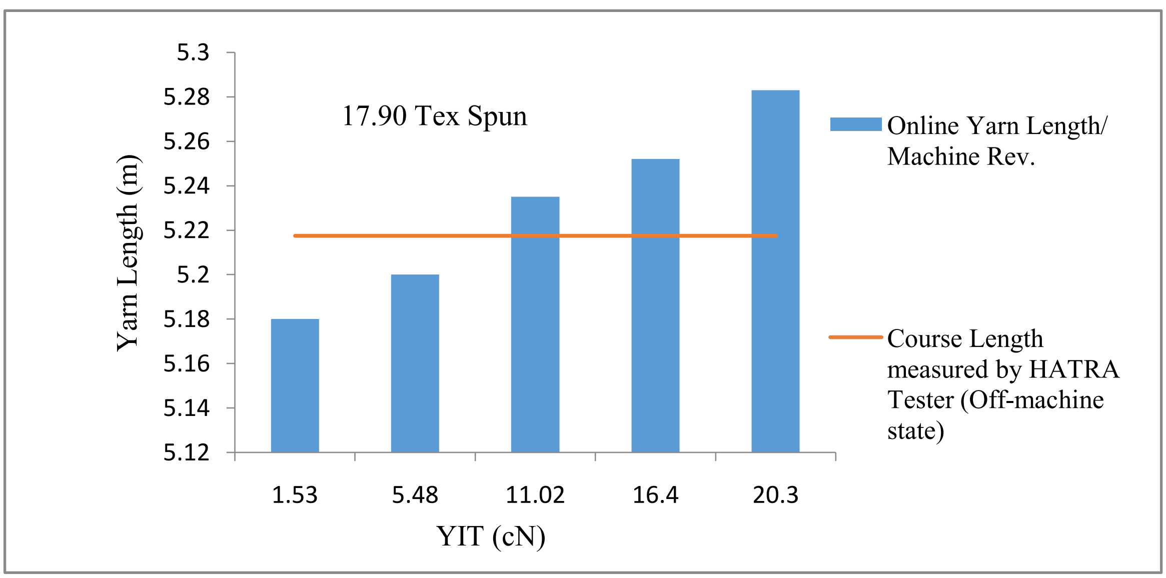


Figure **4.13**: Comparison between fabric (knitted with 17.90 Tex spun polyester) course length and online yarn length/machine rev. for different yarn input tension

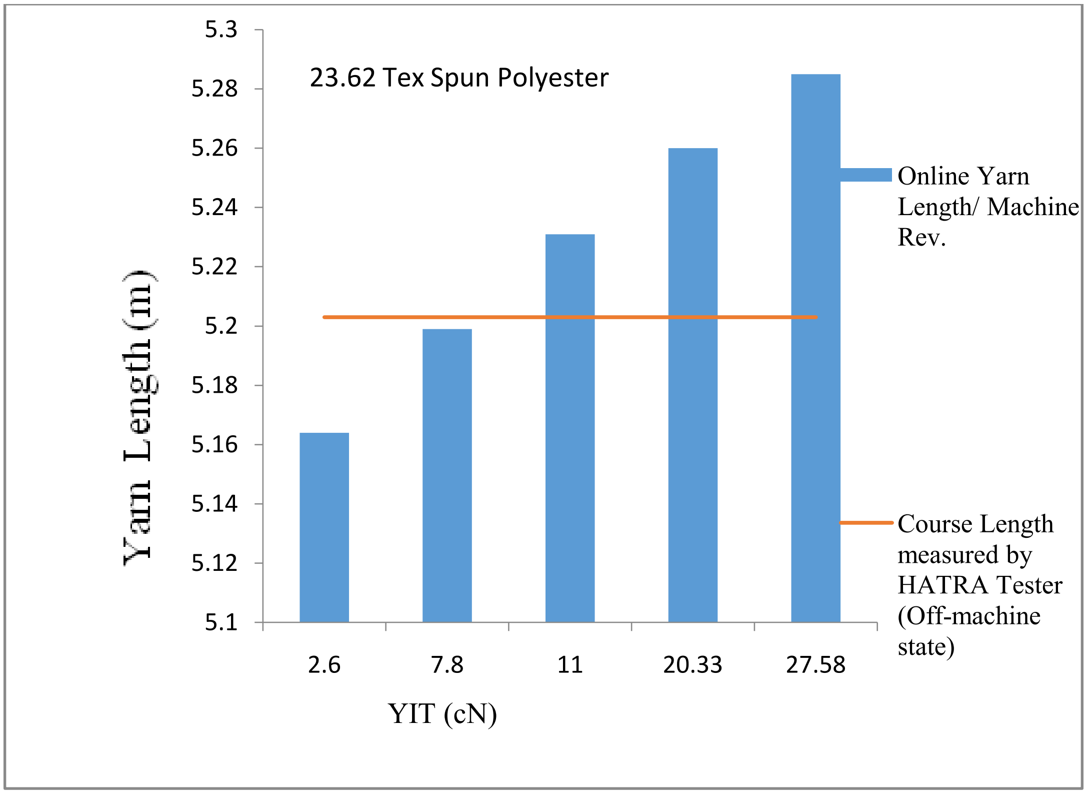


Figure **4.14**: Comparison between fabric (knitted with 23.62 Tex spun polyester) course length and online yarn length/machine rev. for different yarn input tension values

From the figures it is quite clear that online yarn length /machine revolution is positively correlated with yarn input tension. For some values of yarn input tension it is smaller than fabric course length and for others it exceeds fabric course length. Therefore Using online yarn length/ machine revolution as course length may lead to erroneous judgement on fabric quality.

4.6.2 Data analysis for Spun Polyester yarns

4.6.2.1 Prediction of actual (off-machine) course length

The values of yarn length /cylinder revolution obtained through online measurements were used to predict actual course length by the model developed. A simple program was written through MATLAB (version 7.6.0.324 –R2008a) for the said purpose. Table 4.8 shows the corresponding results.

Table **4.8**: Predicted course length values as obtained through the evaluation of „on-machine" measurements of course lengths and YIT for Spun Polyester knitted fabric

Yarn	Reading No.	Average Yarn Input Tension (cN)	Average Experimental Course Length in dynamic state(m)	Model prediction for course length through Matlab (m)	Average	CV (%)
17.90 Tex	1	1.53	5.1800	5.1723[Using reading no.1 & 2]	5.1707	0.33
	2	5.48	5.2000	5.1713[Using reading no.1 & 3]		
	3	11.02	5.2350	5.1728[Using reading no.1 & 4]		
	4	16.40	5.2520	5.1719[Using reading no.1 & 5]		
	5	20.30	5.2830	5.1661[Using reading no.2 & 3]		
				5.1745[Using reading no.2 & 4]		
				5.1703[Using reading no.2 & 5]		
				5.2007[Using reading no.3 & 4]		
				5.1797[Using reading no.3 & 5]		
				5.1274[Using reading no.4 & 5]		
23.62 Tex	1	2.60	5.1640	5.1468[Using reading no.1 & 2]	5.163	0.48
	2	7.80	5.1990	5.1438[Using reading no.1 & 3]		
	3	11.00	5.2310	5.1504[Using reading no.1 & 4]		
	4	20.33	5.2600	5.1519[Using reading no.1 & 5]		
	5	27.58	5.2850	5.1234[Using reading no.2 & 3]		
				5.1621[Using reading no.2 & 4]		
				5.1662[Using reading no.2 & 5]		
				5.1974[Using reading no.3 & 4]		
				5.1961[Using reading no.3 & 5]		
				5.1918[Using reading no.4 & 5]		

4.6.2.2 Two sample t-test between predicted and actual course lengths

Predicted course length values obtained through the model and the actual course length values measured by HATRA Course Length Tester were compared using t-tests. Table 4.9 and 4.10 show the corresponding results. (See APPENDIX L for Two Student"s t-distribution Table).

Table **4.9**: Results of t-test of predicted course length values through model and actual course length values for fabric knitted with 17.90 Tex Spun Polyester

Statistical parameters for a two samples t-test assuming equal variance	**Model prediction**	**HATRA Course Length Tester Measurement**
No. of observations	10	10
Mean	5.1707	5.2175
Mean Difference	0.0468m	
Variance	0.000290042	0.0001125
t-Value	5.31080014	
p-value	0.00000128943	

Table **4.10**: Results of t-test of predicted course length values through model and actual course length values for fabric knitted with23.62Tex Spun Polyester

Statistical parameters for a two samples t-test assuming equal variance	**Model prediction**	**HATRA Course Length Tester Measurement**
No. of observations	10	10
Mean	5.163	5.203
Mean Difference	0.040m	
Variance	0.000622297	0.00019
t-Value	3.192661075	
p-value	0.000316741	

4.6.2.3 Two sample t-tests between predicted course lengths obtained with yarns of different linear densities

Predicted course length values obtained through the model from polyester samples of two different linear densities were compared using t-tests. Table 4.11 shows the corresponding results.

Table **4.11**: Results of t-test of course length values predicted through the model for17.90Tex Spun Polyester and 23.62Tex Spun Polyester yarns

Statistical parameters for a two samples t-test assuming equal variance	**Model predicted Course lengths from fabrics knitted with 17.90 Tex Spun Polyester**	**Model predicted Course lengths from fabrics knitted with 23.62 Tex Spun Polyester**
No. of observations	10	10
Mean	5.1707	5.16299
Mean Difference	0.00771m	
Variance	0.000322269	0.000622297
t-Value	0.570163605	
p-value	0.437934935	

4.6.2.4 Two sample t-tests between actual course lengths obtained with yarns of different linear densities

Actual course length values (measured by HATRA Course Length Tester) obtained from polyester samples of two different linear densities were compared using t-tests. Table 4.12 shows the corresponding results.

Table **4.12**: Results of t-test of course length values measured through HATRA apparatus for fabrics knitted with 17.90Tex Spun Polyester and 23.62Tex Spun Polyester yarns

Statistical parameters for a two samples t-test assuming equal variance	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 17.90 Tex Spun Polyester**	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 23.62 Tex Spun Polyester**
No. of observations	10	10
Mean	5.2175	5.203
Mean Difference	0.0145m	
Variance	0.0001125	0.00019
t-Value	1.902640666	
p-value	0.116764792	

4.6.3 Data Analysis for Cotton yarns

4.6.3.1 Prediction of actual (off-machine) course length

The values of yarn length /cylinder revolution obtained through online measurements were used to predict actual course length by the model and the results are shown in Table 4.13

Table **4.13**: Predicted course length values as obtained through the evaluation of „on-machine‟ measurements of course lengths and YIT for Cotton knitted fabric

Yarn	**Reading No.**	**Average Yarn Input Tension (cN)**	**Average Experimental Course Length in dynamic state(m)**	**Model prediction for course length through Matlab (m)**	**Average**	**CV (%)**
29.98 Tex	1	8.3	5.174	5.1411[Using reading no.1 & 2]	5.1558	0.33
	2	15.48	5.203	5.1746[Using reading no.2 & 3]		
	3	25.7	5.222	5.1516[Using reading no.1 & 3]		
23.38 Tex	1	4.58	5.187	5.1682[Using reading no.1 & 2]	5.1695	0.11
	2	11.07	5.214	5.1768[Using reading no.2 & 3]		
	3	19.24	5.242	5.1602[Using reading no.3 & 4]		
	4	26.07	5.272	5.1702[Using reading no.1 & 3]		
				5.1724[Using reading no.2 & 4]		
				5.1694[Using reading no.1 & 4]		
19.92 Tex	1	3.7	5.181	5.1680[Using reading no.1 & 2]	5.1661	0.05
	2	9.91	5.203	5.1632[Using reading no.2 & 3]		
	3	15.54	5.226	5.1672[Using reading no.1 & 3]		
15.22 Tex	1	4.41	5.186	5.1613[Using reading no.1 & 2]	5.1789	0.43
	2	10.2	5.219	5.2041[Using reading no.2 & 3]		
	3	17	5.229	5.1712[Using reading no.1 & 3]		

4.6.3.2 Two sample t-test between predicted and actual course lengths

Predicted course length values obtained through the model and the actual course length values measured by HATRA Course Length Tester were compared using t-test. This was done only for 23.38 Tex Cotton knitted fabric as considerable amount of data points were available for the test (Table 4.14).

Table **4.14**: Results of t-test of predicted course length values through model and actual course length values for fabric knitted with 23.38 Tex Cotton

Statistical parameters for a two samples t-test	**Model prediction**	**HATRA Course Length Tester Measurement**
No. of observations	06	10
Mean	5.1695	5.208
Mean Difference	0.0385m	
Variance	0.0000300747	0.000134444
t-Value	6.839379331	
p-value	0.00000264187	

4.6.3.3 Two sample t-tests between actual course lengths obtained with yarns of different linear densities

Actual course length values obtained from cotton samples knitted with four different linear densities were subjected to two sample test with one another. Table 4.15 shows one corresponding result as an example. Rests are shown on APPENDIX M .

Table **4.15**: Results of t-test of course length values measured through HATRA apparatus for fabric knitted with 29.98Tex Cotton and 23.38Tex Cotton yarns

Statistical parameters for a two samples t-test	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 23.38Tex Cotton**	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 29.98 Tex Cotton**
No. of observations	10	10
Mean	5.208	5.2035
Mean Difference	0.0045 m	
Variance	0.000134444	0.000128056
t-Value	0.633711747	
p-value	0.391349156	

4.6.4 Comparison between predicted and actual course length values

From Table 4.9,Table 4.10 and Table 4.14 it can be found that the average course length values predicted by the model is always smaller than that found actually in fabric by the HATRA Course Length Tester. This was true for both spun polyester and cotton knitted fabrics. The obtained t-values(APPENDIX L) reject the null hypothesis and indicate that there is a statistically significant difference between the outcomes obtained through the model and the HATRA Course Length Tester (p-value=0.00000128943 for table 4.9,p-value=0.000316741 for table 4.10 and p-value=0.00000264187 for table 4.14).The differences between the predicted course lengths and the HATRA findings results a variation of around 0.02 mm in stitch length [as found from the mean differences in course lengths of 0.0468 meter for table 4.9 ,0.040 meter for table 4.10 and 0.0385 meter for table 4.14 and consequently using equation(1)].The reason for such difference may be well understood if we examine the change in the tensile properties of the yarn after the knitting process as shown in Figure 4.15 and Figure 4.16.

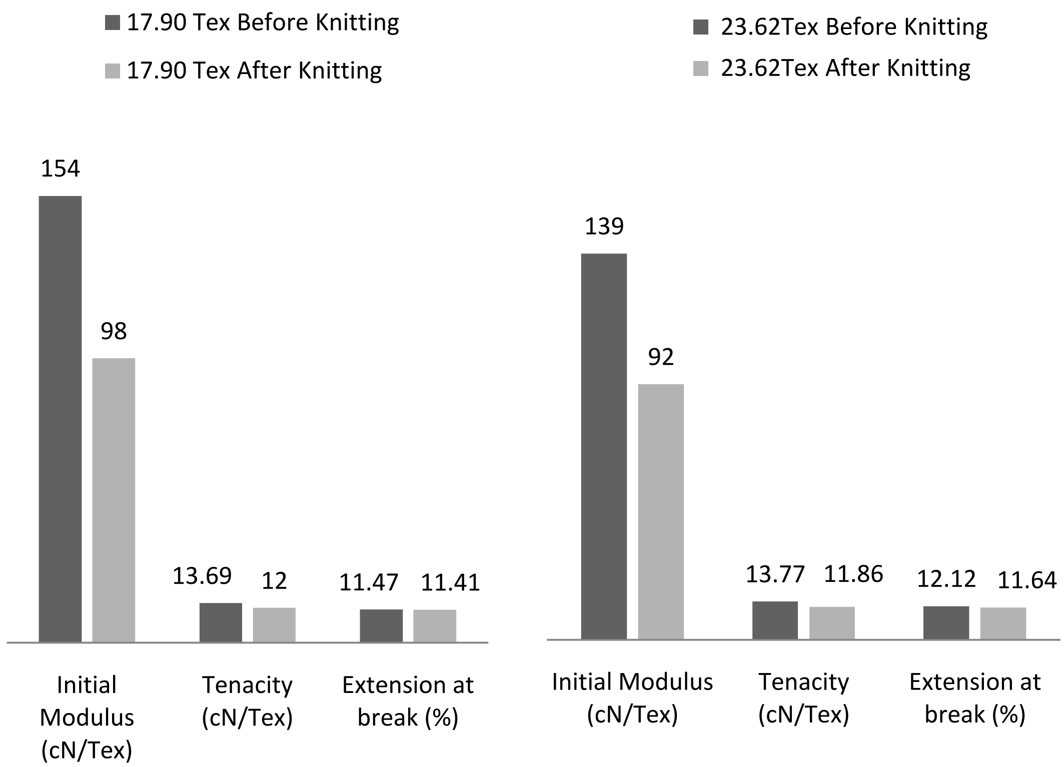


Figure **4.15**: Comparison between some mechanical properties of spun polyester yarns, obtained by Titan Universal Strength Tester

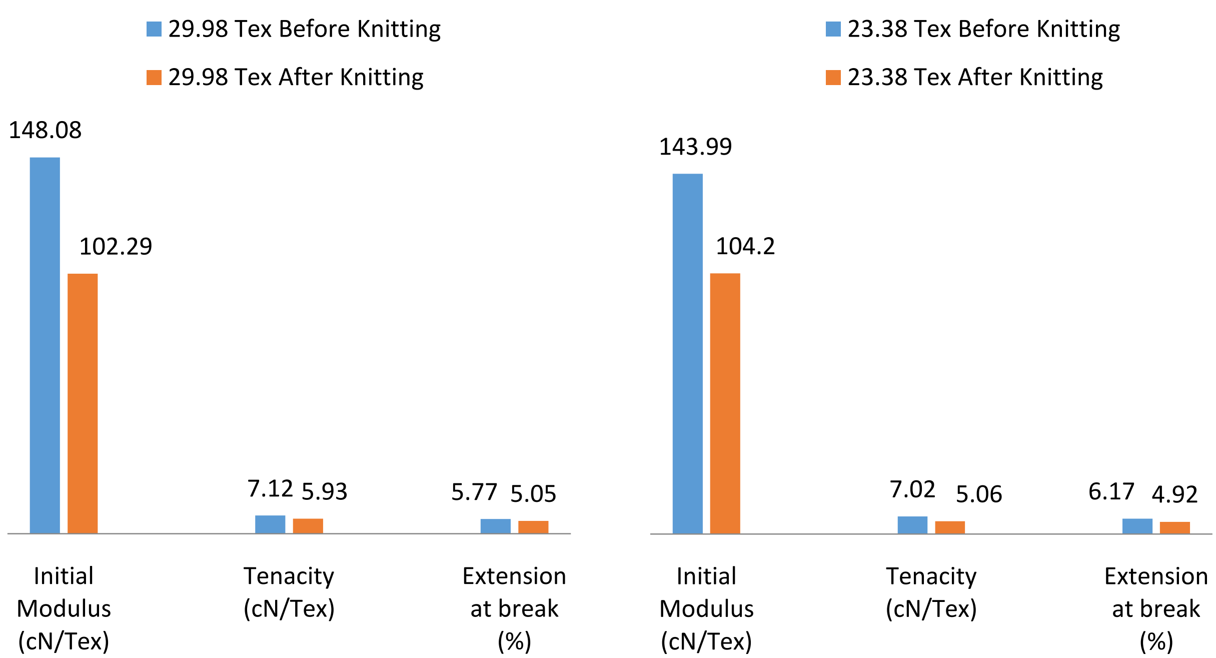


Figure **4.16**: Comparison between some mechanical properties of cotton yarns, obtained by Titan Universal Strength Tester

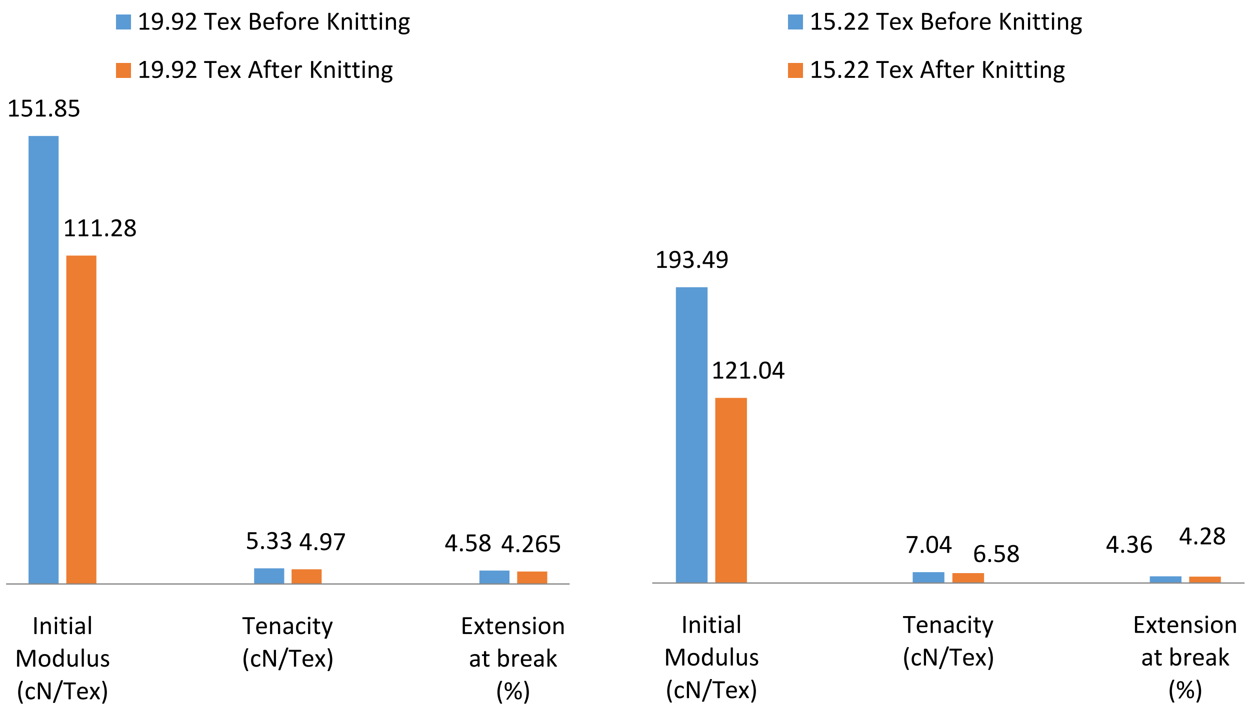


Figure **4.16**: Comparison between some mechanical properties of cotton yarns, obtained by Titan Universal Strength Tester (continued)

Yarn, assuming that any permanent deformation has not occurred may suffer from local microfractures when subjected to variable stress, even if its maximum value does not exceed the yield point (Wlochowicz, Kukla and Drobina,,2016). According to Jurasz‟s 2003 study [as cited in(Wlochowicz, Kukla and Drobina,,2016)], the internal destruction of threads changes the modulus of yarn. Inside the knitting zone yarn experiences variable stress as well as frictional drag by knitting elements like needles and sinkers, which are mainly responsible for significant reduction in yarn modulus. Due to this reason it is not surprising that yarn may have stretched considerably after straightening on the application of preload of 10cN while measuring course length through HATRA instrument resulting positive deviation from that predicted values through the equation. Little and Heapworth (Little and Heapworth, 1977) also expressed similar opinion over such type of extension. Table 4.16 has been generated from Table 4..6, Table 4.7, Table

4.8 and Table 4.13, where a comparison of mean values of actual and predicted course lengths for all the experimental yarns have been summarized.

Table **4.16**: Comparison between actual and model predicted course lengths

Yarn	Average Actual course length obtained through HATRA equipment (m)	Average Model predicted course length(m)	Differences between actual and model predicted course lengths(m)	Difference (%) with respect to model predicted course length	Differences in loop length obtained through the differences between actual and model predicted course lengths (mm)
17.90 Tex Spun Polyester	5.2175	5.1707	0.0468	0.90	0.02
23.62 Tex Spun Polyester	5.203	5.163	0.04	0.77	0.02
29.98 Tex Cotton	5.2035	5.1558	0.0477	0.92	0.02
23.38 Tex Cotton	5.208	5.1695	0.0385	0.74	0.02
19.92 Tex Cotton	5.2025	5.1661	0.0364	0.70	0.02
15.22 Tex Cotton	5.1975	5.1789	0.0186	0.36	0.01

4.6.5 Justification for the effect of machine setting (stitch cam position) over yarn tension and course length

From table 4.4 it is clear that average experimental course length is positively correlated with average yarn input tension. The yarn tension was increased by adjusting the stitch cam to a lower position through increasing stitch cam setting point (Figure 4.18)

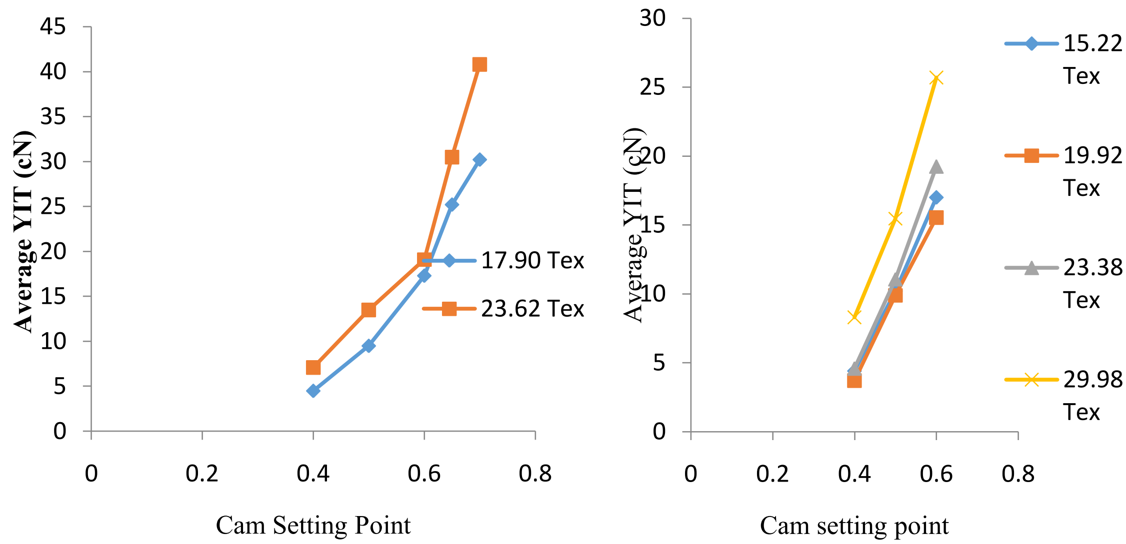


Figure **4.18:** Effect of machine setting on yarn input tension (Left- for Spun Polyester yarn, Right-for Cotton yarn)

Due to such machine setting the needles tend to form large stitches; but as the positive storage feeder is set to deliver yarn into the needles at fixed rate, the yarn tension increases and the yarn become stretched by the needles (Lek-Uthai, 1999). However the actual or relaxed course lengths for different yarn input tension values remain almost same. This can also be verified by different readings of table 4.6 and 4.7, which were randomly selected from spun polyester and cotton knitted fabric samples knitted at different yarn input tension values. Even the model predicted course length values for different yarn input tension showed less variation (e.g. CV is below 1% as found in table 4.8 and table 4.13) justifying the influence of machine setting. Therefore stitch cam position has direct influence on yarn tension and corresponding online yarn length though actual course length remains almost unaffected. The influence on actual course length may also be justified from Figure 4.19 and Figure 4.20, as examples, which have been built with some typical values of course lengths for spun polyester knitted fabric at different cam setting (APPENDIX N)).

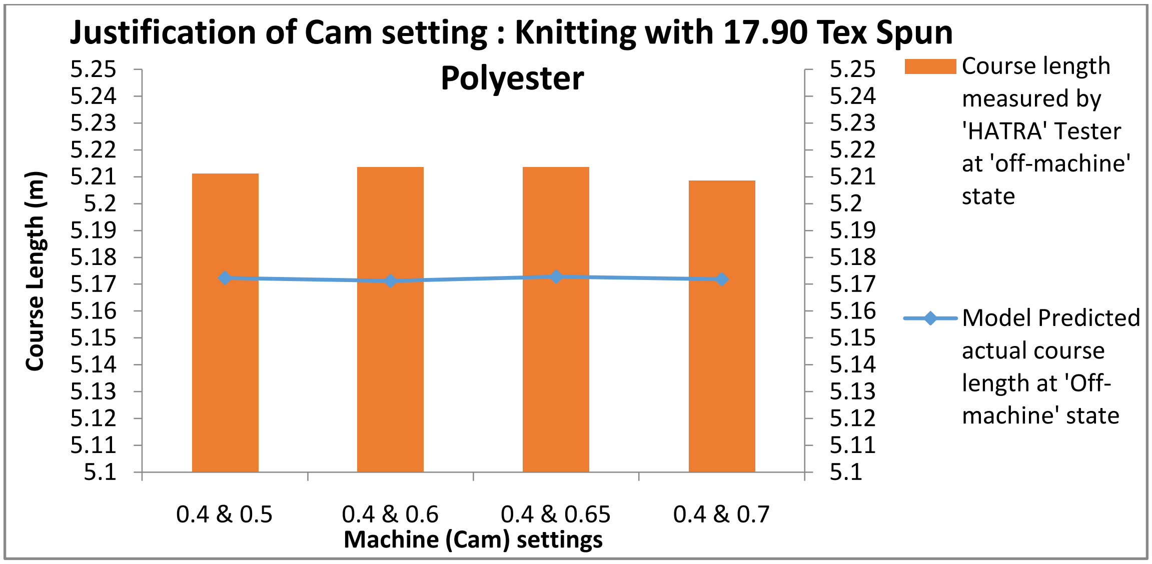


Figure **4.19**: Graphical representation of model predicted and actual course lengths for 17.90 Tex Spun Polyester Plain Jersey Fabric for justifying the effect of cam setting points

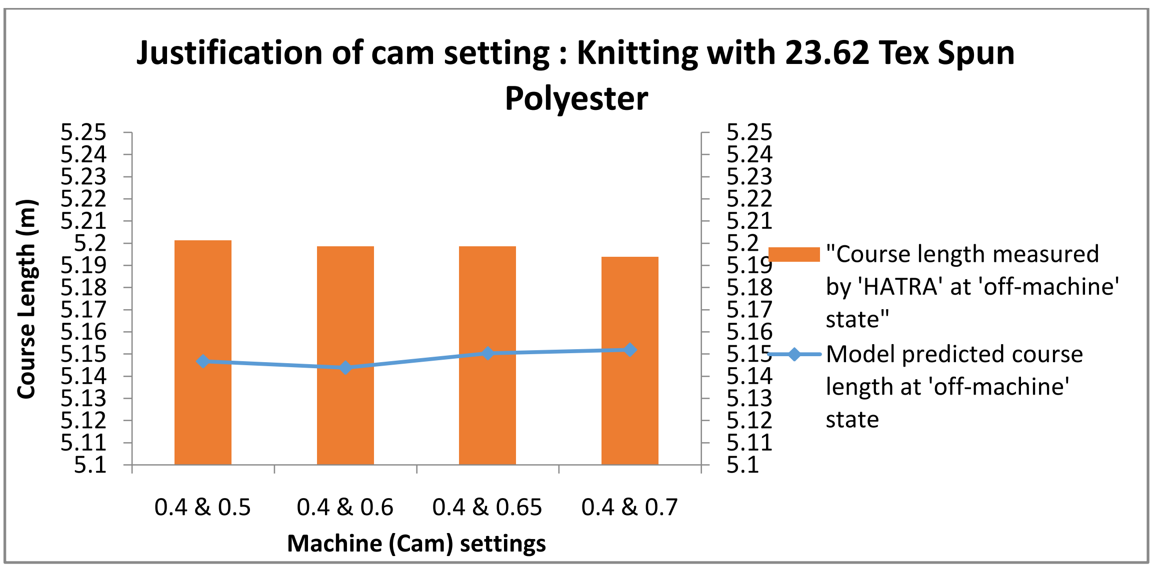
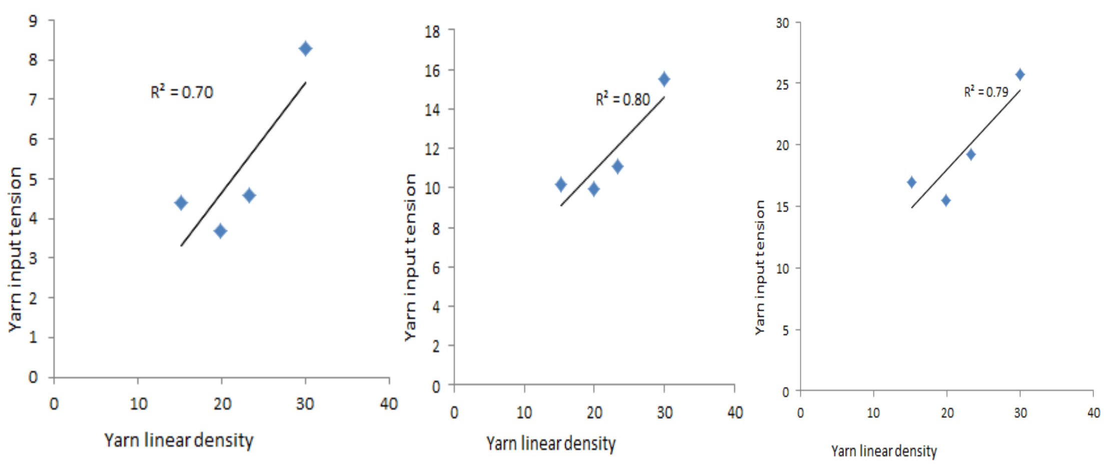


Figure **4.20**: Graphical representation of model predicted and actual course lengths for 23.62 Tex Spun Polyester Plain Jersey Fabric for justifying the effect of cam setting points

Therefore model predicted course lengths seem to be not influenced (just like the measured course lengths from fabric) by cam setting points. However this is not necessarily the case for machine setting,i.e. stitch cam position which results tensile force on yarn beyond elastic limit. Moreover the finding from this part of the research differ from that found by Jovani, Roberto, Edgar A. and Laura (Jovani et al.,2018), where they showed that loop length increases as the level of stitch cam increases. This may be due to the fact that the experimental weft knitting machine used by the researchers was of rectilinear type instead of circular type, which were not equipped with positive storage feeders.

4.6.6 Justification for the Influence of yarn fineness (yarn linear density) over yarn tension and course length

The effect of yarn fineness on observed yarn input tension has been shown on Figure 4.21. Here only cotton yarn has been evaluated for three different cam setting points. It may be found that variation in yarn input tension may not be explained well enough by yarn linear density as the R-square values (Coefficient of determination or Goodness of



Cam setting point 0.4 Cam setting point 0.5 Cam setting point 0.6

Figure **4.21**: Yarn linear density (Tex) versus yarn input tension (cN)

fit measure for linear regression model) don‟t exceed 0.8 (Linear Correlation ,n.d.) in each case .However this may be due to some variations in dynamic co-efficient of friction as observed on experimental cotton yarns of different linear densities [Table 4.17]

Table **4.17**: Measured dynamic co-efficient of friction on experimental cotton yarns of different linear densities

Yarn type	Yarn linear density (Tex)	Dynamic co-efficient of friction
Cotton	29.98	0.14-0.15
	23.38	0.16-0.17
	19.92	0.17-0.18
	15.22	0.17-0.18

According to Lek-uthai (1999), when yarn coefficient of friction increases, YIT decreases. Nevertheless the nature of correlation found here supports the equation developed by Crabbe (1964) for positive feed.

Table 4.12 represents the comparison of two sets of course length observations found through the HATRA course Length Tester for two different linear densities of spun polyester yarn. Similarly Table 4.15 represents the comparisons of two sets of course length observations with each other found through the HATRA course Length Tester for two different linear densities of cotton yarn. Evaluating corresponding t and p-values, it may be found that, in each case, no significant difference was observed between the course length values that were measured by HATRA instrument with the recommended preload of 10 cN. So it can be concluded that yarn linear density shows almost no effect on course length. This can also be justified by comparing the model predicted course lengths through Two-sample t-test. For instance, while comparing two sets of model predicted course lengths found through the HATRA course Length Tester for two different linear densities of spun polyester yarn, i.e., 17.90 Tex and 23.62 Tex, the null hypothesis could not be rejected as the t –value of 0.570163605 with the corresponding p-value of 0.437934935 indicate no significant difference based on the 95% confidence level [Table 4.11]. Graphically this can also be clarified through Figure 4.17 (as shown earlier) and Figure 4.22 which has been generated for cotton knitted fabric loop lengths only.

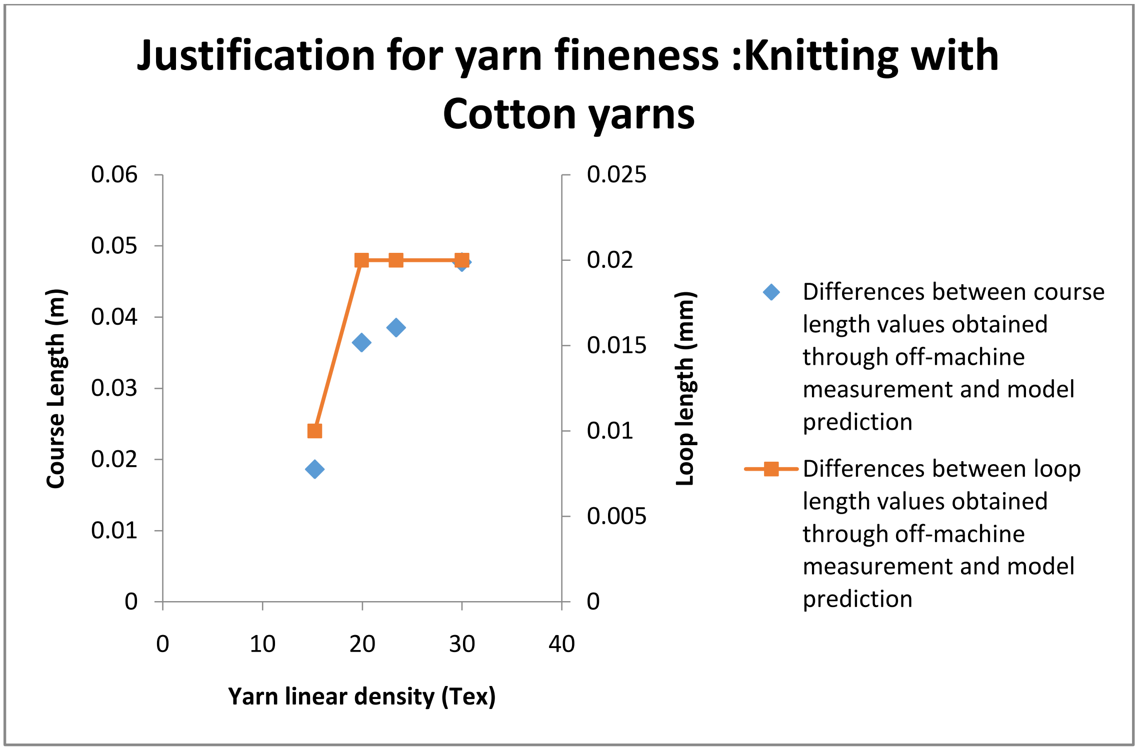


Figure 4.22: Influence of yarn fineness over loop length variation for model predicted and measured course lengths

Therefore mass concentration per unit length or yarn linear density has no mentionable influence on course length. Though this was found for spun polyester and cotton knitted fabric but it is expected to be true for other yarns if the values are maintained within the specified range for same machine setting and off-machine measurements are carried out through HATRA course Length Tester at defined preload.

4.6.7 Justification for the effect of yarn elasticity

The effect of elasticity could not be evaluated properly from the experimental yarns as most of them shows no significant difference in stiffness under load as can be understood from Figure 4.23. that has been generated from Table 4.3.

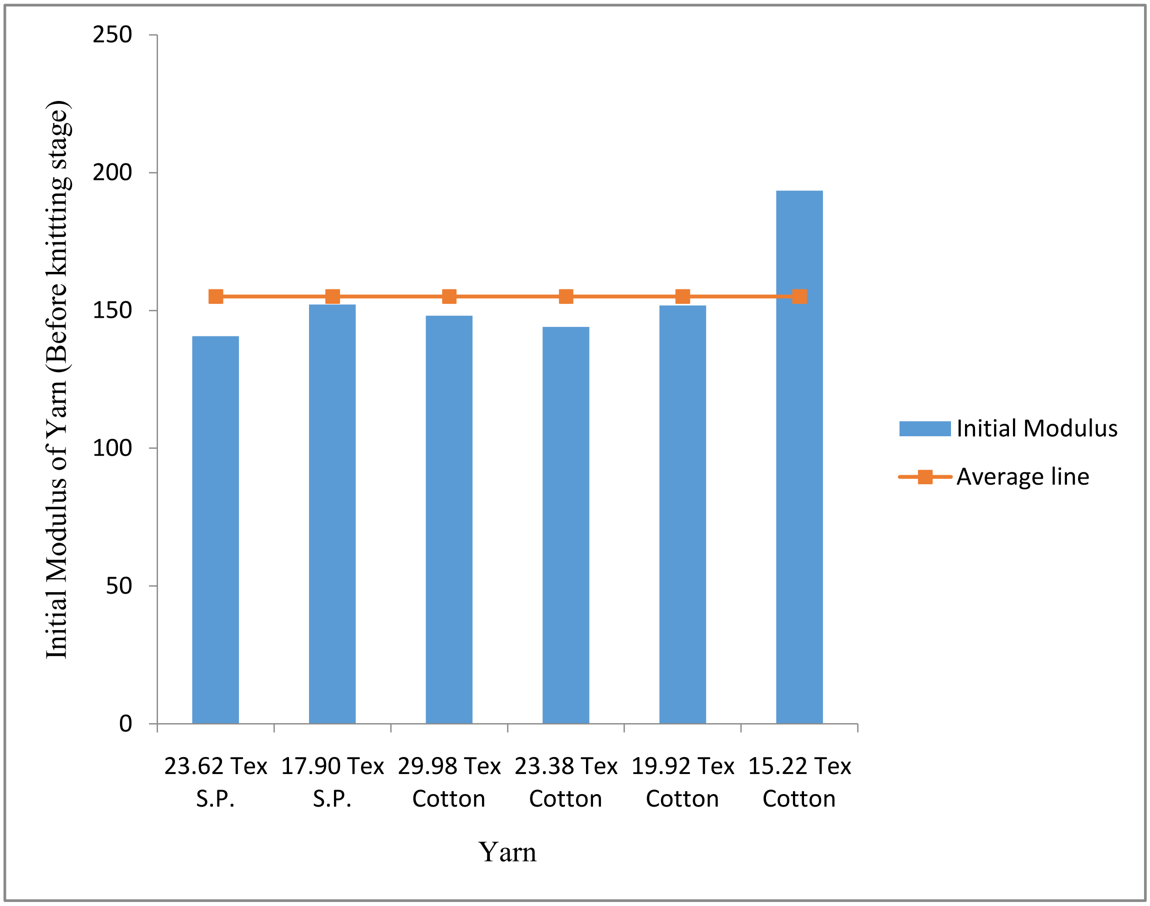


Figure **4.23**: Initial Modulus of experimental yarns at before knitting stage

However when comparing between cotton yarns of different linear densities it may be observed that 15.22 Tex yarn showed somewhat higher Initial Modulus at both before knit and after knit stages and therefore model predicted course length showed comparatively lower deviation from actual course length measured through HATRA course length tester, which can be checked from Table 4.18

Table **4.18**: Differences between measured course lengths (through HATRA equipment) and model predicted course lengths while knitting fabrics with cotton yarns of different linear densities

Yarn Type	**Yarn count (Tex)**	**Initial Modulus (cN/ Tex)**		**Measured course length (m) from fabric**	**Model predicted course length(m)**	**Differences between measured and model predicted course lengths (m)**
		Before knit	After knit			
Cotton	29.98	148.08	102.29	5.2035	5.1558	0.0477
	23.38	143.99	104.2	5.208	5.1695	0.0385
	19.92	151.85	111.28	5.2025	5.1661	0.0364
	15.22	193.49	121.04	5.1975	5.1789	0.0186

The effect of elasticity on yarn tension could not be experimentally analyzed due to lack of sufficient samples having significant variations in modulus.

4.7 Limitation

The model may not be justified with stretch or hyper elastic yarn like spandex where large strain may be observed within the elastic range of yarn. For such cases appropriate stress and strain measures should be taken to identify elastic properties. However the model is expected to be quite applicable with most of commercial knitting yarns like cotton, spun polyester, PC etc. which constitute the major portion of knitted fabrics produced in Bangladesh.

CHAPTER-5

MACHINE SPEED AND CORRESPONDING YARN TENSION

5.1 Research Drive

Yarn tension is believed to be influenced by machine speed but the nature of this correlation is yet to be studied for positive feed based circular knitting machines. The corresponding change in online yarn length needs to be observed if these values are arbitrarily selected to be used in the model developed earlier [in chapter 3].

5.2 Preface

It is very much common for a knitted fabric manufacturer to target higher production without unacceptable faults in the process. Considering the production performance influencing factors (Iyer, Mammel and Schach,1995) a knitted fabric manufacturer may find out several ways to increase the production of a particular circular weft knitting machine, for example, changing yarn count, stitch length or machine speed. As yarn count and stitch length are very much interrelated with fabric dimension and performance (International Institute for Cotton, 1988), machine speed is the ultimate choice for a knitter to control production rate of a specific fabric quality on a particular knitting machine. However, maximum limit of machine speed is fixed by the knitting machine manufacturer for a particular model through circumferential speed (Spencer,2001).On the other hand, a knitter determines the maximum limit of production speed considering mainly rise in yarn tension, which breaks the yarn and creates several process troubles (Koo,2002). Particularly YIT influences the online yarn length that is measured on running yarn and can be used to determine the actual CL or LL in the fabric precisely (Hossain and Ali, 2017).

This work is thus aimed to evaluate the influence of machine speed over yarn input tension and corresponding yarn length per machine revolution for a modern circular weft knitting machine that operates with a „quality" yarn delivery system like positive storage feed device.

5.3 Experimental Procedure

5.3.1 Source of data

The major portion of the experimental work was carried out on a multi-feeder industrial circular knitting machine (Orizio, Johnan) of 24-gauge and 26-inch diameter (Figure 3.10) with a circumferential speed of 1.31 m/sec (Orizio Paolo S.p.A.,n.d.). The Yarn delivery of this machine was „positive storage feed" type where storage/feed wheels, driven by Quality Adjusting Pulley (QAP), were deployed for yarn pulling from the package and supplying to the needles. YIT and „on-machine" course length data were recorded from the zone of yarn path immediately before the feeder ring eye (Figure 1.9 of Chapter 1))

Spun Polyester yarns of four different counts were taken as the raw material whose mechanical properties were tested through TITAN Universal Strength Tester (Figure 3.12) following a standard test method. (ASTM D2256-10). Some of these properties are mentioned in Table 5.1

Table **5.1**: Mechanical Properties of the Experimental Yarns Obtained Through TITAN Universal Strength Tester

Yarn → **Mechanical Property ↓**	**Spun Polyester , (Count=23.62Tex, Twist per cm=8.1)**	**Spun Polyester , (Count=20.36Tex, Twist per cm=8.8)**	**Spun Polyester (Count=17.90Tex, Twist per cm=9.4)**	**Spun Polyester (Count=14.91Tex, Twist per cm=10.1)**
Initial Modulus (cN/Tex)	140.71 (*cv*=5.22%)	138.74 (*cv*=5.82%)	152.15 (*cv*=8.66%)	133.77 (*cv*=5.05%)
Tenacity(cN/Tex)	13.77 (*cv*=4.50%)	13.60 (*cv*=4.04%)	13.69 (*cv*=8.69%)	13.17 (*cv*=4.94%)
Extension at break (%)	12.12 (cv=4.62%)	11.85(*cv*=2.95%)	11.47 (*cv*=4.18%)	11.83 (*cv*=3.89%)
Proportional Limit (cN/Tex)	1.96(*cv*=4.08%)	1.74 (*cv*=7.47%)	1.72 (*cv*=7.56%)	1.88 (*cv*=3.19%)

5.3.2 Knitting

Before taking any experimental reading the machine was run for around 30 minutes to heat it up to normal working condition. Plain Jersey fabric samples were then produced with different count of spun polyester yarn using same yarn delivery setting at positive storage feed device. The disc reading of 131 for QAP indicated feeding unit driving belt speed of 5.38m/sec (Orizio Paolo S.p.A.,n.d.) though the yarn delivery rate might differ somewhat from the belt speed (Dias and Lanarolle,2002). The samples were knitted at five different machine speed (changed through the inverter drive) for two different loop sinking depths (Figure 5.1-5.3) identified by stitch cam positions. The two cam positions, as obtained through adjusting the graduated knob, were selected so that the experimental results may be observed for two different zones of YIT. It may be mentionable here that lower positioning of the stitch cam setting, i.e. lower cam setting point results lower YIT(Lek-Uthai,1999). Average room temperature and relative humidity recorded during the experimental hours were around 29°C and 67% respectively

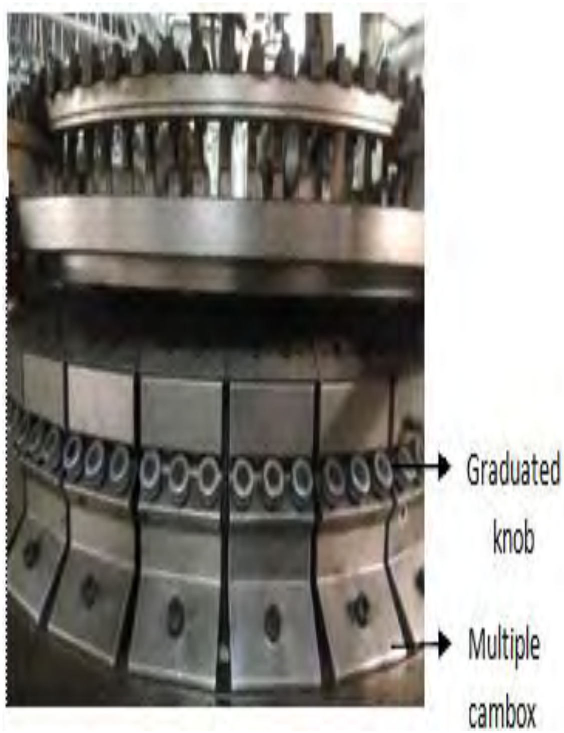


Figure **5.1**: Camboxes around the cylinder

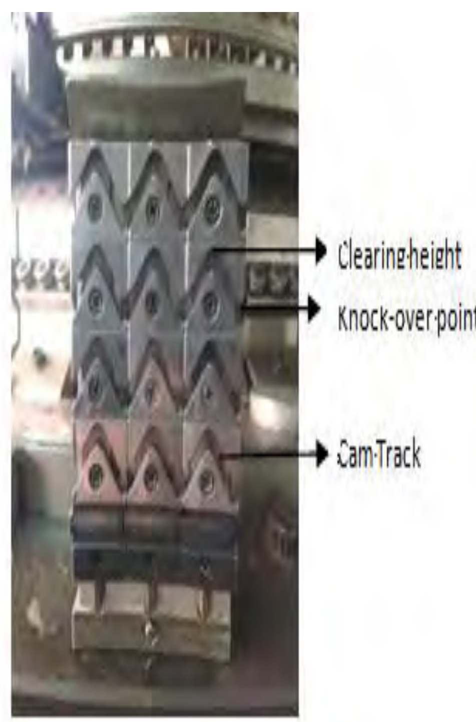


Figure **5.2**: Cam track/race inside camboxes

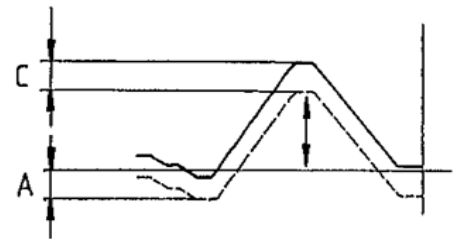


Figure **5.3:** A Schematic diagram of changing loop sinking depth through cam setting: C-Alterable clearing height; A-Alterable knock-over point (Iyer, Mammel and Schach, 1995)

5.3.3 Data collection during dynamic knitting

Machine speed, YIT and corresponding yarn delivery/cylinder rev. (online yarn length/machine revolution) were recorded at a particular feeder by MLT Wesco yarn meter (Figure 4.11 of Chapter 4) for two cam settings as indicated by uppermost scale readings, i.e., 0.6 and 0.7 of graduated knob. Dynamic coefficient of friction values were also obtained by Lawson-Hemphill"s Yarn Friction Meter (Figure 5.4) from running yarn. Collected data has been presented by Table 5.2 and Table 5.3.

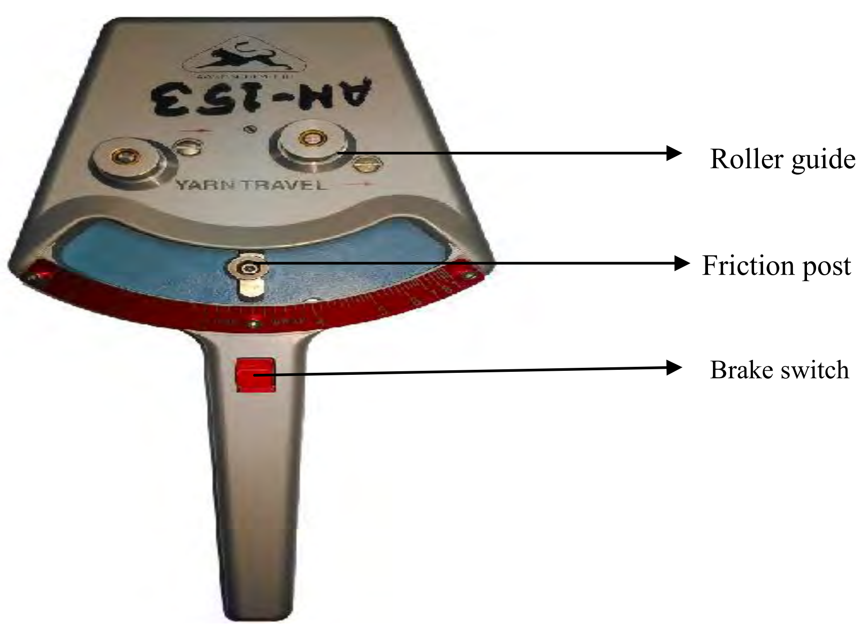


Figure **5.4** : Lawson-Hemphill"s Hand-held Direct-reading yarn friction meter

Table **5.2**: Data on Machine Speed, Yarn Input Tension, Online Yarn Length per Machine Revolution and Dynamic Coefficient of Friction for Cam Setting Point of 0.6

23.62 Tex	**Machine Speed (rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed (m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension (cN)	13.95	14.75	15.98	17.21	18.43
	[Yarn delivery /Cylinder revolution,m]	5.265	5.272	5.279	5.285	5.29
	Dynamic Co-efficient of Friction	0.20-0.21	0.20-0.21	0.21-0.22	0.21-0.22	0.22-0.23
20.36 Tex	**Machine Speed (rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed (m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension (cN)	13.51	14.39	15.19	17.38	18.3
	[Yarn delivery /Cylinder revolution,m]	5.267	5.277	5.281	5.288	5.292
	Dynamic Co-efficient of Friction	0.20-0.21	0.20-0.21	0.21-0.22	0.21-0.22	0.22-0.23
17.90 Tex	**Machine Speed (rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed (m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension (cN)	15.35	17.26	18.45	19.2	20.15
	[Yarn delivery /Cylinder revolution,m]	5.255	5.26	5.264	5.27	5.275
	Dynamic Co-efficient of Friction	0.20-0.21	0.21-0.22	0.21-0.22	0.22-0.23	0.22-0.23
14.91 Tex	**Machine Speed(rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed(m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension (cN)	11.43	13.1	13.61	14.75	15.82
	[Yarn delivery /Cylinder revolution,m]	5.275	5.281	5.288	5.294	5.298
	Dynamic Co-efficient of Friction	0.19-0.20	0.20-0.21	0.20-0.21	0.20-0.21	0.21-0.22

Table **5.3**: Data on Machine Speed, Yarn Input Tension, Online Yarn Length per Machine Revolution and Dynamic Coefficient of Friction for Cam Setting Point of 0.7

23.62 Tex	**Machine Speed(rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed(m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension(cN)	20.01	22	23.98	26.93	28.92
	[Yarn delivery /Cylinder revolution,m]	5.28	5.289	5.299	5.314	5.322
	Dynamic Co-efficient of Friction	0.22-0.23	0.22-0.23	0.23-0.24	0.23-0.24	0.24-0.25
20.36 Tex	**Machine Speed(rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed(m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension(cN)	18.61	20.59	22.34	25.24	28.12
	[Yarn delivery /Cylinder revolution,m]	5.277	5.291	5.3	5.315	5.325
	Dynamic Co-efficient of Friction	0.22-0.23	0.22-0.23	0.22-0.23	0.23-0.24	0.23-0.24
17.90 Tex	**Machine Speed(rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed(m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension(cN)	23.15	24.63	26.59	28.12	30.25
	[Yarn delivery /Cylinder revolution,m]	5.282	5.286	5.295	5.301	5.312
	Dynamic Co-efficient of Friction	0.22-0.23	0.23-0.24	0.23-0.24	0.24-0.25	0.24-0.25
14.91 Tex	**Machine Speed(rpm)**	5.5	10.5	15.9	21.2	26.4
	Machine Speed(m/sec)	0.19	0.363	0.549	0.733	0.912
	Average Yarn Input Tension(cN)	16.33	18.33	20.84	23.65	25.4
	[Yarn delivery /Cylinder revolution,m]	5.29	5.305	5.315	5.324	5.335
	Dynamic Co-efficient of Friction	0.21-0.22	0.21-0.22	0.22-0.23	0.22-0.23	0.23-0.24

5.4 Result and Discussion

5.4.1 Data analysis

To model the relationship between machine speed and yarn tension, linear regression was chosen with least squares approach. Table 5.4 and Table 5.5 show the corresponding results for machine speed (m/sec) and yarn input tension (cN). Table 5.6 and Table 5.7 show the corresponding results for machine speed (m/sec) and online yarn length per machine revolution, i.e. yarn delivery/cylinder rev.

Table **5.4**: Linear Regression Analysis between Machine Speeds (MS) and Yarn Input Tension (YIT) for Cam Setting Point of 0.6

Regression Summary	23.62 Tex	20.36 Tex	17.90 Tex	14.91 Tex
Multiple R	0.997882021	0.984357967	0.980696251	0.988042296
R Square	0.995768528	0.968960606	0.961765137	0.976227578
Standard Error, S_e	0.136003897	0.411172071	0.419403423	0.296698351
Intercept	12.60325671	11.94330137	14.59283693	10.58816836
Slope	6.299132303	6.936109622	6.350861073	5.740501706
t-Statistic for Slope	26.57015632	9.677363943	8.686911059	11.09939867
p-Value for slope	0.000116971	0.002342891	0.00321022	0.001566841
Regression Equation	YIT(cN)= 6.299132303*MS +12.60325671	YIT(cN)= 6.936109622*MS +11.94330137	YIT(cN)= 6.350861073*MS +14.59283693	YIT(cN)= 5.740501706*MS +10.58816836
Predicted approximate change in YIT(cN) for change in machine speed by 5 rpm or 0.173 m/sec	1.09	1.2	1.1	0.99

Table **5. 5**: Linear Regression Analysis between Machine Speed (MS) and Yarn Input Tension (YIT) for Cam Setting Point of 0.7

Regression Summary	**23.62 Tex**	**20.36 Tex**	**17.90 Tex**	**14.91 Tex**
Multiple R	0.997718053	0.993881501	0.998425147	0.998091632
R Square	0.995441313	0.987800438	0.996852773	0.996186906
Standard Error, S_e	0.281193778	0.48037274	0.181504804	0.265131857
Intercept	17.47547743	15.80989706	21.18973519	13.80149775
Slope	12.54554526	13.05078803	9.752939217	12.93866446
t-Statistic for Slope	25.59461304	15.58558522	30.82564167	27.99576047
p-Value for slope	0.000130811	0.000573987	0.0000750052	0.000100047
Regression Equation	YIT(cN)= 12.54554526*MS+ 17.47547743	YIT(cN)= 13.05078803*MS+ 15.80989706	YIT(cN)= 9.752939217*MS+ 21.18973519	YIT(cN)= 12.93866446*MS+ 13.80149775
Predicted approximate change in YIT(cN) for change in machine speed by 5 rpm or 0.173 m/sec	2.17	2.26	1.69	2.24

Table **5.6**: Linear Regression Analysis for Machine Speed (MS) and Online Yarn Length per Machine revolution for Cam Setting Point of 0.6

Regression Summary	**23.62 Tex**	**20.36 Tex**	**17.90 Tex**	**14.91 Tex**
Multiple R	0.997412294	0.985610144	0.998384754	0.996267397
R Square	0.994831284	0.971427355	0.996772118	0.992548727
Standard Error	0.000828912	0.00190742	0.000519472	0.000933436
Intercept	5.259124488	5.262551512	5.249657917	5.269329791
Slope	0.034720627	0.033579337	0.027561127	0.032526773
t-Statistic for Slope	24.02946022	10.0992837	30.43685272	19.99039175
p-Value for slope	0.000157957	0.002067659	0.0000779088	0.000273595
Regression Equation	YL=0.034720627 *MS+5.259124488	YL=0.033579337 *MS+5.262551512	YL=0.027561127 *MS+5.249657917	YL=0.032526773 *MS+5.269329791
Predicted approximate change in CL(m) for change in machine speed by 5 rpm or 0.173 m/sec	0.006 m	0.006m	0.005m	0.006m

Table **5.7**: Linear Regression Analysis for Machine Speed (MS) and online yarn length per machine revolution (m) for Cam Setting Point of 0.7

Regression Summary	**23.62 Tex**	**20.36 Tex**	**17.90 Tex**	**14.91 Tex**
Multiple R	0.996159049	0.997208016	0.989950938	0.994497643
R Square	0.992332851	0.994423828	0.98000286	0.989025562
Standard Error	0.001750369	0.001640105	0.00195741	0.002094131
Intercept	5.267768677	5.265269284	5.272470181	5.280823767
Slope	0.06012254	0.066127987	0.041372076	0.060022267
t-Statistic for Slope	19.70481493	23.1301422	12.12524029	16.44270373
p-Value for slope	0.000285589	0.00017702	0.00120744	0.000489551
Regression Equation	YL=0.06012254 *MS+5.267768677	YL=0.066127987 *MS+5.265269284	YL=0.041372076 *MS+5.272470181	YL=0.060022267 *MS+5.280823767
Predicted approximate change in CL(m) for change in machine speed by 5 rpm or 0.173 m/sec	0.010m	0.011m	0.007m	0.010m

5.4.2 Effect of machine speed on yarn input tension

From Figure 5.5 it may be observed that machine speed has a positive influence on yarn input tension. The regression analyses as shown in Table 5.4 and Table 5.5 reveal that a good correlation exists between machine speed and yarn tension. The value of R^2 was greater than 0.95 in each case indicating that more than 95% of the variation in the tension values can be explained by the explanatory variable, i.e. machine speed. Again

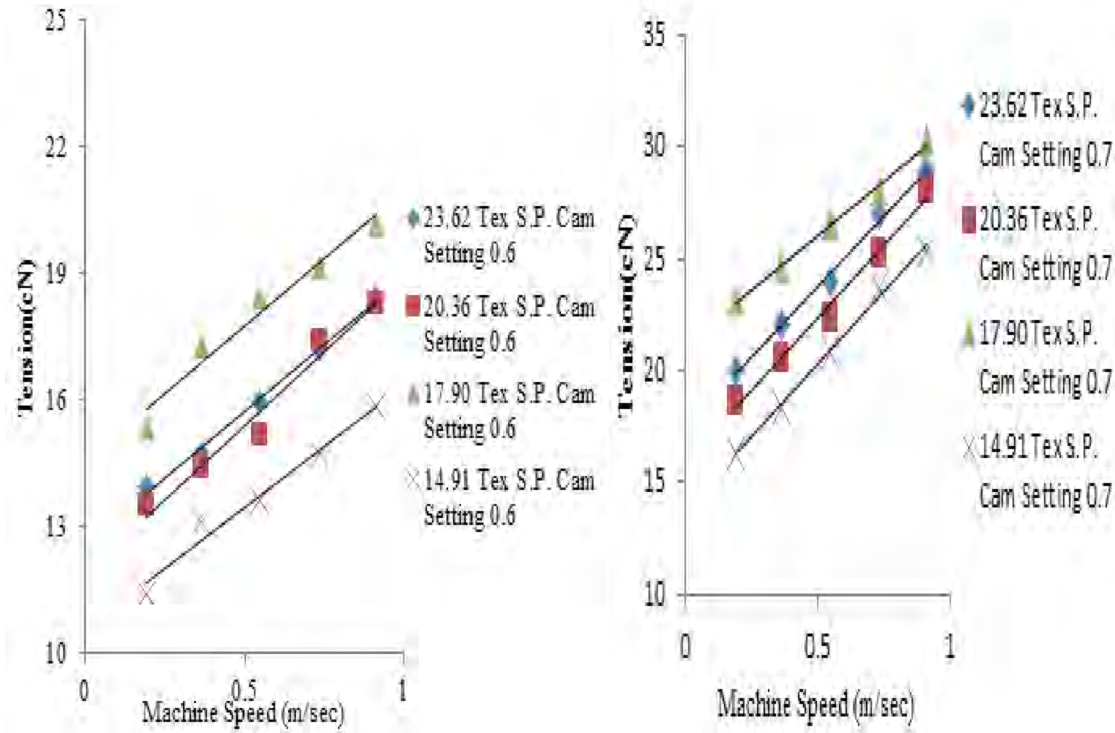


Figure **5.5**: Machine Speed vs. Yarn Input Tension with Least Square Trend Line for Different Spun Polyester (S. P) Yarns at Different Cam Settings; Left- for Cam Setting Point of 0.6 and Right- for Cam Setting Point of 0.7

the obtained p-values for slope parameter were always less than 0.05, revealing that the slope is statistically significantly different than zero based on 95% confidence level and the possibility of no relationship between machine speed and yarn tension can be excluded. Moreover using the regression equation yarn input tension may be predicted from machine speed and the standard error determines the limit of confidence for the forecasted value. As an example it may be estimated that for yarn of 23.62 Tex Spun Polyester a change of machine speed by 0.173 m/sec (05 rev./min for the experimental machine of 26 in. diameter) would result a change of yarn input tension by 1.09 cN for cam setting of 0.6 and 2.17 cN for cam setting of 0.7 (Table 5.4) The actual value of yarn input tension would be within +/-2 S_e of the predicted value based on 95% confidence. However it should be noted that the prediction is particularly valid for machine speed ranging from 0.19 to 0.912 m/sec.

When speed of a circular knitting machine increases, the belt speed of the positive feed system increases as well, this in turn results in higher yarn delivery from the feed wheel. Simultaneously knitting speed also increases so that the ratio of calculated yarn speed/unit time to the number of needles knitting/unit time remains constant and the purpose of positive feeding is fulfilled. Therefore the average YIT is expected to remain unaffected if the machine speed is changed for circular weft knitting with positive storage feeding. Through this experimental study it was found that YIT is influenced by machine speed. The reason for such contradiction with the theoretical expectation may be attributed to the fact that the temporary increase of the depth of stitch draw is more at higher knitting speed due to the inertia force on the needle after the knitting point (Figure 5.6).

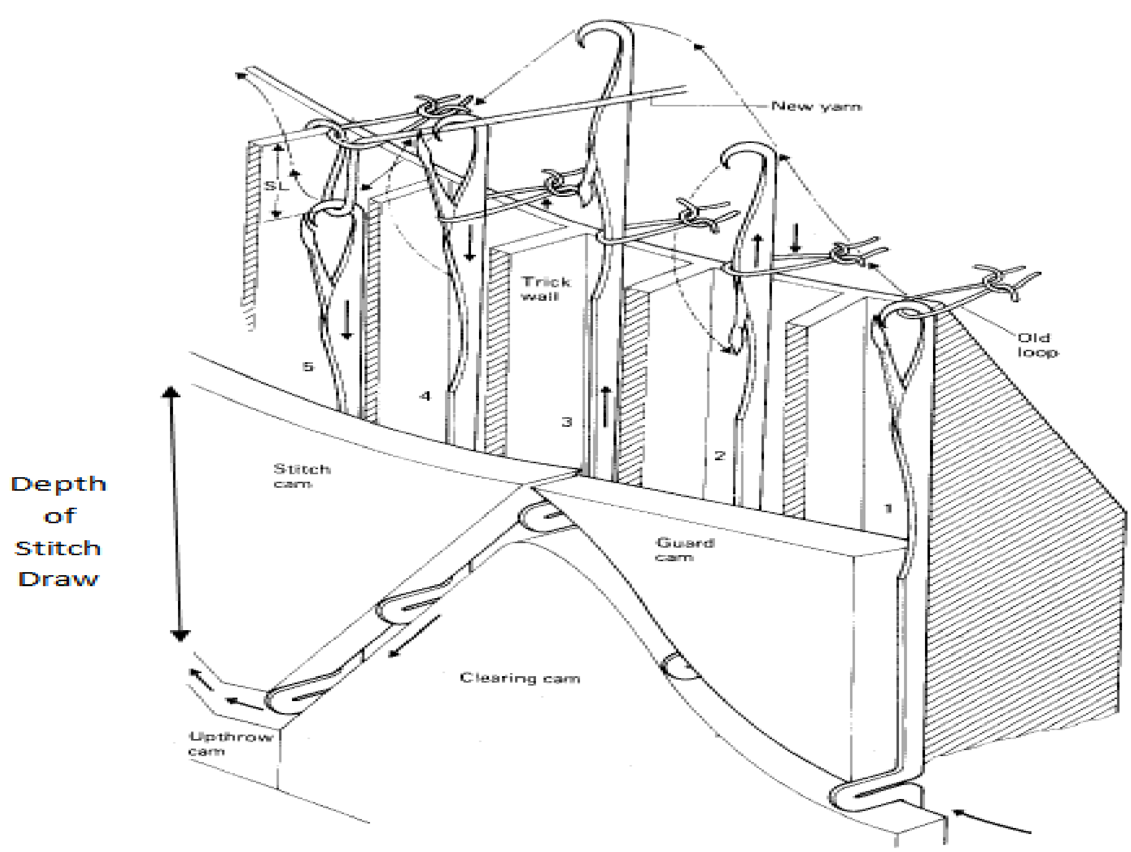


Figure **5.6**: Knitting action of the latch needle (Spencer, 2001)

Oinuma also pointed out this phenomenon when he investigated on end breakage rate due to knots of spun yarns during knitting (Oinuma, 1986). The dynamic coefficient of friction as measured through Lawson-Hemphil yarn friction meter during the experimental study also showed the evidence for rise in yarn tension due to change in machine speed as shown in Figure 5.7.

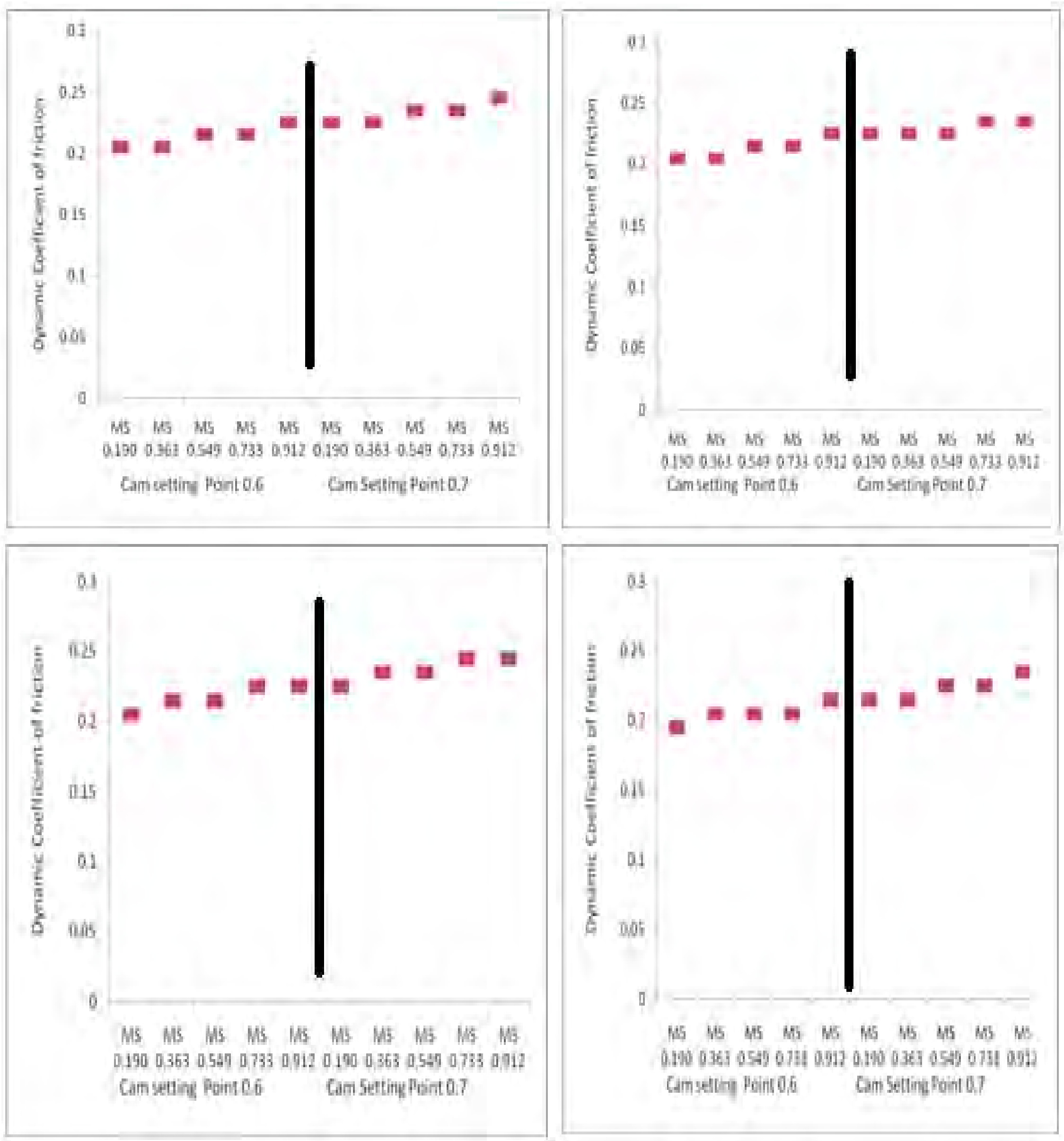


Figure **5.7**: Values of Dynamic Coefficient of Friction at Different Machine Speed (MS) for Different Spun Polyester Yarns; top left- for 23.62 Tex, top right- for 20.36 Tex, bottom left -for17.90 Tex and bottom right- for14.91 Tex

5.4.3 Effect of machine speed on online yarn length

From Figure 5.8 it can be found that online yarn length per cylinder revolution is influenced by machine speed.

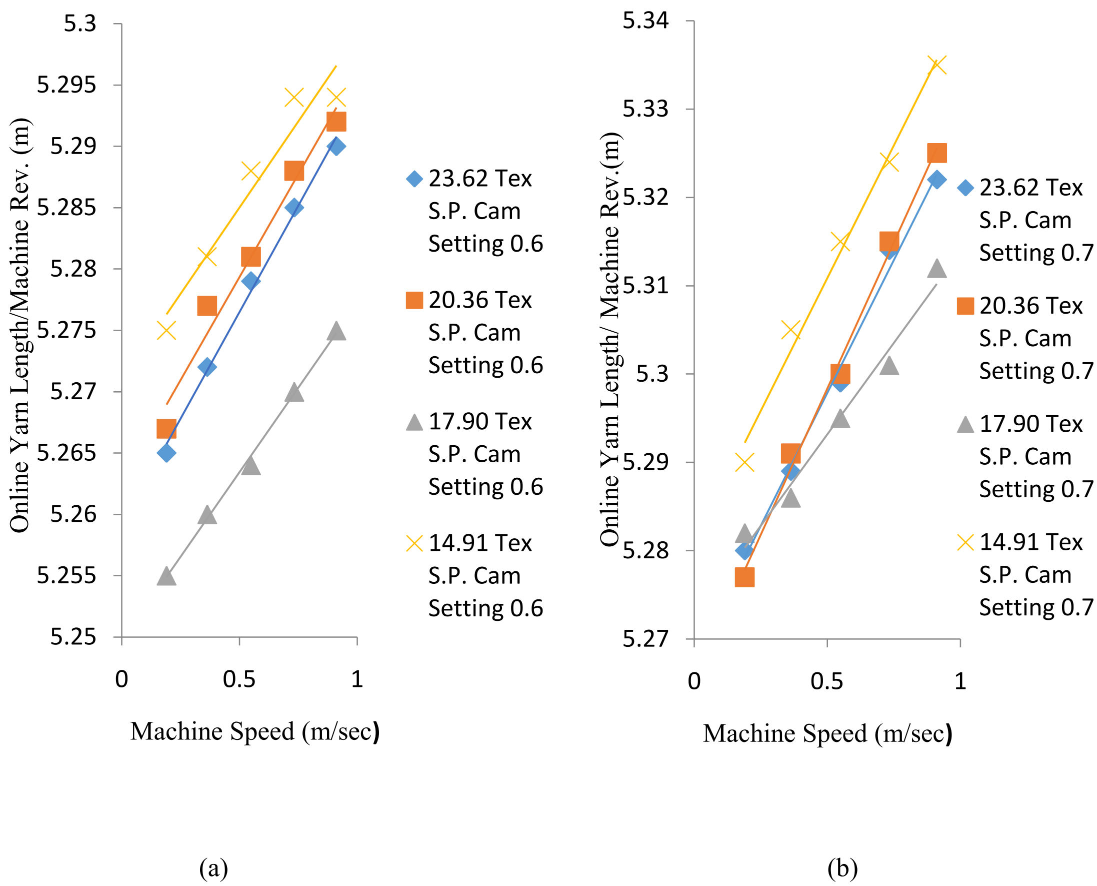


Figure **5.8**: Machine Speed vs. Online Yarn Length /Machine Rev. with Least Square Trend Line for Different Spun Polyester (S.P.) Yarns at Different Cam Settings: (a) for Cam Setting Point of 0.6 and (b) for Cam Setting Point of 0.7

From the regression analysis, as shown in Table 5.6 and Table 5.7, it may be predicted that a change of machine speed by 0.173 m/sec, i.e., 5 rev/min. would results, for example, a change in online yarn length/machine rev. by 0.006 m at cam setting point of 0.6 and 0.10 m at cam setting point of 0.7 for 23.62 Tex .

When yarn input tension increases through cam setting or machine speed at fixed PSF setting, the corresponding yarn delivery as measured by a yarn length and rate meter also increases (Figure 5.9). This is due to the fact that yarn becomes stretched due to tension as yarn delivery from the feed system remains unchanged.(Lek-Uthai,1999)(Dias and Lanarolle,2002)

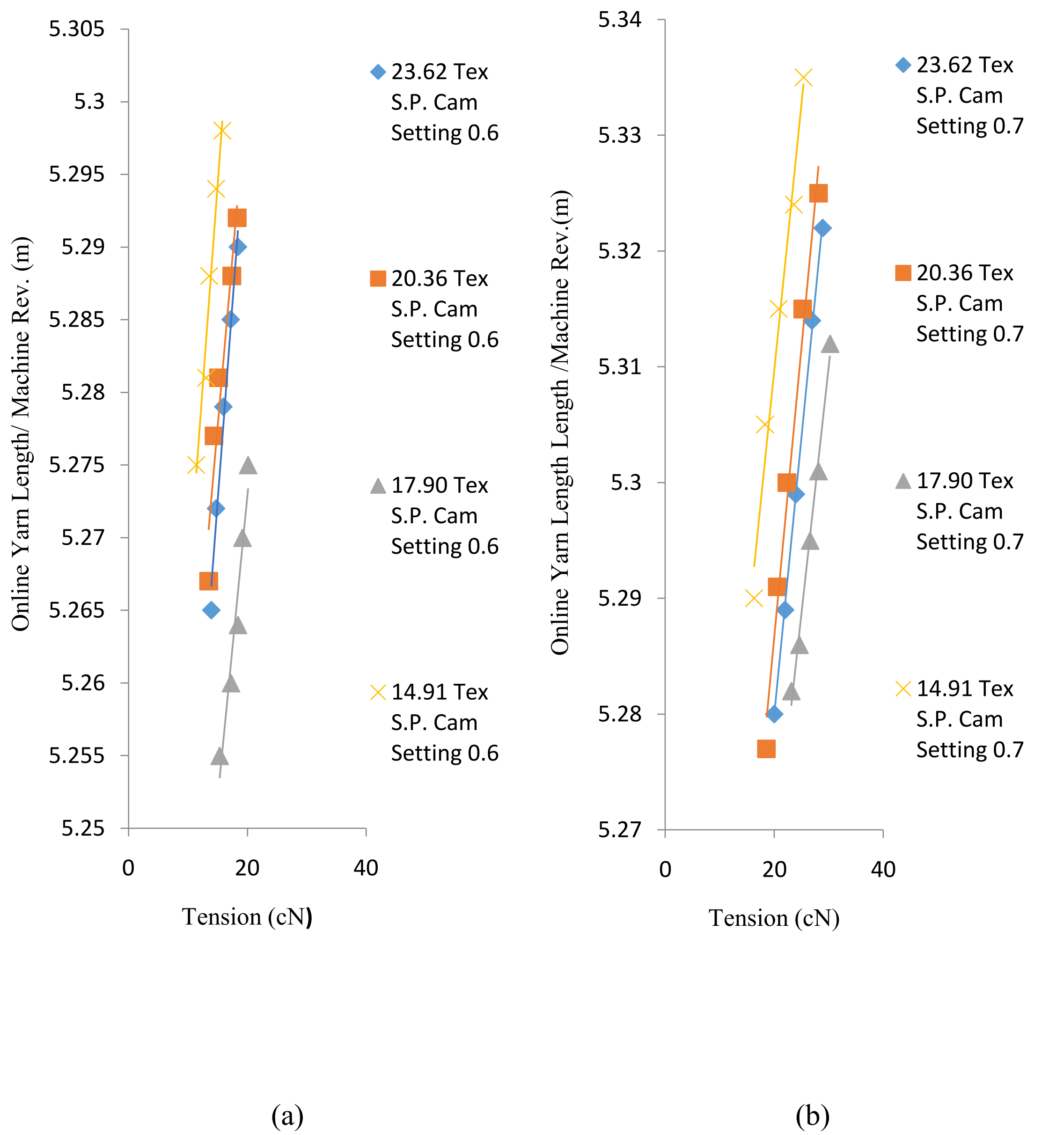


Figure **5.9**: Yarn Input Tension vs. Online Yarn Length /Machine Rev. with Least Square Trend Line for Different Spun Polyester (S. P) Yarns at Different Cam Settings: (a) for Cam Setting Point of 0.6 and (b) for Cam Setting Point of 0.7

To find out numerically how yarn delivery /machine revolution, i.e. on-machine course length could be affected by yarn input tension a summarized table (Table 5.8) from regression analysis has been generated.

Table **5.8**: Selected Regression Data for Yarn Input Tension (YIT) and Online Yarn Length per Machine Revolution (m) as Found Using Cam Setting Point of 0.6 and 0.7

Cam Setting Point	**Spun polyester yarn count (Tex)**	**Some Regression summary output**				**Predicted change in online yarn length/machine Rev. (m) for a unit change in yarn input tension (cN)**
		R Square	Intercept	Slope	Regreesion Equation	
0.6	23.62	0.982883792	5.190375418	0.005467168	YL=0.005467168*YIT+5.190375418	0.0055
	20.36	0.931697644	5.207475446	0.00466704	YL=0.00466704*YIT +5.207475446	0.0047
	17.90	0.949600625	5.189686518	0.004154047	YL=0.004154047*YIT+5.189686518	0.0041
	14.91	0.966691248	5.211275038	0.00552503	YL=0.00552503*YIT +5.211275038	0.0055
0.7	23.62	0.998797343	5.183907809	0.004796955	YL=0.004796955* YIT +5.183907809	0.0048
	20.36	0.985049347	5.18642017	0.005012177	YL=0.005012177*YIT +5.18642017	0.0050
	17.90	0.991833953	5.182083767	0.004260819	YL=0.004260819* YIT +5.182083767	0.0043
	14.91	0.991833953	5.21747972	0.004606422	YL=0.004606422* YIT +5.21747972	0.0046

***YL=Online Yarn Length/Machine Rev., YIT= Yarn Input Tension (cN)**

It can easily be understood that though significant variation in yarn input tension values were observed for change in cam setting point (Table 5.2 and Table 5.3), the rate of change in course length with respect to yarn tension is expected to be almost similar. As found through this experimental work, while knitting with spun polyester yarns, a change in yarn input tension by 1 cN might turn to a change of around 0.005 m or 5 mm in online yarn length per machine revolution (Table 5.8). It should be noted that yarn input tension was within the proportional limit (as mentioned in Table 5.1) in each case during the experimental hours. It may also be pointed out that the comparatively higher modulus of 17.90 Tex spun polyester yarn might be, somewhat, responsible for lesser slope value in its YIT-YL regression equation.

5.5 Summary

In the research work correlation of machine speed with yarn input tension and online yarn length were evaluated independently through regression analysis. Yarn input tension was positively influenced by machine speed and the maximum forecasted change in tension was around 2 cN for change of machine speed by 0.173 m/sec, i.e., 05 rev/min for the experimental circular knitting machine at a fixed positive feed setting. Consequently a maximum change in online yarn length/ machine rev. of around 0.010m or around 2% was also predicted for similar alteration in machine speed. Such variation may be overlooked as the actual course length will remain almost unaffected (can be understood from Section 4.7.2 of Chapter 4) taking into account that the product quality does not fall beyond the acceptable limit (Figure 5.10) and yarn‟s elastic properties are not damaged. Therefore an extensive study for a wide variety of yarn and yarn delivery rate is suggested to depict a more expanded figure over the influence of machine speed on yarn input tension and course length.

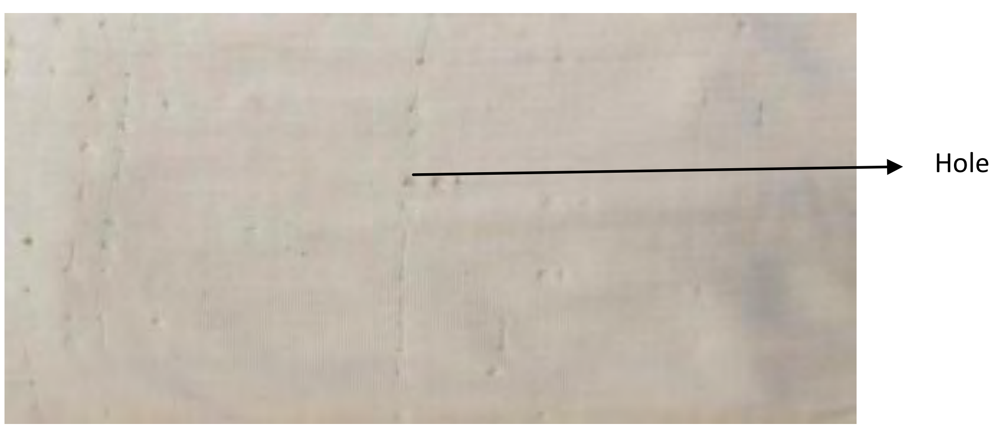


Figure **5.10**: „Hole‟ in knitted fabric due to excessive yarn tension

CHAPTER-6

YARN TENSION ANALYSIS FOR PERFORMANCE EVALUATION

6.1 Research Drive

The aim here is to evaluate the performance of experimental circular knitting machine (used for justification of the developed model as shown in chapter 4 and for verifying the effect of machine speed on yarn tension and online yarn length as shown in chapter 5) for identifying possible machine flaws, if any, that is responsible for unacceptable variation in yarn tension during the knitting process.

As we know, the knowledge of how well a knitting machine is working during production is very important for a knitter. This information allows scheduling all plans and necessary actions required for improved productivity and quality in a manufacturing plant (Catarino et al.,2004). According to Catarino as cited by Catarino, Rocha, Monteiro and Soares (Catarino et al.,2004) yarn input tension in a modern circular weft knitting machine can be used as a valuable resource of information concerning in particular the knitting process, and in more general term, the overall behavior of the knitting machine.

The analysis of yarn input tension reveals that it should be basically a fairly well-shaped sinusoidal waveform, with a frequency equivalent to the time elapsed between each loop formation (Catarino et al.,2005). However, there are all other mechanisms involved in the production of the knitted structure that will induce other harmonics and thus change the shape of the YIT waveform (Catarino et al.,2005). Nevertheless, YIT is considered as one of the most important parameters for weft knitting industry and its inspection allows the detection of several problems during production (Catarino et al.,2004).

When some abnormality occurs in the knitting process it will always be reflected in the YIT (Catarino et al.,2004) which is a reflection of the whole knitting process for a given yarn feeder (De Araujo,Catarino and Hong,1999). Through the YIT waveform it is possible to identify the appearance of a fault, which is represented by a sudden increase/decrease in the force, determine eccentricities of the feeding system, which are represented with sinusoidal waveform, determine abnormalities that can degenerate in fault (Catarino et al.,2004). However, any abnormality resulting from machine performance will produce some kind of periodic behavior as almost all moving parts depend on one main engine and their movement is almost always circular (Catarino et al.,2005).Therefore monitoring yarn input tension during operational hours may be an invaluable tool for assessing the performance of a modern knitting machine.

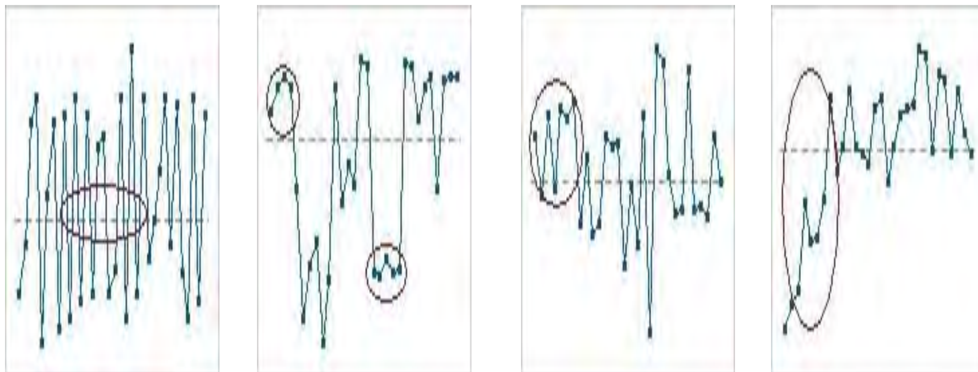
6.2 Statistical Evaluation of YIT

The simple inspection of YIT waveform allows the detection of faults and malfunctions of knitting machines. However, the representation on graphics of the entire YIT from a feeder and inspection of YIT waveform may lead to erroneous judgment in an industrial environment as YIT fluctuates due to yarn irregularity, dust and other situations which do not constitute a fault (Catarino et al.,2004). Instead, it would be very useful to deal with any particular state of YIT (like average or peak) to evaluate the whole process of loop formation thus enabling the detection of abnormalities and possible cause diagnosis. Statistical quality tools, like run charts, may be deployed to fulfill the above purpose.

6.2.1 Run chart

A run chart is a graphical display of data over time or a time series chart of data. It can reveal evidence of special cause variation those creates recognizable patterns. Therefore, it may be used as a quick test of system performance.

When statistical software like Minitab is used to create a run chart, it plots individual observations in the order they were collected and draws a horizontal reference line at the median. Four basic patterns of non-randomness are detected by run chart (Run chart basics, n.d.), i.e. mixture, cluster, oscillating and trend, which are sometimes termed as special cause variations as shown in Figure 6.1.



(i) (ii) (iii) (iv)

Figure **6.1**: Non-random patterns as identified by a run chart-(i) Mixture (ii) Clusters (iii) Oscillation and (iv) Trend (Run chart basics, n.d.)

Moreover, astronomical data points (MEASUREMENT : Interpreting Run Charts ,n.d.) are also detected on a run chart through noticeable shift from the median. Consequently, all the possible causes responsible for non-randomness may be evaluated to judge the performance of the machine.

6.3 Methodology

6.3.1 Monitoring of knitted fabric production through YIT

The test machine is a multifeeder industrial circular knitting machine (Orizio, Johnan) of 24 gauge and 26 inch diameter. To evaluate its performance run charts were built with the help of highest tension values recorded at a particular feeder for a fixed QAP setting, i.e., yarn delivery setting, which occurred at each second for a machine running period of 30 seconds. YIT waveform was obtained through MLT Wesco PC software as can be seen in Figure 6.2. Advanced memory mode with zoom option of this program was used to discover second wise graphical shape of YIT as can be seen in Figure 6.3 - thanks to Memminger-IRO.

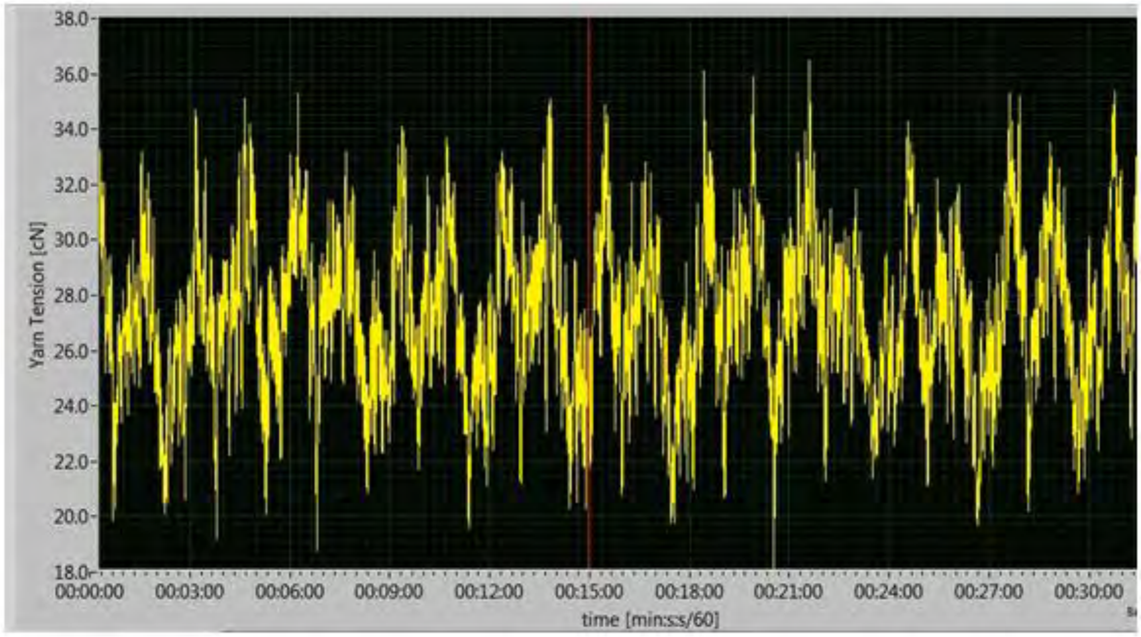


Figure **6.2**: A typical YIT wave form (for 30 seconds)

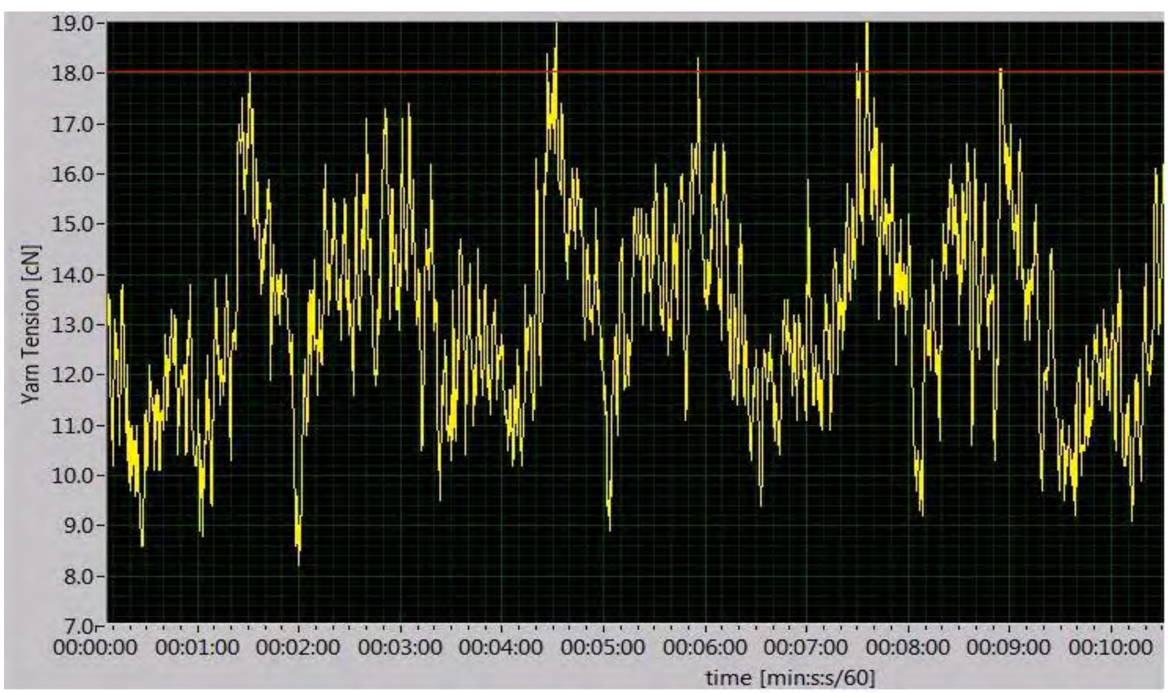


Figure **6.3**: A typical YIT waveform (for 10 seconds)

A total of 16 production runs producing plain jersey fabrics with spun polyester and Cotton yarns were evaluated. Two different counts (as measured experimentally) were used for each type of yarn at four different cam setting points. All other machine settings were kept constant. The machine rpm of 10.5 indicates more than 5 revolutions of the needle bed in the chosen run time. Average temperature and relative humidity recorded during the experimental hours were around 29°C and 67% respectively.

6.4 Data Analysis and Discussion

6.4.1 Interpretation of developed run charts

Tension values for each process were plotted through run charts (APPENDIX O) in the order that they were collected. The run chart built through Minitab (version 17.1.0) also calculates p-values for different special cause variations. These are presented in Table 6.1. The p-value is a probability that measures the evidence against the null hypothesis. The null hypothesis is that there exists no non-randomness pattern in the data. A p-value that is less than the specified level of significance indicates a tendency for non-randomness or special cause variation. Usually a significance level (denoted as α or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that a nonrandom pattern exists when the data are actually randomly distributed. If the p-value is less than or equal to the significance level, the null hypothesis can be rejected and it can be concluded that the data are not randomly distributed (All statistics and graphs for Run Chart, n.d.).

Table **6.1**: Summarized results for different run charts obtained through Minitab software

Run No.	Yarn	Cam setting Point	p-value for clustering	p-value for mixtures	p-value for trends	p-value for oscillation	Special Cause Variation/Non Randomness type (If any)	Presence of astronomical data point (if any)
01	23.62 Tex Spun Polyester	0.7	0.500	0.500	0.974	0.026	Oscillation	--
02	23.62 Tex Spun Polyester	0.6	0.874	0.126	0.559	0.441	--	--
03	23.62 Tex Spun Polyester	0.5	0.771	0.229	0.228	0.772	--	--
04	23.62 Tex Spun Polyester	0.4	0.771	0.229	0.383	0.617	--	Yes
05	20.36 Tex Spun Polyester	0.7	0.500	0.500	0.559	0.441	--	--
06	20.36 Tex Spun Polyester	0.6	0.655	0.345	0.559	0.441	--	--
07	20.36 Tex Spun Polyester	0.5	0.645	0.355	0.117	0.883	--	--
08	20.36 Tex Spun Polyester	0.4	0.510	0.490	0.383	0.617	--	--
09	19.92 Tex Cotton	0.7	0.931	0.069	0.383	0.617	--	--
10	19.92 Tex Cotton	0.6	0.229	0.771	0.724	0.276	--	--
11	19.92 Tex Cotton	0.5	0.936	0.064	0.383	0.617	--	--
12	19.92 Tex Cotton	0.4	0.645	0.355	0.383	0.617	--	--

Run No.	Yarn	Cam setting Point	p-value for clustering	p-value for mixtures	p-value for trends	p-value for oscillation	Special Cause Variation/Non Randomness type (If any)	Presence of astronomical data point (if any)
13	15.22 Tex Cotton	0.7	0.500	0.500	0.383	0.617	--	--
14	15.22 Tex Cotton	0.6	0.931	0.069	0.383	0.617	--	--
15	15.22 Tex Cotton	0.5	0.510	0.490	0.724	0.276	--	--
16	15.22 Tex Cotton	0.4	0.229	0.771	0.228	0.772	--	--

6.4.2 About production run no. 2-3 & 5-16

Here in every case the p-values for clustering, mixtures, trends and oscillation are all greater than α-value of 0.05. So, presence of special cause variation or non-randomness is absent for these production runs.

6.4.3 About production run no. 1

The p-value for oscillation is less than α-value of 0.05, indicating that the process is not steady. It can be found in Figures 6.4 & 6.5.

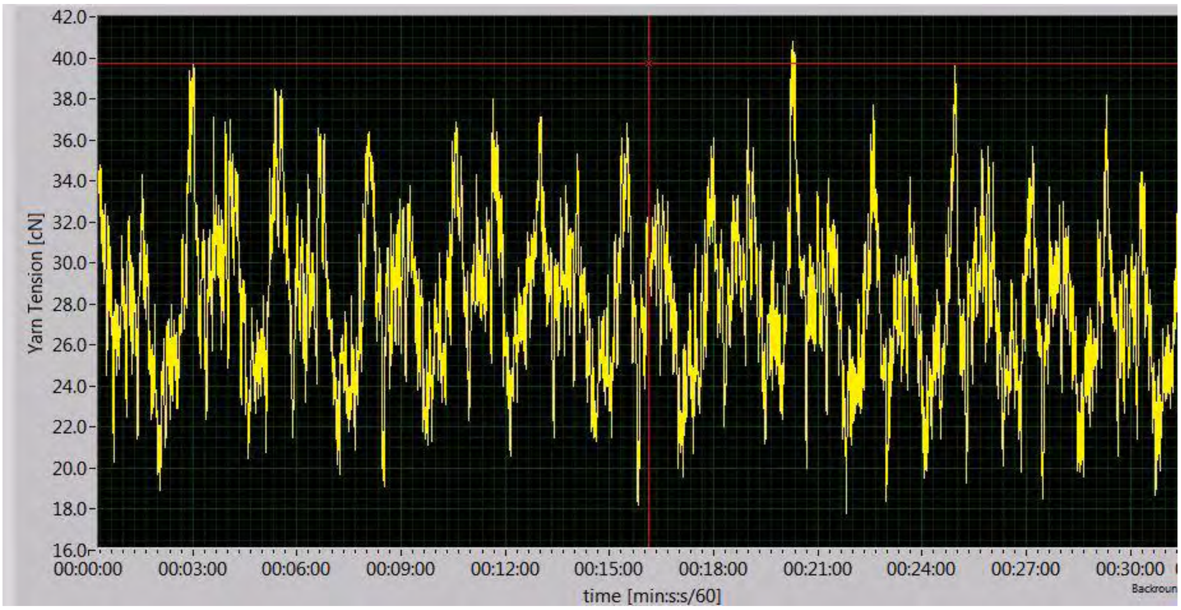


Figure **6.4**: YIT waveform obtained for knitting with 23.62 Tex Spun Polyester at cam setting 0.7 (production run no.01)

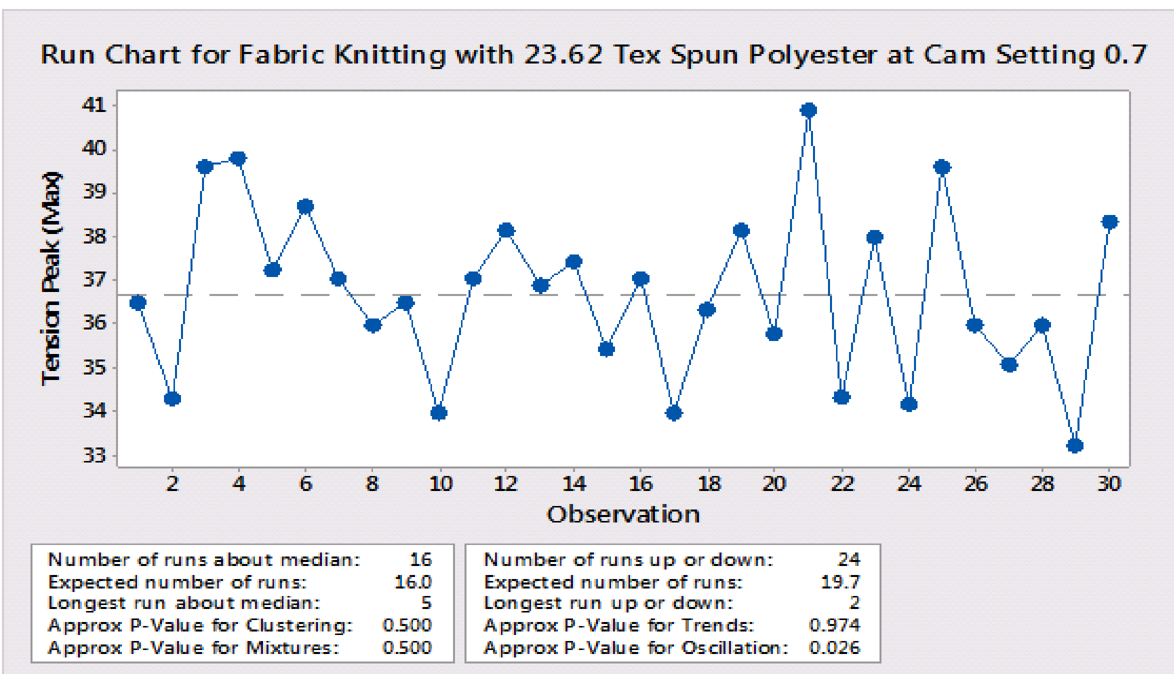


Figure **6.5**: Run chart for production run no.01 (30 seconds)

Fluctuatuion in maximum yarn input tension may be attributed to periodic variation of yarn delivery rate from the feed wheel. The cause-effect diagram (Figure 6.6) for oscillation in yarn tension on a knitting machine may be depicted as:

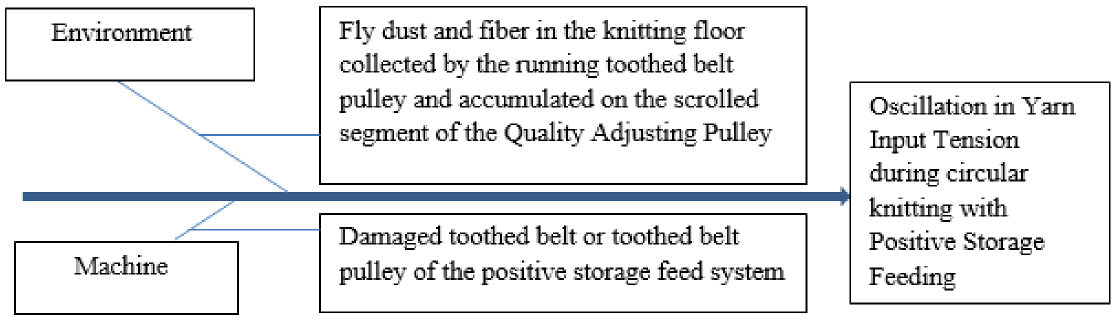


Figure **6.6**: A cause-effect diagram for oscillating yarn input tension in a circular weft knitting machine with positive storage feeding

In this particular case it was found that fluff deposition around the scrolled segments of quality pulley (Figures 6.7 & 6.8) built non-uniform diameter, which in turn introduced some kind of periodic variation in yarn delivery from the feed wheel.

Figure **6.7**: QAP-Top view

Figure **6.8**: Fluff deposition inside QAP

As the machine speed and cam setting remained same, such variation in yarn delivery resulted oscillation in tension peaks.

6.4.4 About Production run no. 4

Here the p-values for clustering, mixtures, trends and oscillation are all greater than α-value of 0.05. So, presence of special cause variation or non-randomness is absent here. However, observation no. 19 may be judged as an astronomical data point. It seems to be fleeting-a one-time occurrence of a special cause (Figures 6.9 and 6.10)

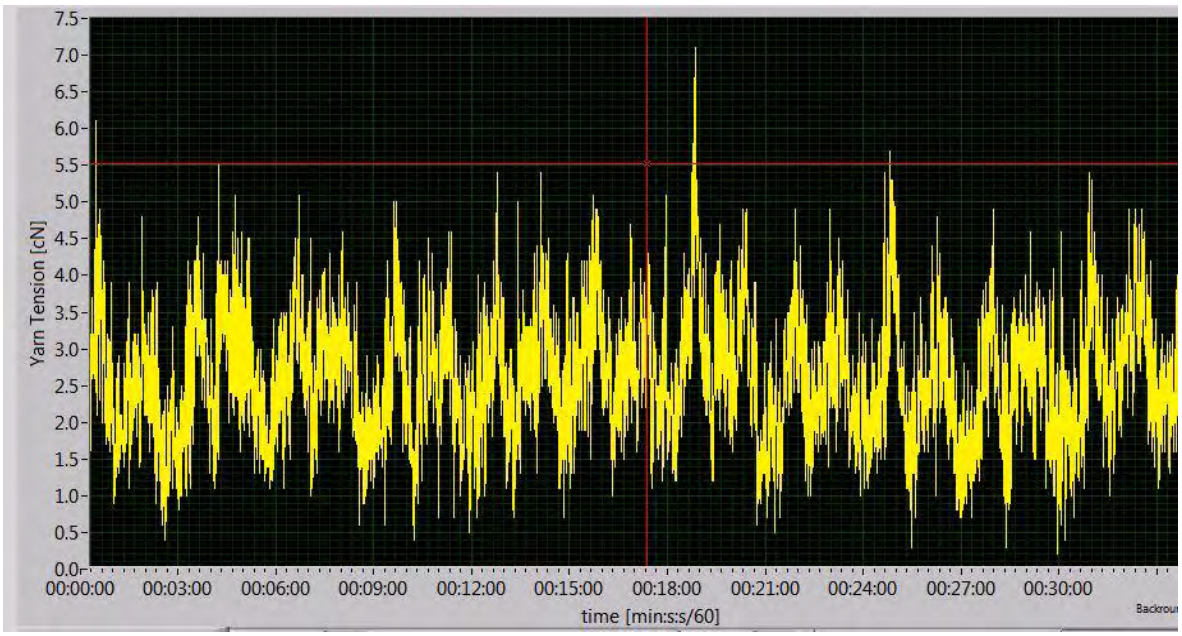


Figure **6.9**: YIT waveform obtained for knitting with 23.62 Tex Spun Polyester at cam setting 0.4

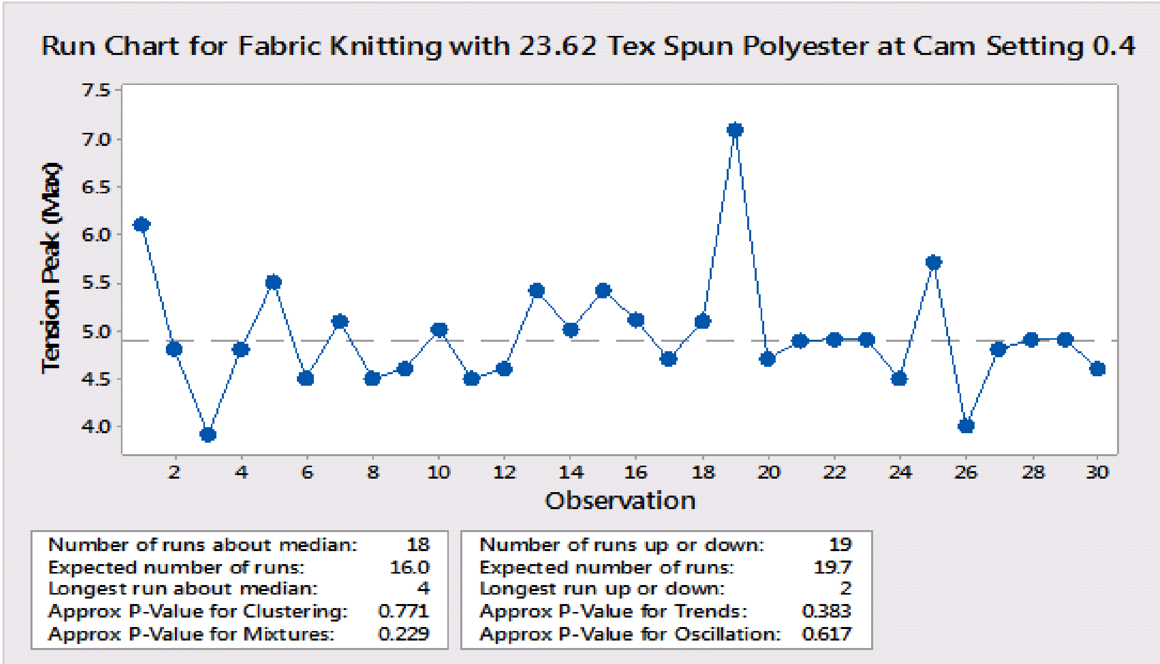


Figure **6.10**: Run chart for production run no.04 (1st 30 seconds)

To find out whether it comes back again or not- another run chart (Figure 6.11), built with tension peak values for next 30 seconds, was examined.

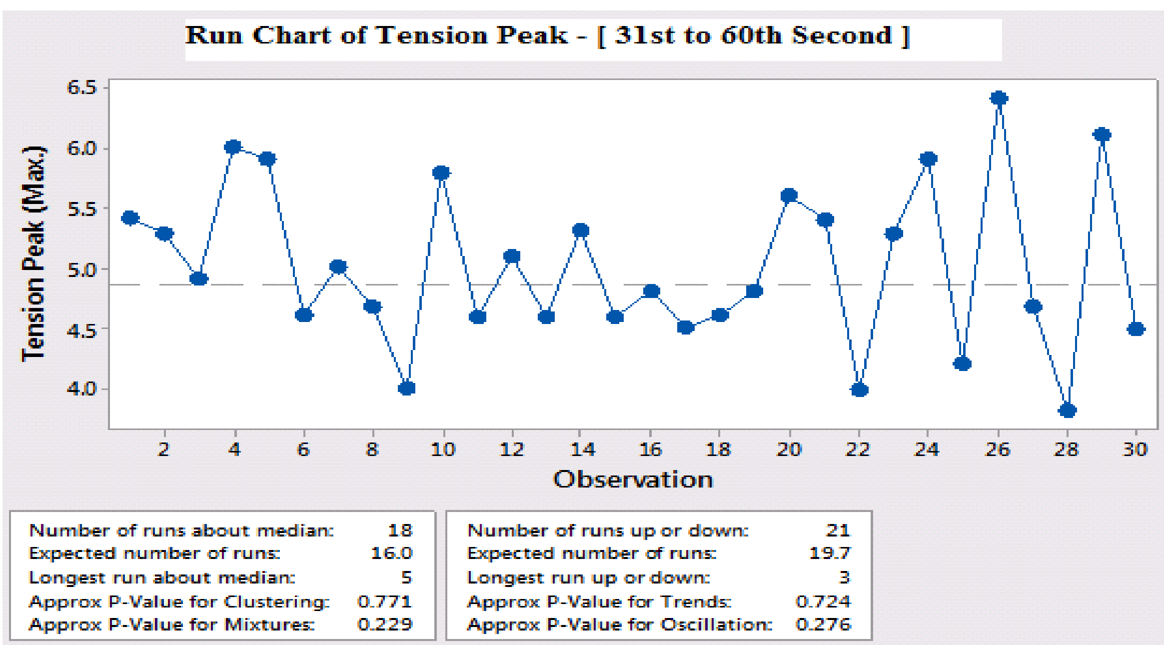


Figure **6.11**: Run chart for production run no. 04 (31st to 60th second)

On the 2nd run chart built for fabric knitting with 23.62 Tex spun polyester at cam setting 0.4, the presence of any astronomical data point is not prominent. So, the sudden large shift of tension peak value at a particular observation on Figure 6.10 was caused by a fleeting special cause-it was there and then it was gone.

6.5 Comments on the Machine Performance

The aim of this research was mainly concentrated on discovering machine related flaws that could hamper its performance, ultimately the process performance. It was found that most of the production runs showed no non-random pattern in the tension values based on an alpha value (significance level) of 0.05, representing absence of special cause variations and thus disclosing quite satisfactory machine performance (Table 6.1).

However the production run with special cause variation was due to environmental rather than machine related cause. Astronomical data point observed in another production run was of fleeting nature rather than periodical. Therefore the said knitting machine was quite flawless during the experimental production hours.

CHAPTER-7

MACHINE MODIFICATION/DEVELOPMENT: YIT ANALYSIS PERSPECTIVE OF PERFORMANCE EVALUATION

7.1 Research Drive

While evaluating the performance of the experimental circular knitting machine, as described in the previous chapter (Chapter 6,) it was observed that, though the overall performance of the machine during experimental hours was almost satisfactory, there is still scope for improvement. The oscillating pattern was observed in the YIT waveform of a particular production run, which was later discovered as the effect of dusty or poor environmental condition. However such environment is sometimes inevitable in knitting floor (particularly while working with spun yarns) and the machine should have some built-in mechanism to get rid of fly accumulation on critical parts. Therefore the aim here is to find an effective modification/development of a circular knitting machine for the said purpose. An elaborated pinpoint analysis of recognized defects is also needed here as background to justify the necessity for machine modification/development.

7.2 Quality Evaluation System for Produced Knit Fabric

Since customers have become more conscious about quality, demand for high quality knitted fabric has increased significantly. Fabric inspection is a crucial quality control procedure followed prior to garments manufacturing to avoid rejection and unexpected loss of final product. The actual process flow chart of knit fabric inspection may be depicted as (Flow Chart of Knit Fabric Inspection in Apparel Industry ,n.d.) :

Flow Chart of Knit Fabric Inspection in Garments Industry

Fabric receiving

↓

Manual fabric inspection

↓

GSM checking

↓

Shade checking

↓

Confirmation of fabric quality

The procedures involved in different steps of the above flow chart are shown in Table 7.1

Table **7.1**: Tasks involved with knit fabric inspection in a knitting industry

Serial No.	**Process**	**Procedure**
01	Fabric receiving	Fabric inspector receives the total quantity of knit fabrics
02	Manual fabric inspection	Fabric inspector inspects the fabrics manually to find out various types of defects like hole, barre etc. which are visible in the fabric Numerical grading for different defects is done to determine the quality status of each roll
03	Areal density checking	Fabric GSM is checked here using GSM cutter to meet buyer‟s GSM requirement
04	Shade checking	Fabric shade has to be checked(after coloration)here by following approved shade
05	Confirmation of fabric quality	Quality inspector confirms here the actual quality of knitted fabrics to be used for clothing purpose

7.3 Knitted Fabric Defects:

A defect is a fault that would reduce the expected performance of the knitted fabric or, if it appeared in a prominent position in an article made from the fabric, would readily be seen and rejected by a prospective purchaser (ISO 8499: 2003) .The following knitted fabric defects have been sorted from the ASTM standard (ASTM D3990-12).

1. Barre
2. „Tucking‟- Tucking defect/ Birdseye/ Pin Hole
3. Bow
4. Crack mark
5. Drop stitch/Run
6. Float
7. Gout
8. Hole
9. Press-off
10. Loose course
11. Miss-Knit
12. Skew
13. Slub
14. Snag
15. Snarl
16. Split stitch
17. Spot
18. Stain
19. Thick place
20. Thin place
21. Streak or Streakiness

These defects mainly occur during the knitting process. Most of them are visible on grey knitted fabric and some of them become apparent on finished fabric.

7.4 Knitted Fabric GSM-Some Insights

Full form of GSM is grams per square meter (grams/m^2). GSM is a critical quality parameter for fabric that represents its areal density in metric unit. Fabric stiffness, handle, feel, shrinkage and many other properties are influenced by GSM .For example, a lower GSM fabric will result a lighter and thinner fabric. Even „Shade Depth Effect" obtained through dyeing is also influenced by fabric GSM.

The tolerances for a change in GSM (plus or minus) are only 4-5% of the ordered GSM value. For example, against the ordered value of 150 GSM, the manufacturer is required to produce a fabric with a GSM in the range of 144-156 (Ray,2013) otherwise it will be treated as a significant „Flaw" and orders may be cancelled.

A knitter should adjust grey GSM through knitting variables so that a particular finished quality target can be achieved successfully. Through his study, K.M. Faridul Hasan showed that grey GSM increases about 15-20% due to wet treatment (dyeing and finishing) of cotton knitted fabric (Hasan,2015).

7.5 Analysis of Different Faults/Flaws of Knitted Fabric:

Knitted fabric faults/flaws are well defined and have been described quite elaborately on many recognized literatures and standards like ASTM D3990 (ASTM D3990-12),ISO 8499 (ISO 8499: 2003) and MIL-STD-1491(MIL-STD-1491).However to identify the potential root causes and eliminate them permanently, a pinpoint analysis should be carried out. This will also open the door to think about for possible modification on a knitting machine.

7.5.1 Cause-and-effect diagram: A root cause analysis tool

Cause-and-effect diagram is a pictorial diagram showing possible causes for a given effect (also called a C&E diagram, a Fishbone diagram or an Ishikawa diagram). It"s an effective tool to identify all the contributing root causes likely to be causing a problem. A cause-and effect diagram consists of a main „bone" to which main causes of the problem are connected. Each main cause may have several sub-causes that lead to the main cause.

The causes are generally identified in relation to man, machine, material, method and environmental factors.

7.5.2 .Fishbone diagrams for different knitted fabric faults/flaws

The Knitted Fabric defects defined by ASTM standard terminology (ASTM D3990-12) have been evaluated to establish the root causes. Specifically the cause analysis was done for faults that are observed on fabrics knitted through a multifeeder circular knitting machine with positive storage feeding. The causes for each defect have been identified through visual observation, interview with factory personnel and also with the help of technical publications. Even some causes of few defects have been justified by deliberately producing faulty fabrics on the knitting machine and then monitoring it through KNIT SCAN (Figure 7.1) - a latest fabric scanner from the renowned

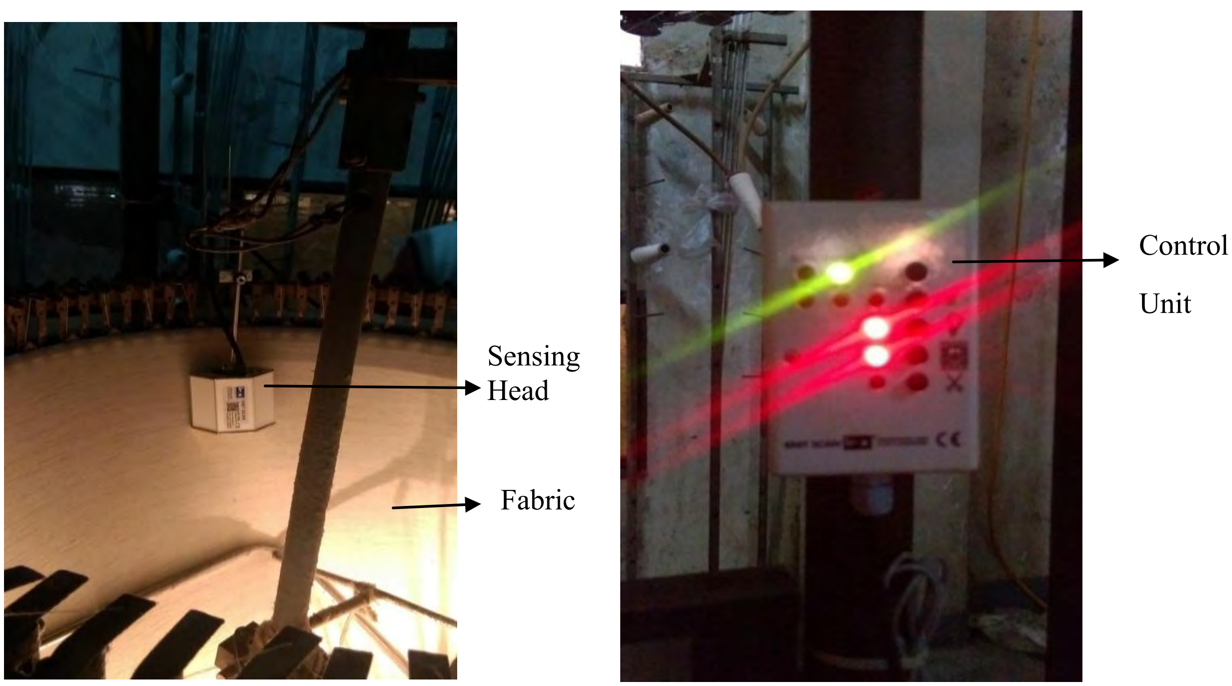


Figure **7.1**: Opto-electronic monitoring of knitted fabric through KNIT SCAN; Left: KNIT SCAN unit in operation, Right: KNIT SCAN control unit indicating fault detection

Memminger-IRO. Besides these the causes of GSM variation have also been investigated. Afterwards cause-and-effect diagram was constructed for each of the defect type using mainly 4M (Man, Machine, Material and Method) bone.

Barre: An unintentional, repetitive visual pattern of continuous bars and stripes usually parallel to the courses of circular knit fabric (ASTM D3990-12) as shown in Figure 7.2.

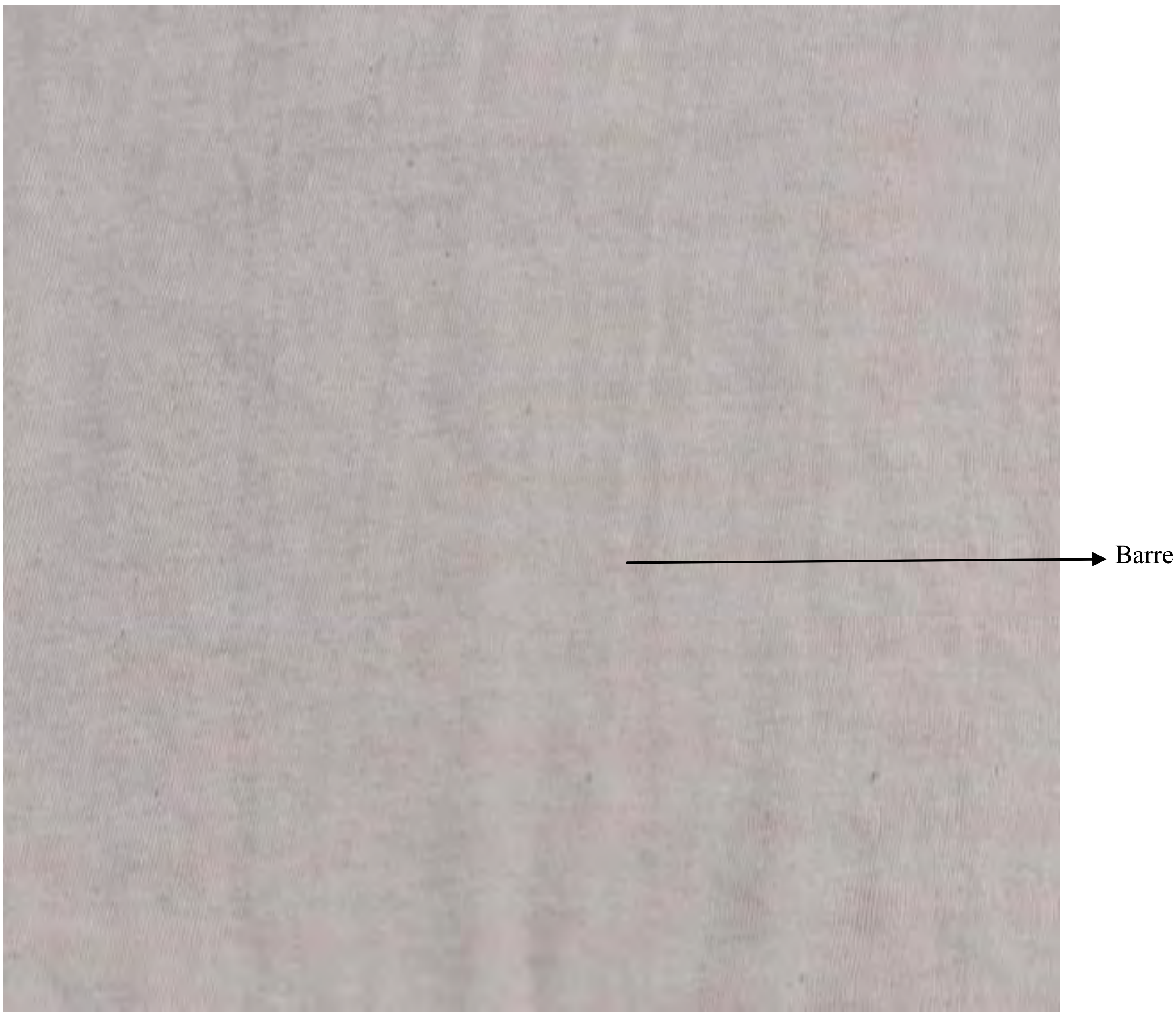


Figure **7.2**: „Barre" in knitted fabric

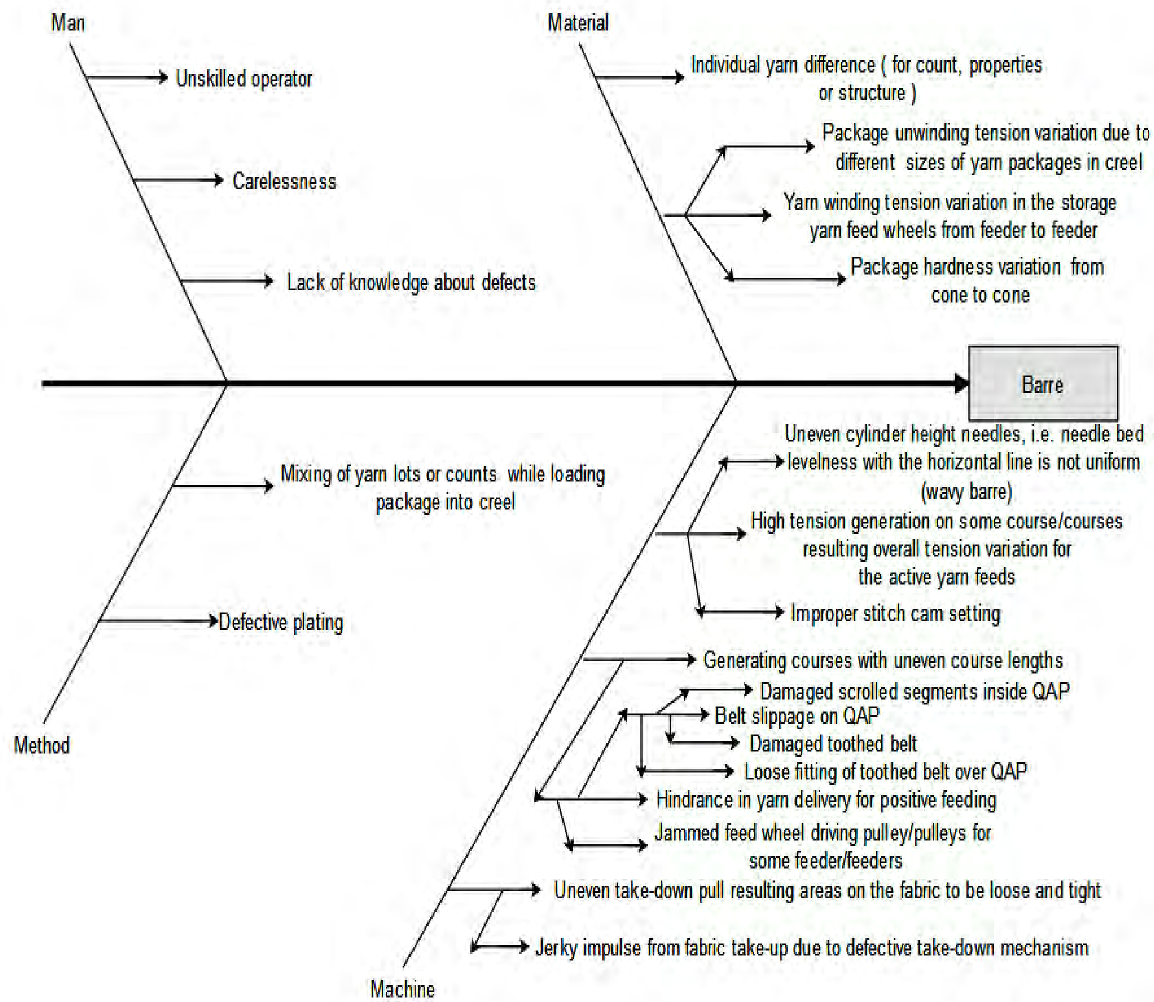


Figure **7.3**:Cause-and-effect diagram for „Barre"

Tucking :

Tucking defect: One or more unwanted tuck loops (ASTM D3990-12)

Birdseye: an unintentional tuck stitch (ASTM D3990-12)**.**Similar to *Tucking defect* (ISO 8499: 2003)

Pin Hole **:**A very small hole, approximately the size of the cross-section of a pin(Figure 7.4). Similar to *Tucking defect* (ISO 8499: 2003)

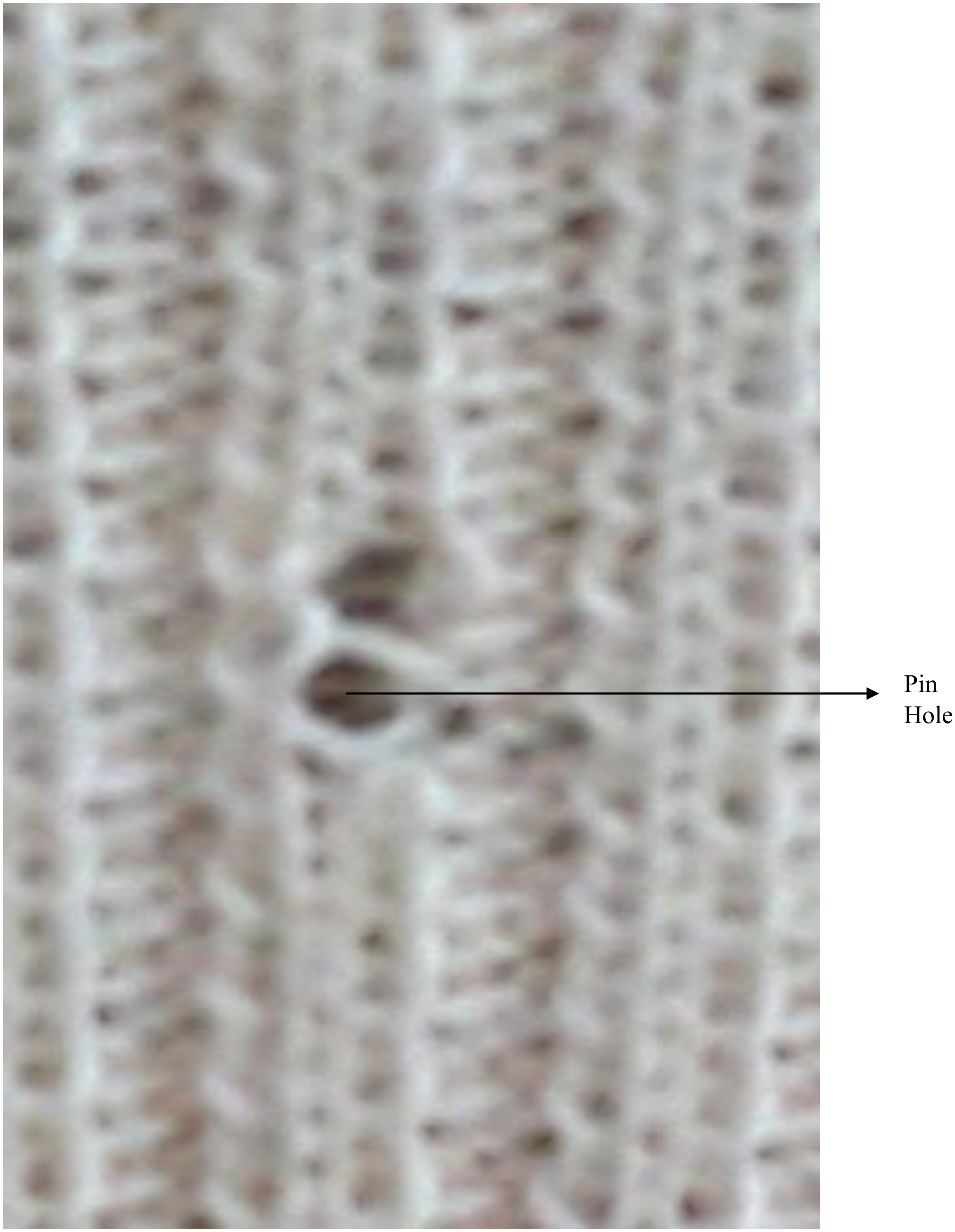


Figure **7.4**: Knitted fabric defects due to tucking: a „Pin hole"

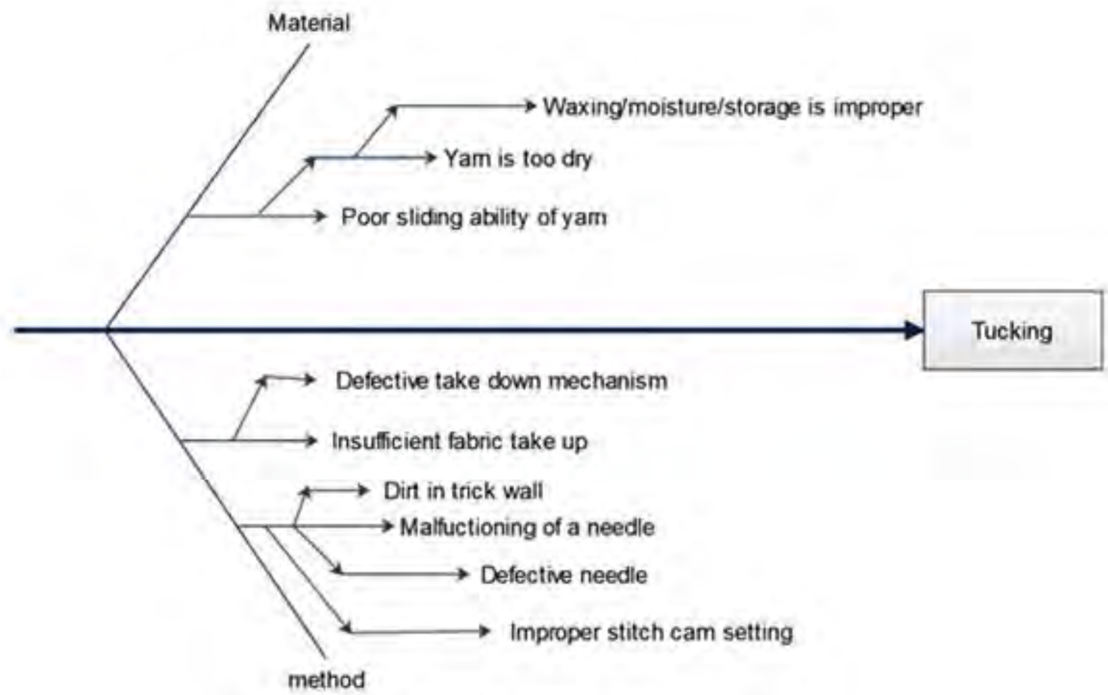


Figure **7.5**: Cause-and-effect diagram for „Tucking"

Bow: Fabric condition resulting when knitting courses are displaced from a line perpendicular to the selvages and form one or more arcs across the width of fabric (ASTM D3990-12).

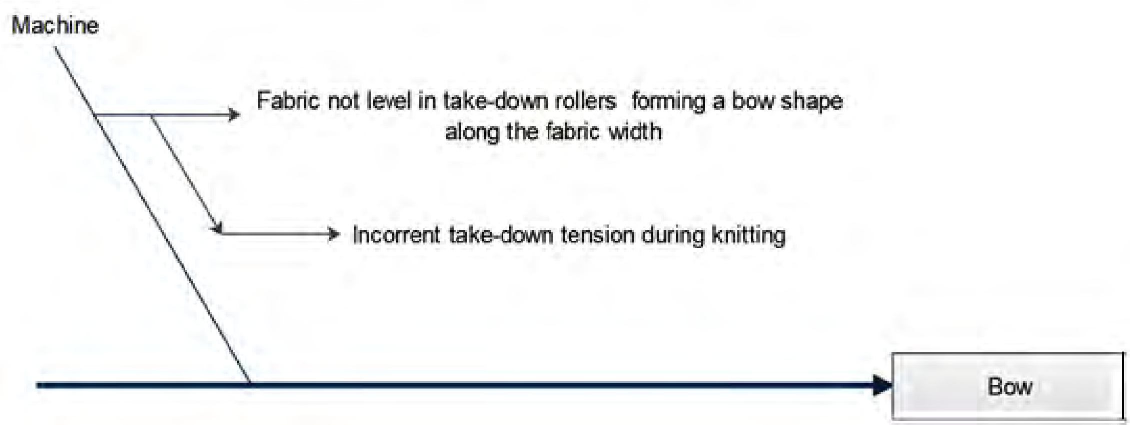


Figure **7.6**: Cause-and-effect diagram for „Bow"

Crack Mark: *An* open place causing a streak of variable length approximately parallel to the length or width (ASTM D3990-12) as shown in Figure 7.7.

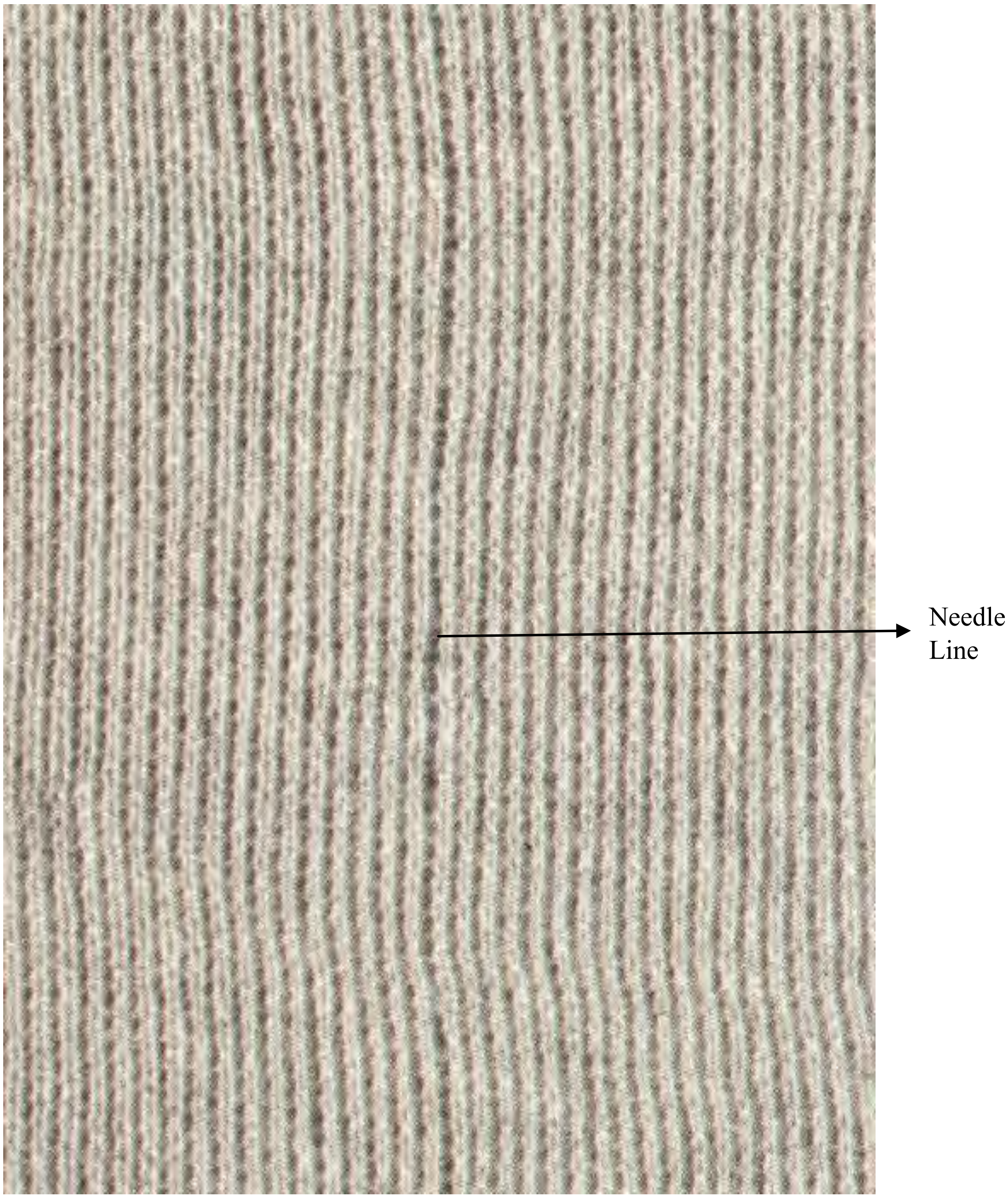


Figure **7.7**: „Needle Line" (a typical „Crack Mark") in knitted fabric

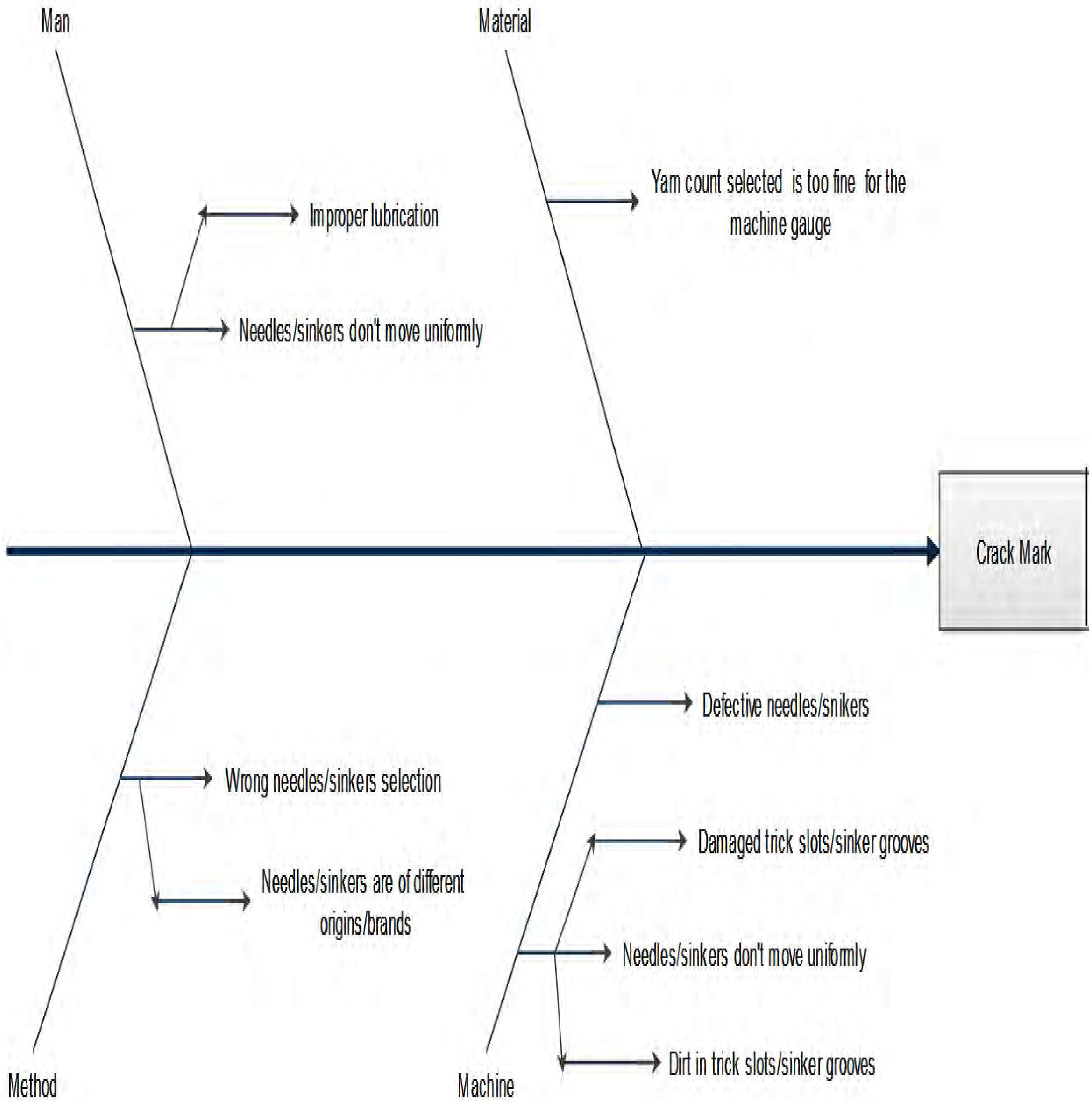


Figure **7.8**: Cause-and-effect diagram for „Crack Mark"

***Drop stitch*:** An unknitted stitch (ASTM D3990-12) as shown in Figure 7.9

Run: A series of dropped stitches (ASTM D3990-12)as shown in Figure 7.10

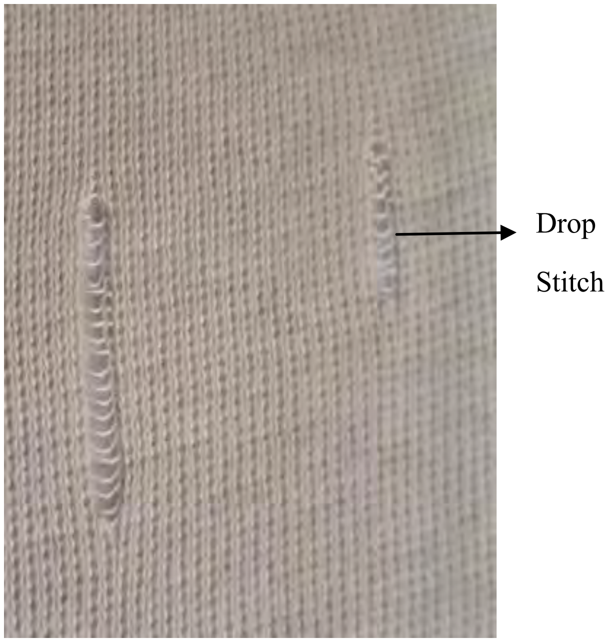


Figure **7.9**: „Drop Stitch" in knitted fabric

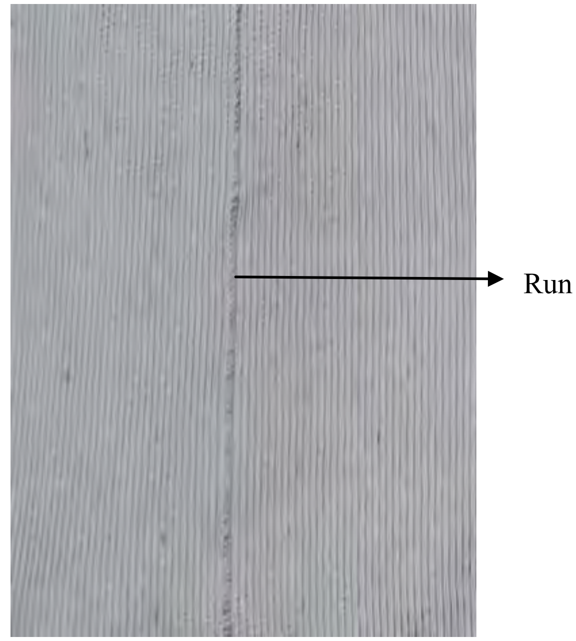


Figure **7.10**: „Run" in knitted fabric

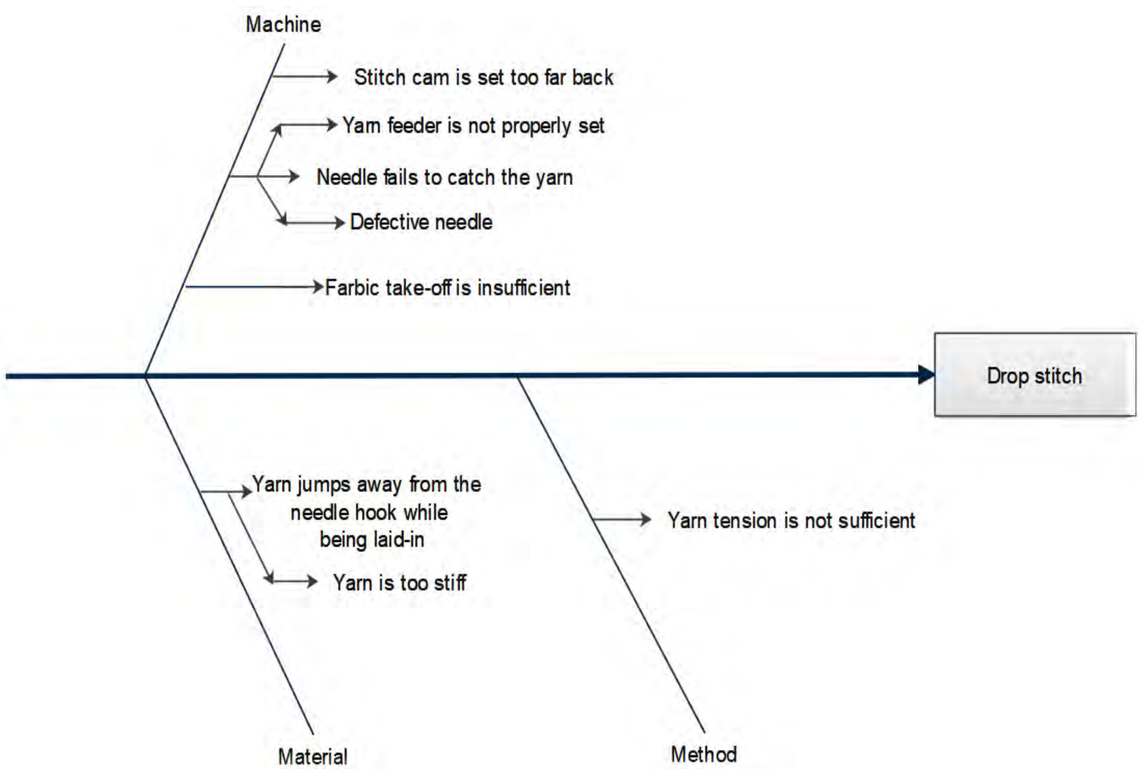


Figure **7.11**: Cause-and-effect diagram for „Drop Stitch"

Float: The portion of a yarn that is not knitted into loops. If intentionally produced floats are constructional characteristics of knit fabric. If unintentionally present, they are considered to be defects (ASTM D3990-12).

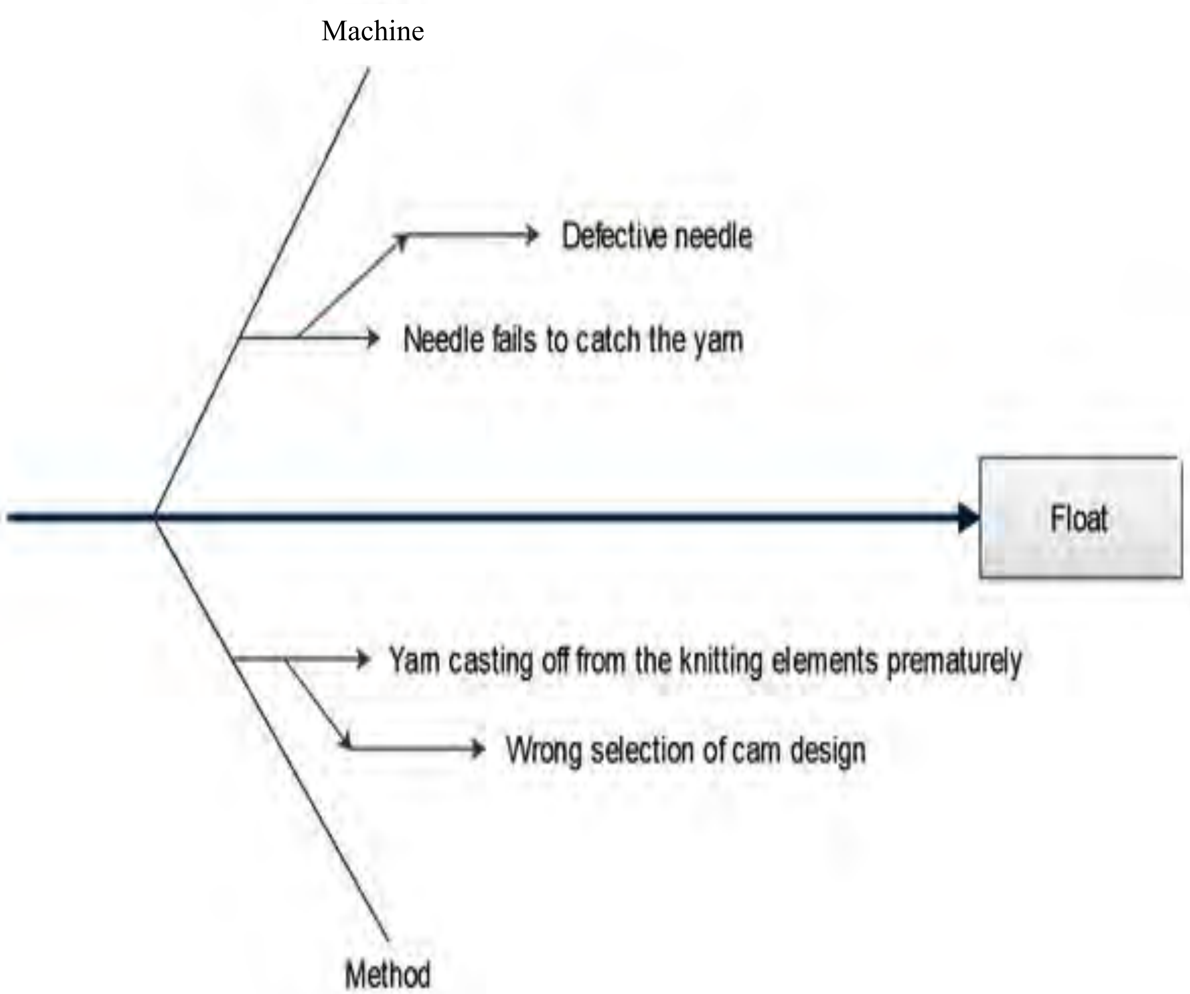


Figure **7.12**: Cause-and-effect diagram for „Float"

Gout: Foreign matter trapped in a fabric by accident, usually lint or waste (ASTM D3990-12) as shown in Figure 7.13.

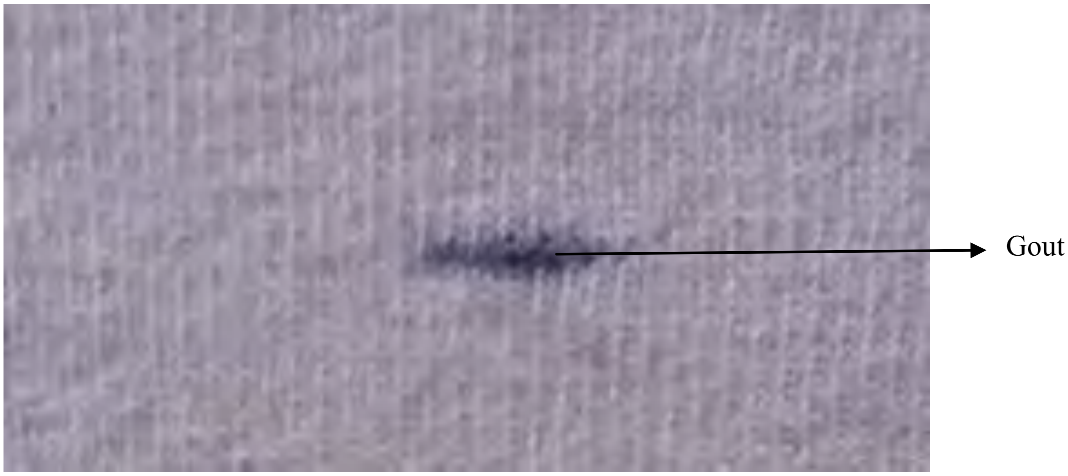


Figure **7.13**:„Gout‟in knitted fabric

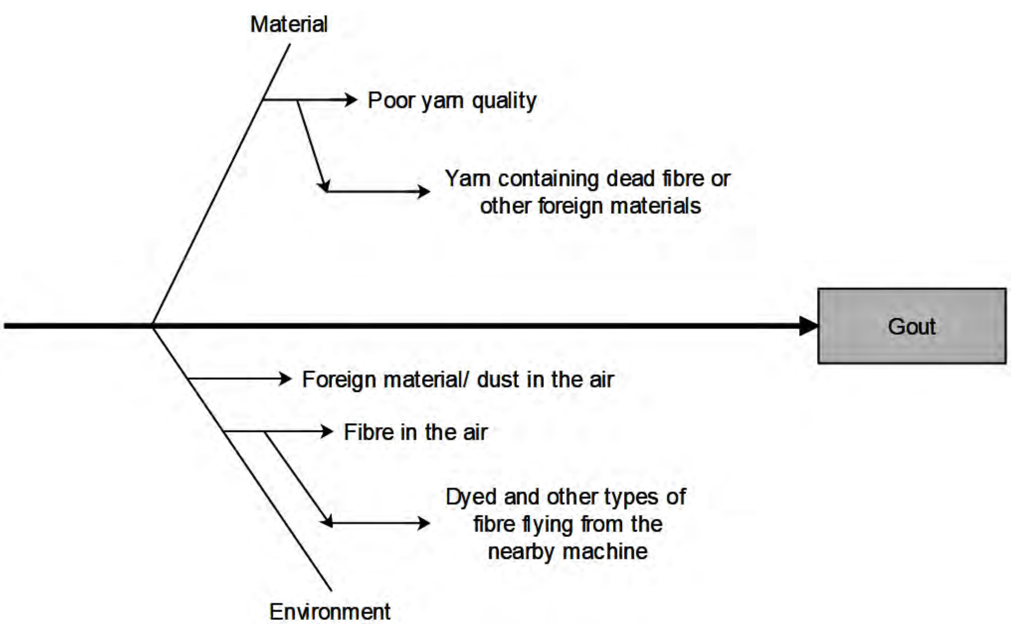


Figure **7.14**: Cause-and-effect diagram for „Gout‟

***Hole*:** An imperfection where one or more yarns are sufficiently damaged to create an aperture (ASTM D3990-12) as shown in Figure 7.15.

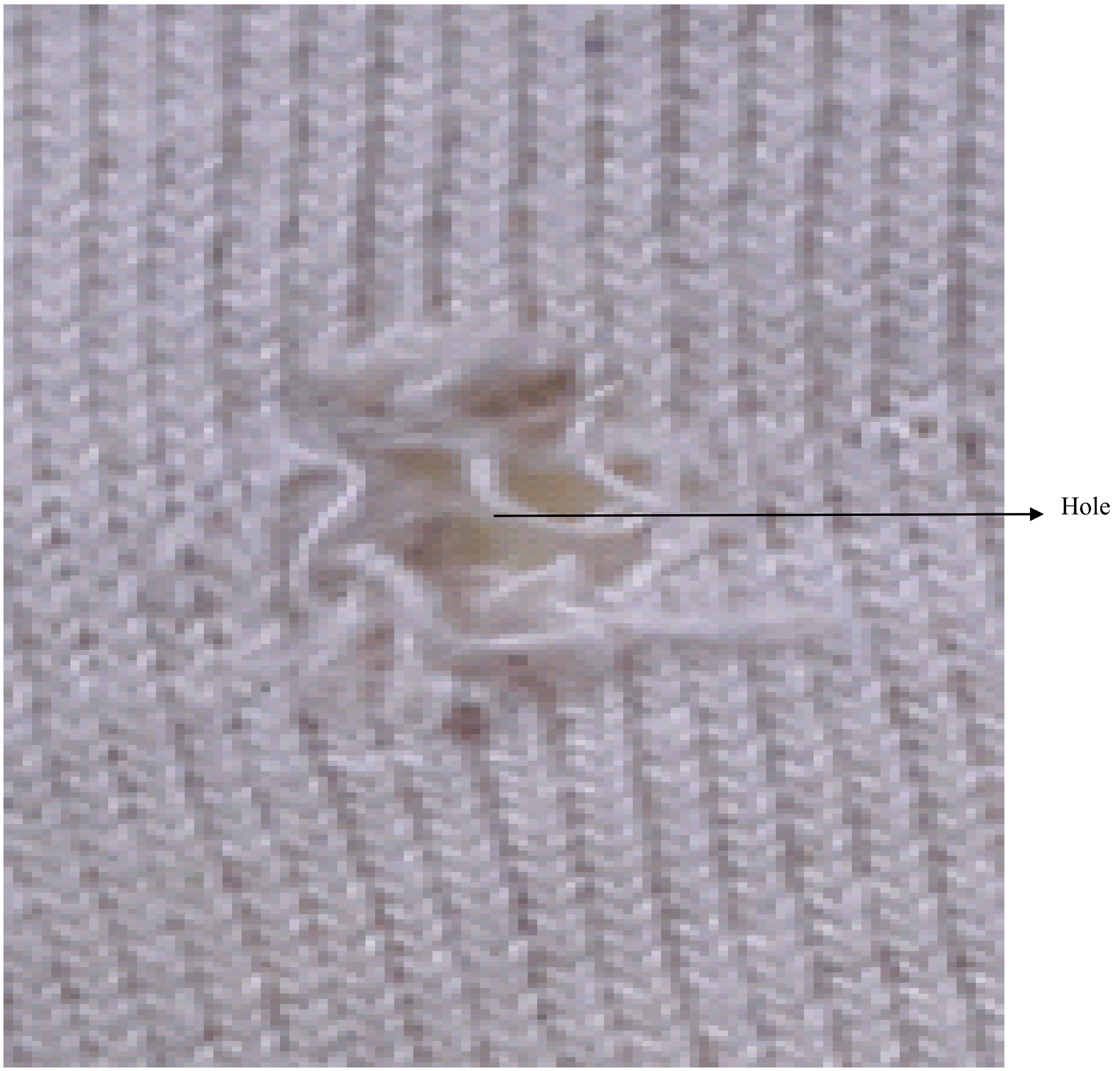


Figure **7.15**:„Hole“ in knitted fabric

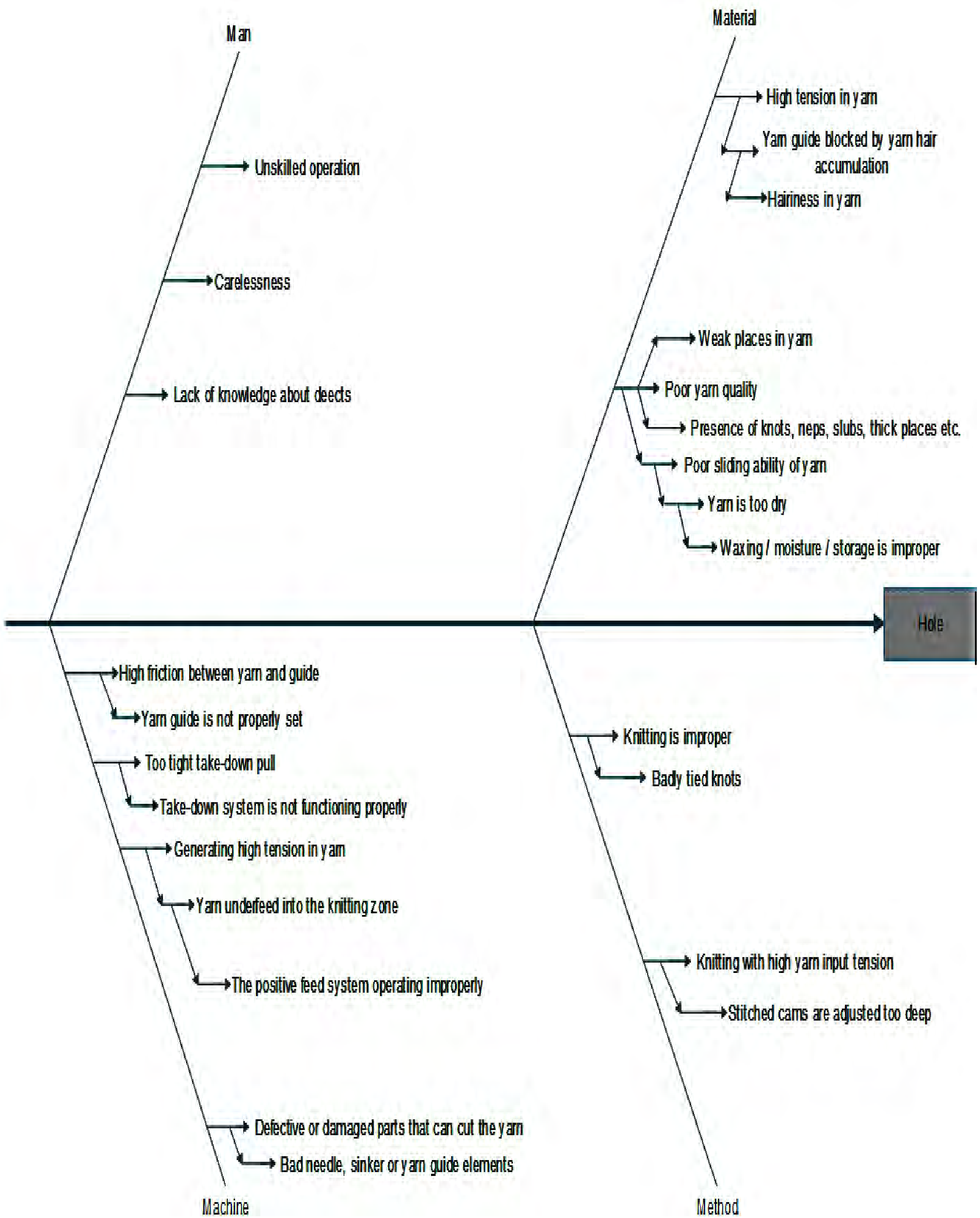


Figure **7.16**: Cause-and-effect diagram for „Hole"

Press-off: A condition in which the yarn fails to knit and either the fabric falls off the needles or the design is distorted or incomplete (ASTM D3990-12), as shown in Figure 7.17.

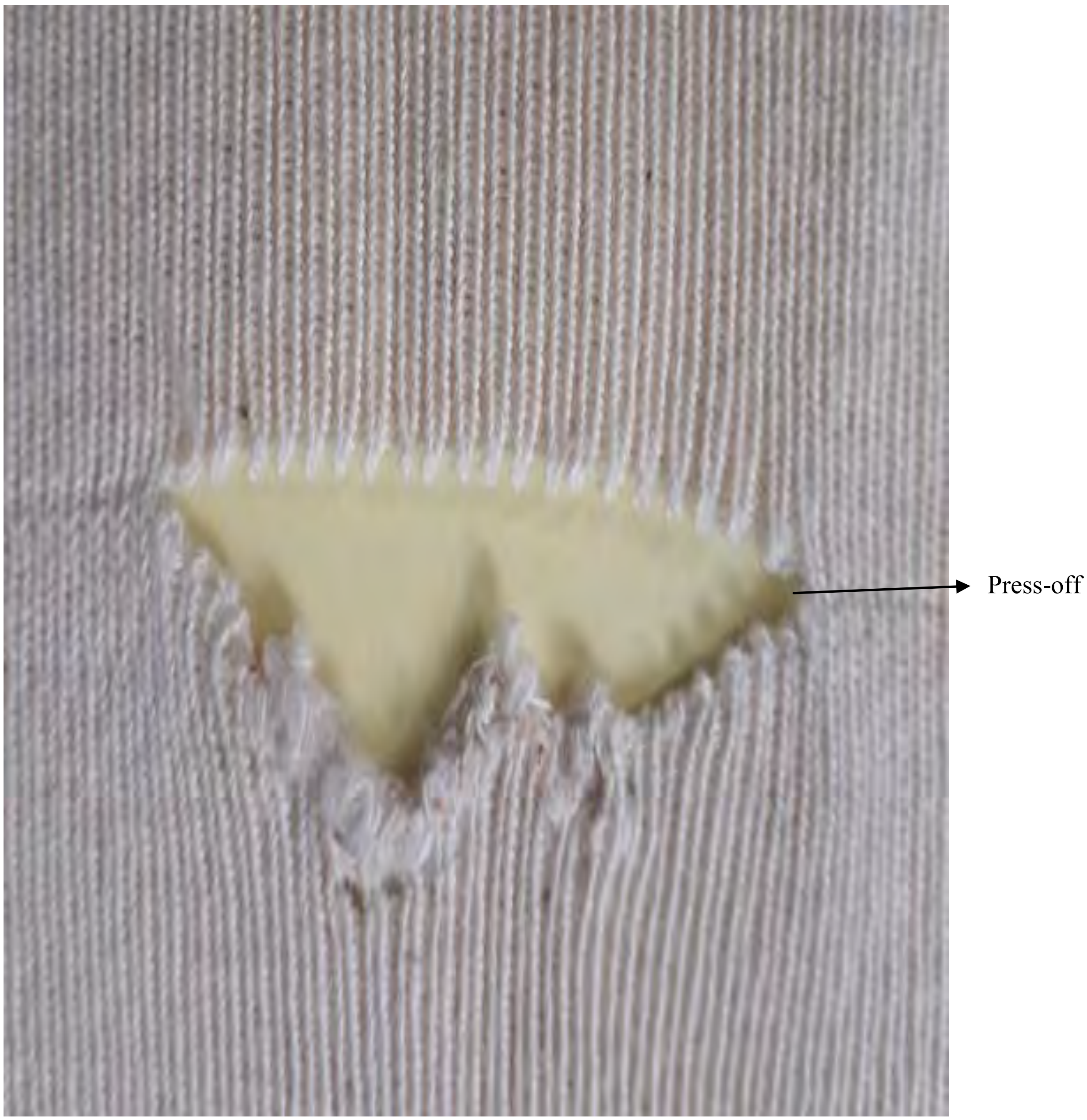


Figure **7.17**: „Press-off" in knitted fabric

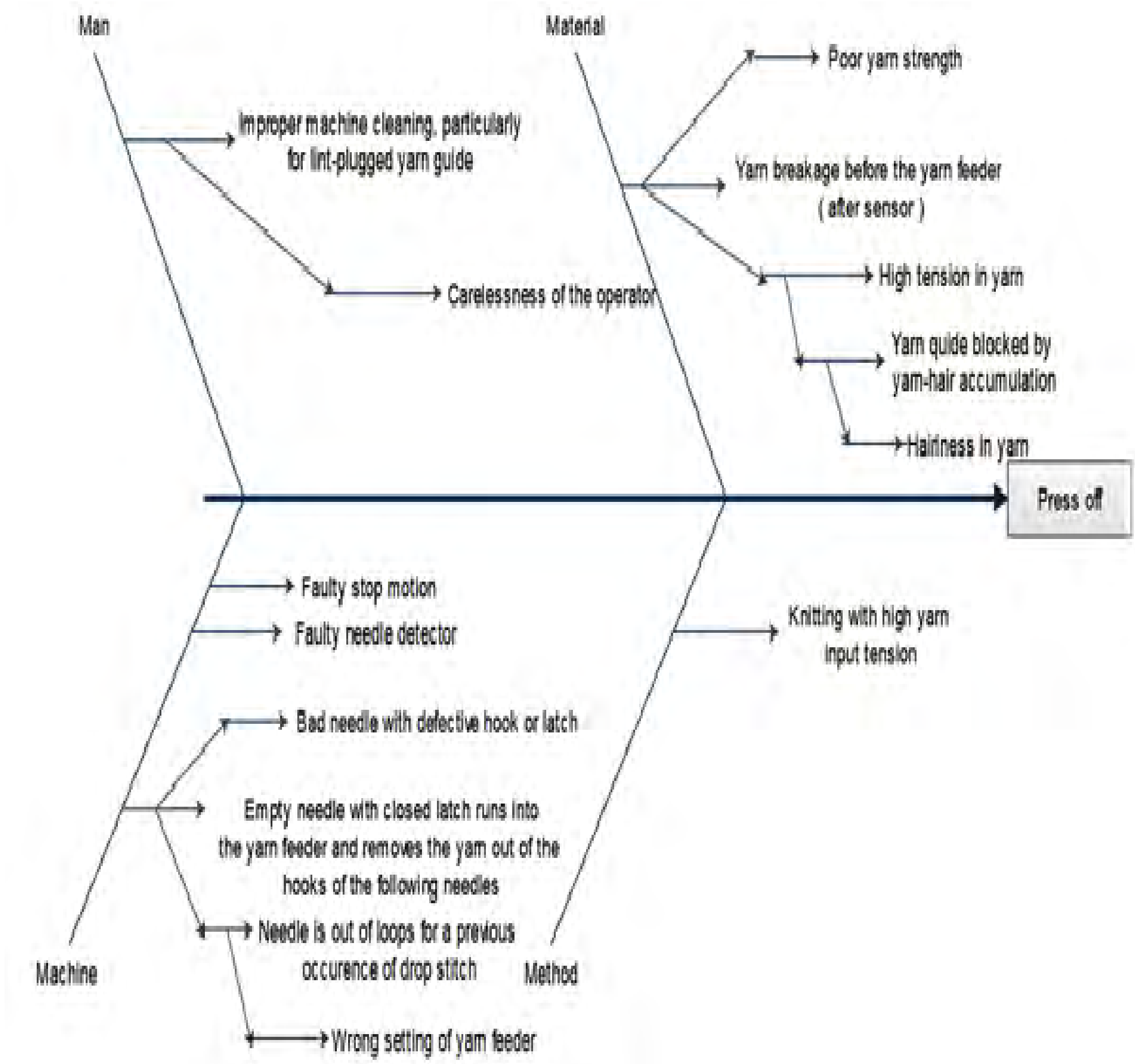


Figure **7.18**: Cause-and-effect diagram for „Press-off"

Loose course*:* A row of loops in the widthwise direction that is larger, looser, or longer than the stitches in the main body of the fabric (ASTM D3990-12) as shown in Figure 7.19

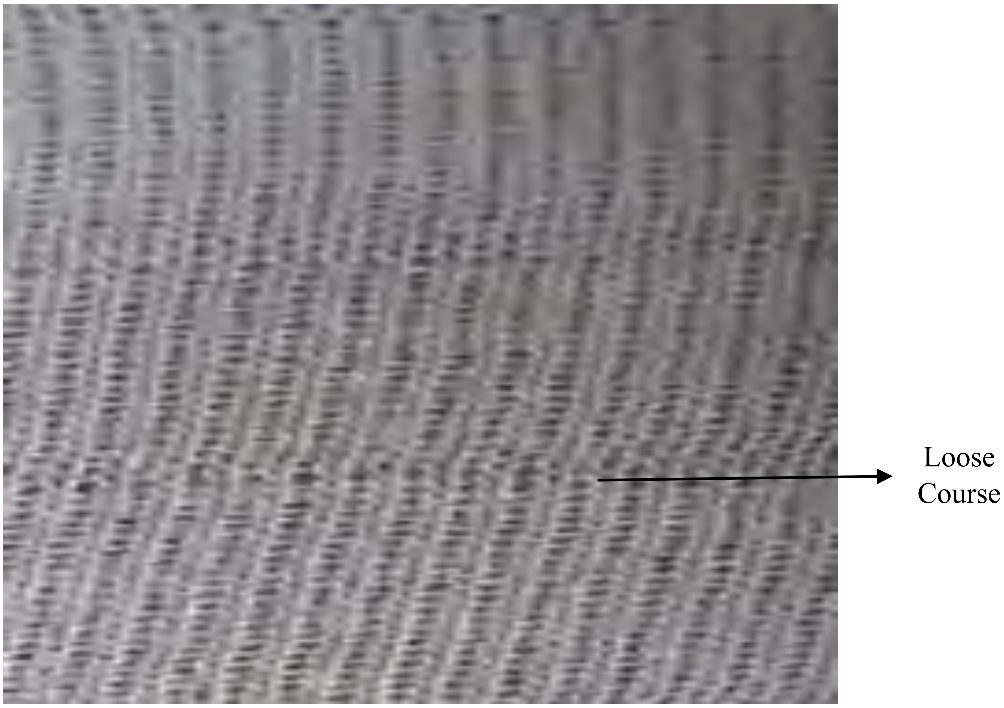


Figure **7.19**:„Loose Course" in knitted fabric

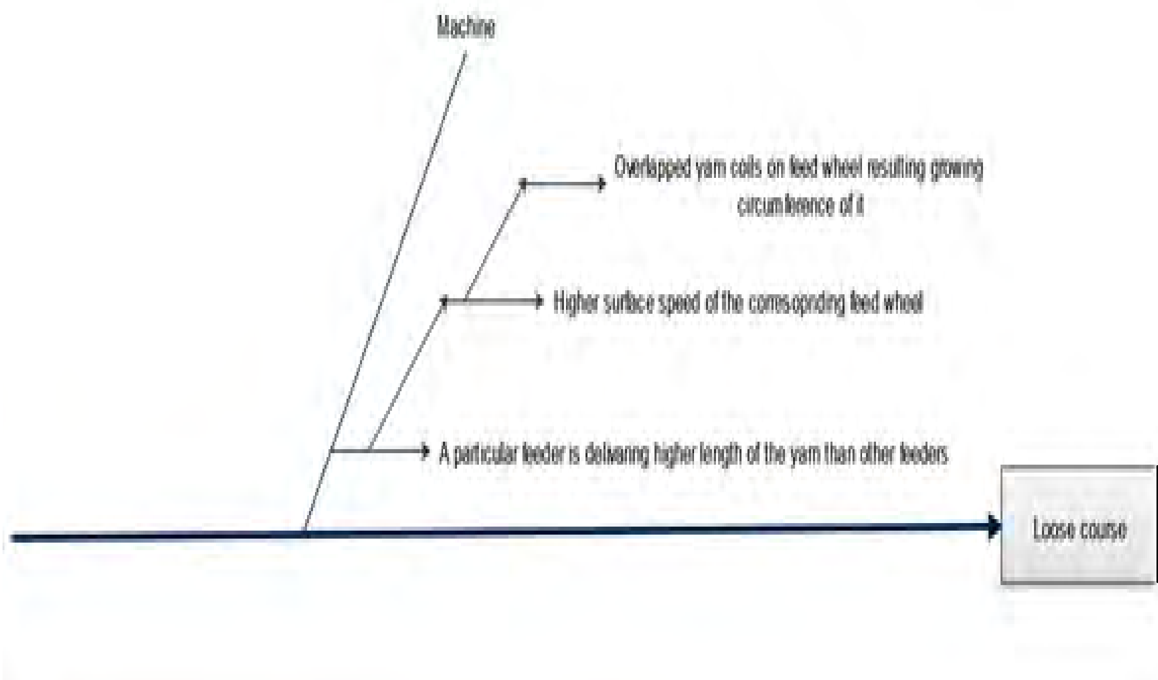


Figure **7.20**: Cause-and-effect diagram for „Loose Course"

Miss-Knit: a deviation from the designated knitting pattern (ASTM D3990-12) as shown in Figure 7.21

Figure **7.21**: „Miss-Knit" in knitted fabrics; Left - Due to single yarn missing from a double yarn course Right- Due to wrong design in some area of fabric

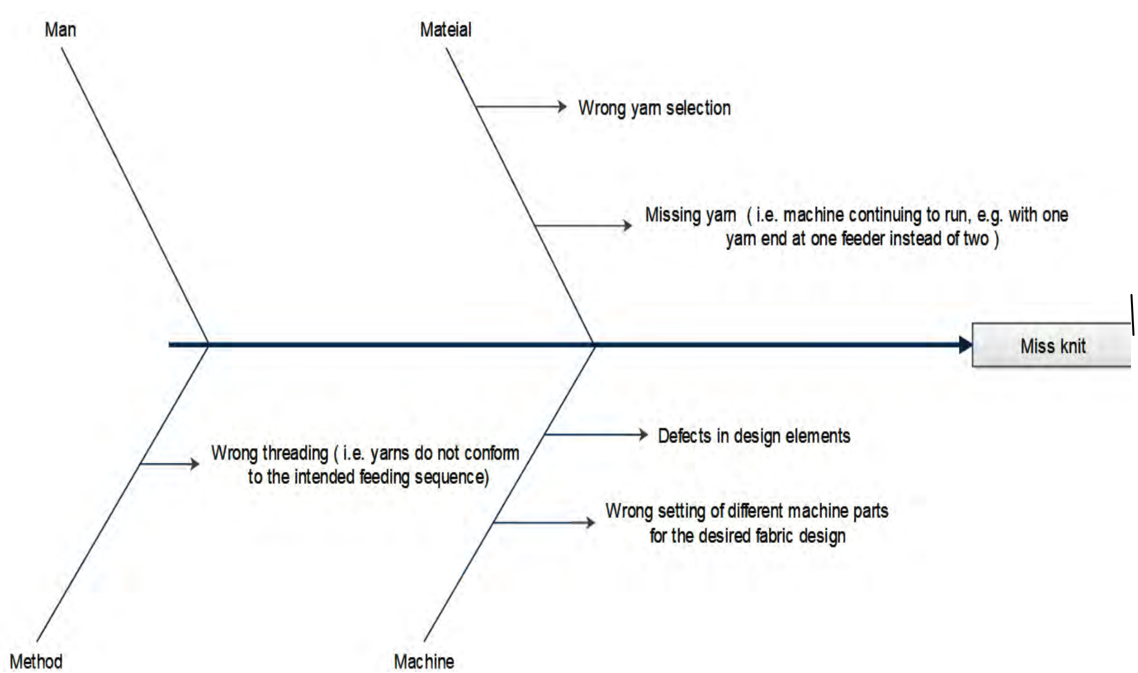


Figure **7.22**: Cause-and-effect diagram for „Miss-Knit"

***Skew**:* A fabric condition resulting when knitted courses are angularly displaced from a line perpendicular to the edge or side of the fabric (ASTM D3990-12).

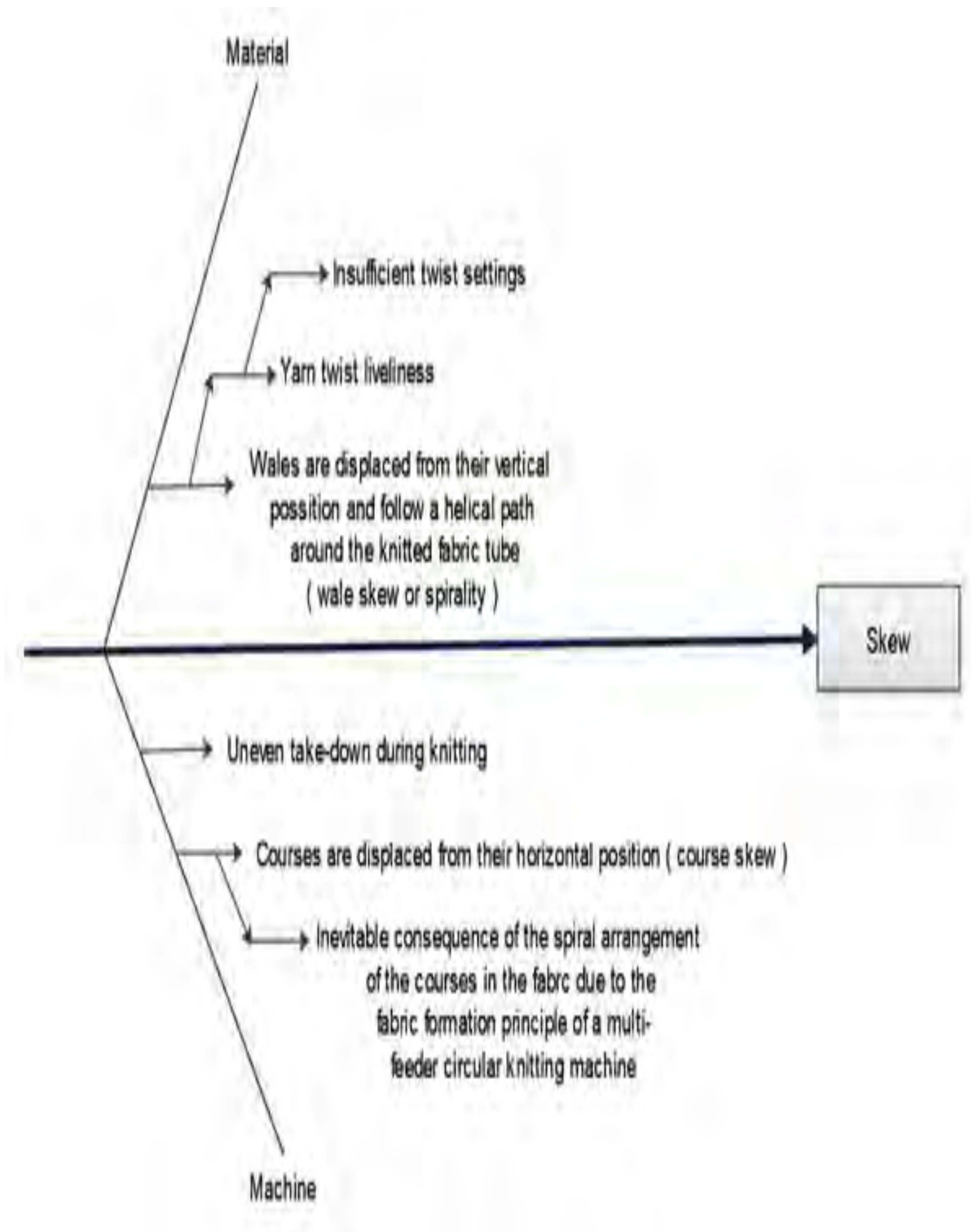


Figure **7.23**: Cause-and-effect diagram for „Skew"

***Slub**: An abruptly thickened place in a yarn (ASTM D3990-12)as shown in Figure 7.24.*

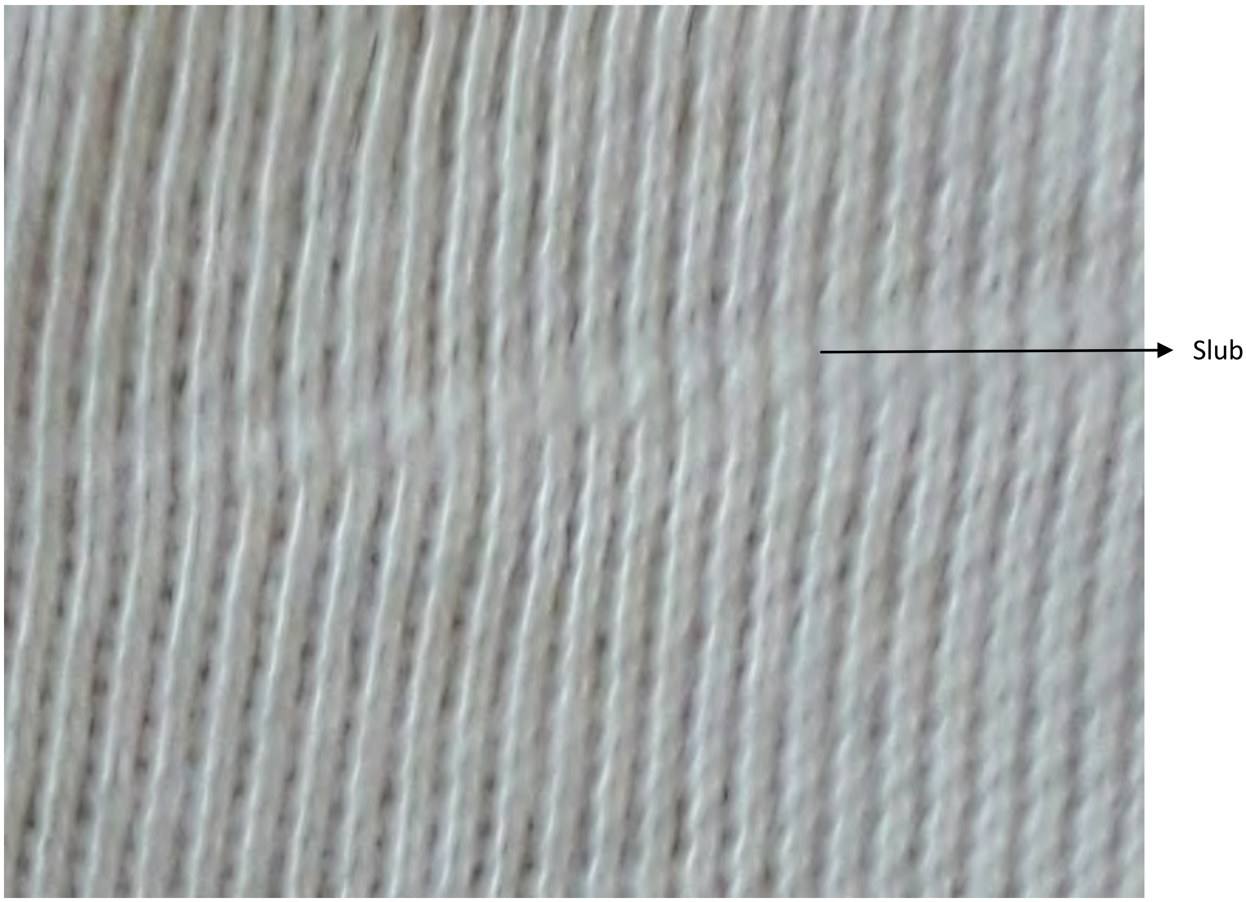


Figure **7.24**: „Slub" in knitted fabric

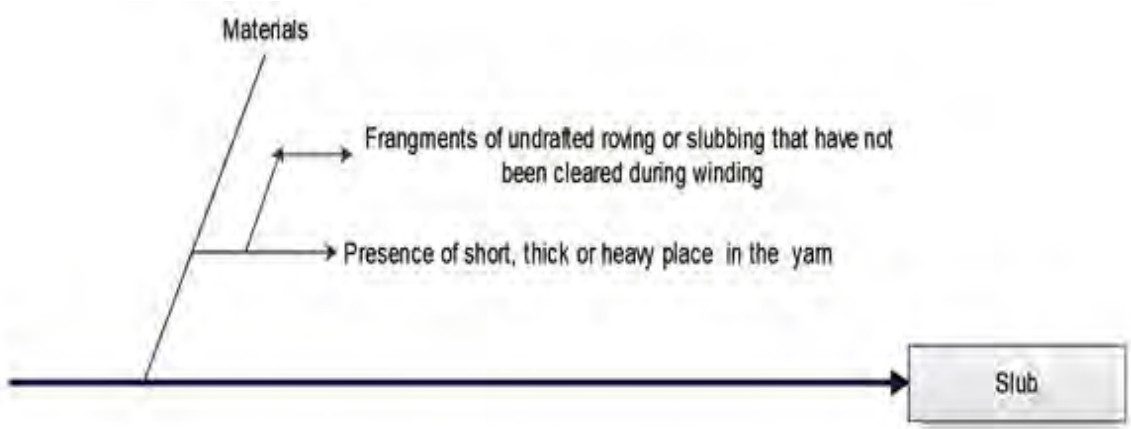


Figure **7.25**: Cause-and-effect diagram for „Slub"

Snag *:* a yarn or part of a yarn pulled or plucked from the surface (ASTM D3990-12) as shown in Figure 7.26

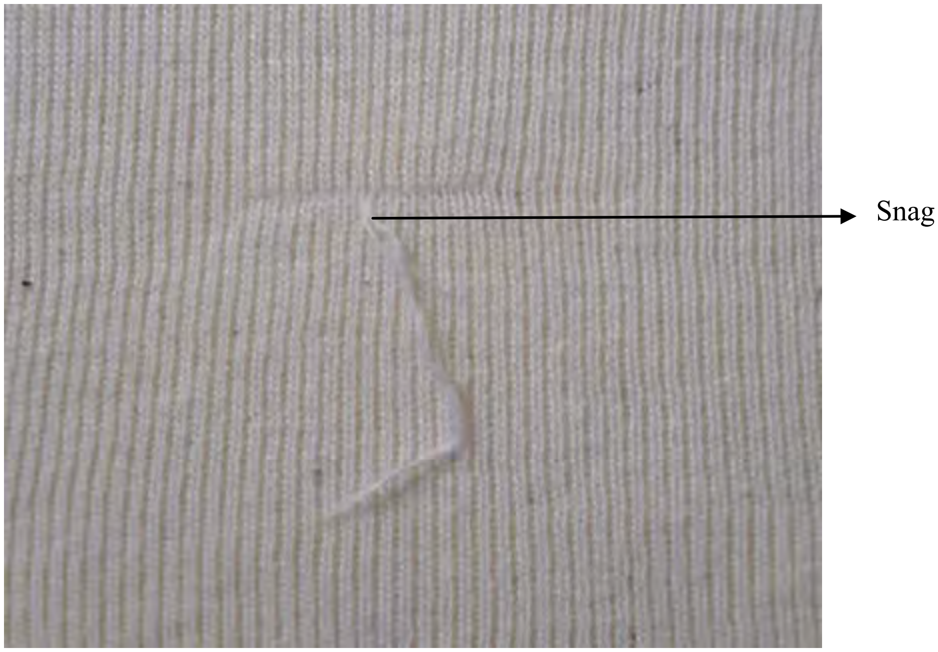


Figure **7.26**: „Snag" in knitted fabric

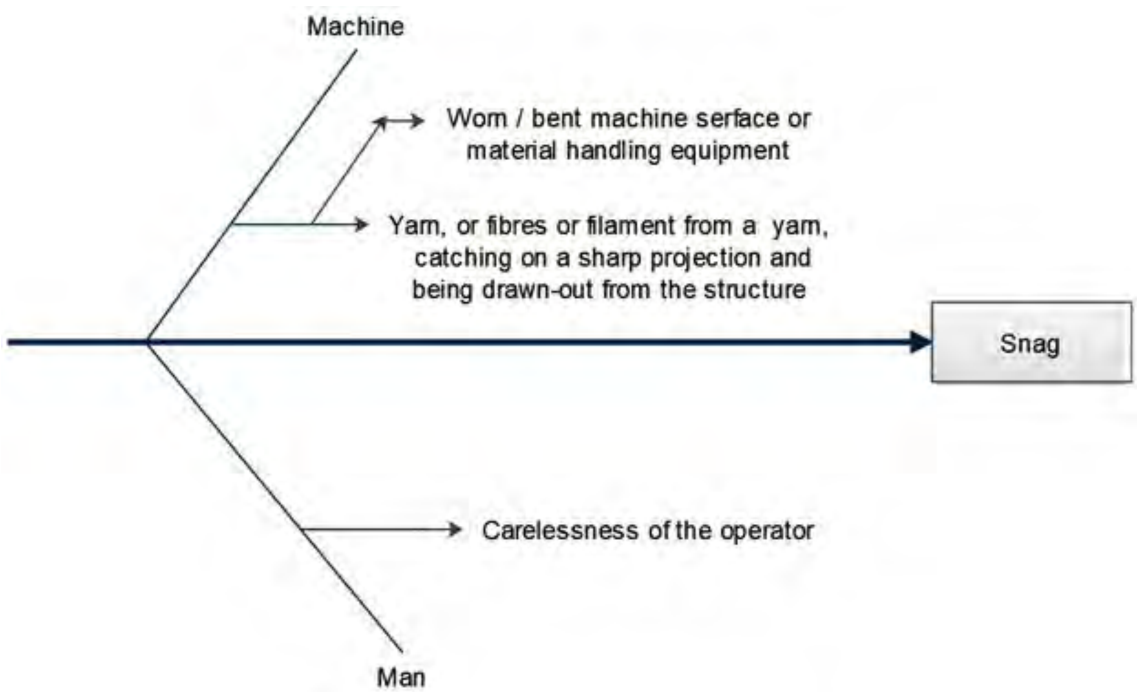


Figure **7.27**: Cause-and-effect diagram for „Snag"

Snarl*:* A short length of yarn that has spontaneously doubled back on itself to form a loop(ASTM D3990-12)

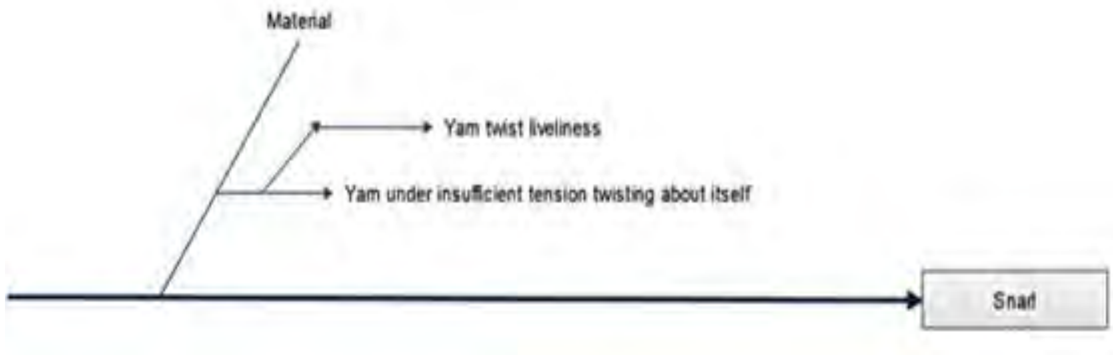


Figure **7.28**: Cause-and-effect diagram for „Snarl"

Split-stitch: A stitch in which one part of the yarn is knit and the other part is dropped (ASTM D3990-12).Split stitch defect results on the yarn that has been pierced by the hook of the needle so that one portion of the yarn goes under and the other portion over the hook of the needle. This defect occurs when the yarn is not properly fed into the hook of the needle (ISO 8499: 2003).

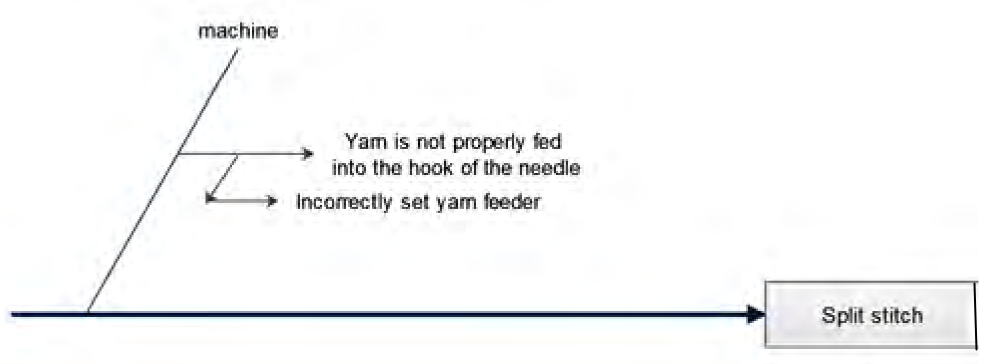


Figure **7.29**: Cause-and-effect diagram for „Split-stitch"

Spot: A small discolored area on, or in, a fabric (ASTM D3990-12) as shown in Figure 7.30

Figure **7.30**: „Spot" in knitted fabric

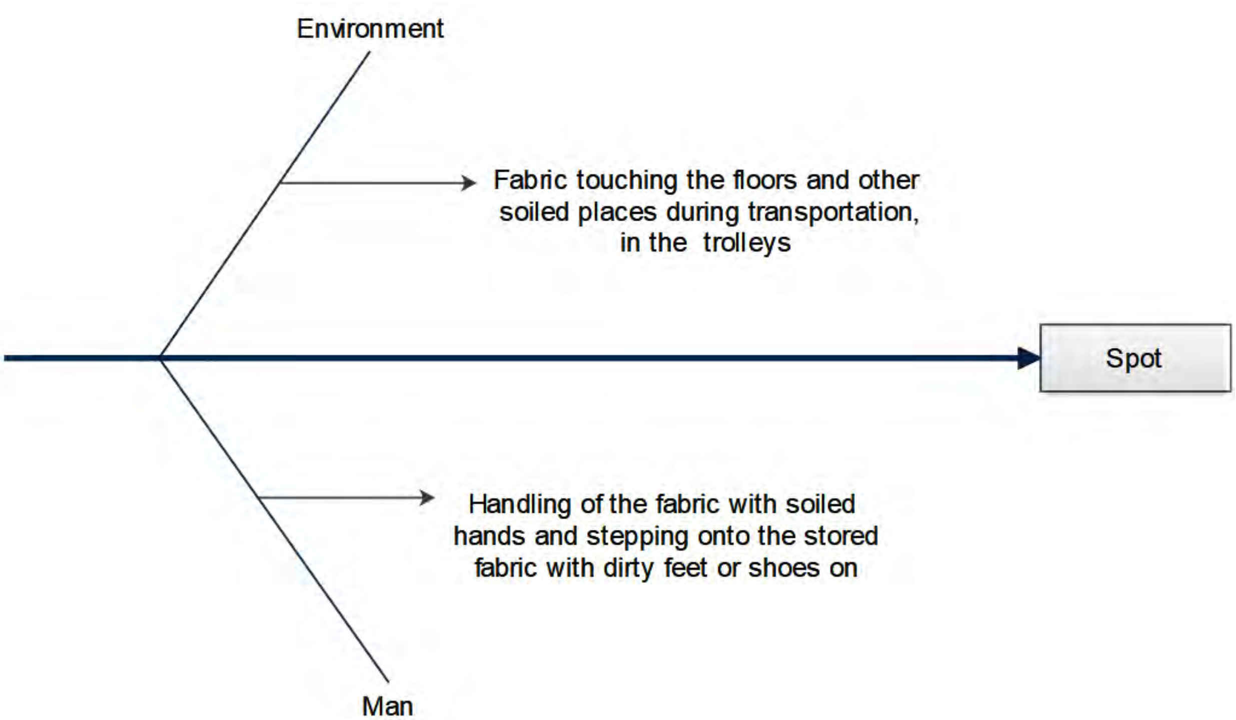


Figure **7.31**: Cause-and-effect diagram for „Spot"

Stain: An area of discoloration that penetrates the fabric surface (ASTM D3990-12) as shown in Figure 7.32

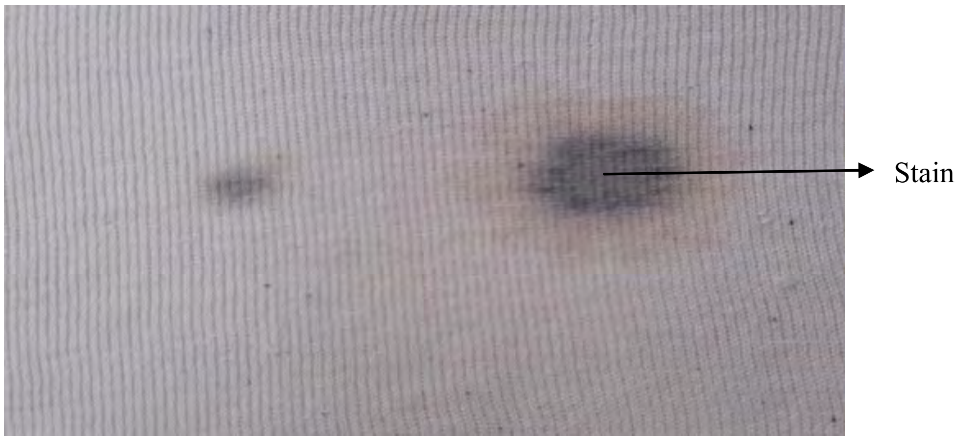


Figure **7.32**:„Stain" in knitted fabric

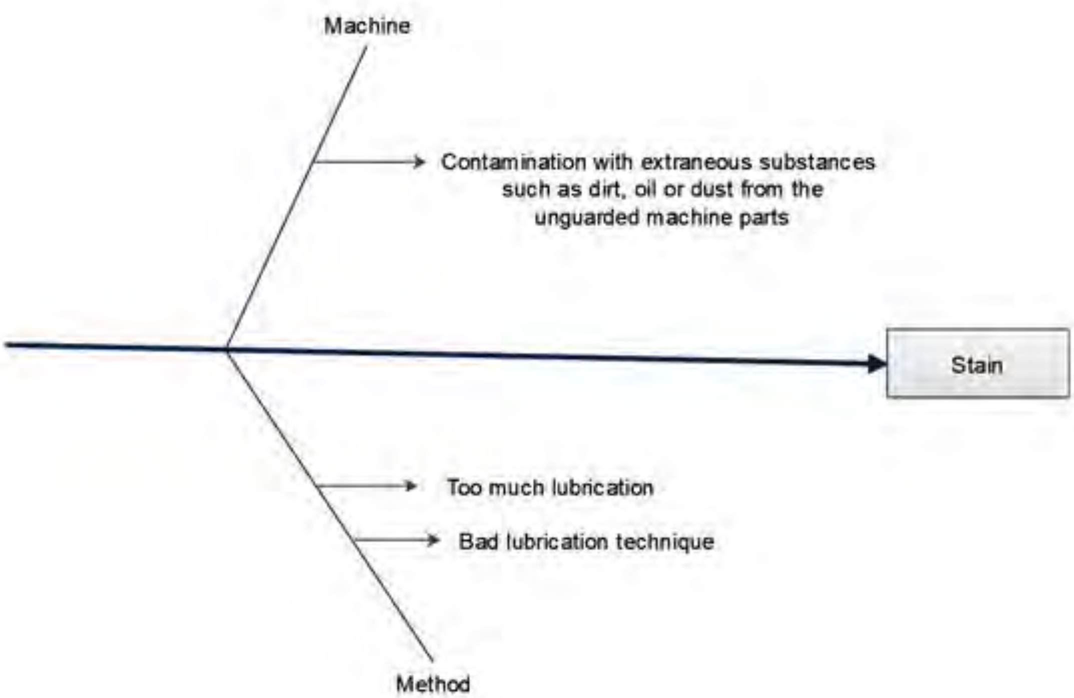


Figure **7.33**: Cause-and-effect diagram for „Stain"

***Thick Place*:**

An unintentional change in fabric appearance characterized by a small area of more closely spaced yarns, or by a congregation of thick yarns as compared to the adjacent construction (ASTM D3990-12) as shown in Figure 7.34.

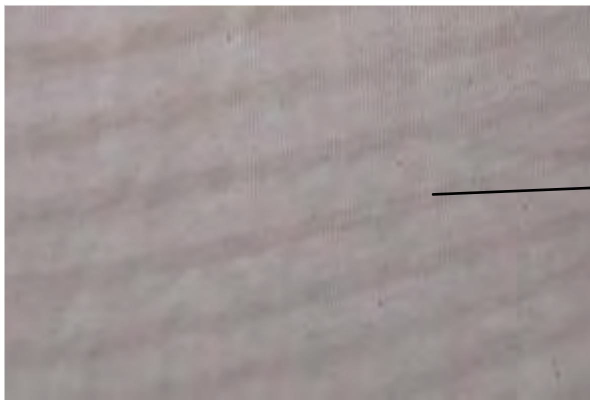


Figure **7.34**:„Thick Place" in knitted fabric

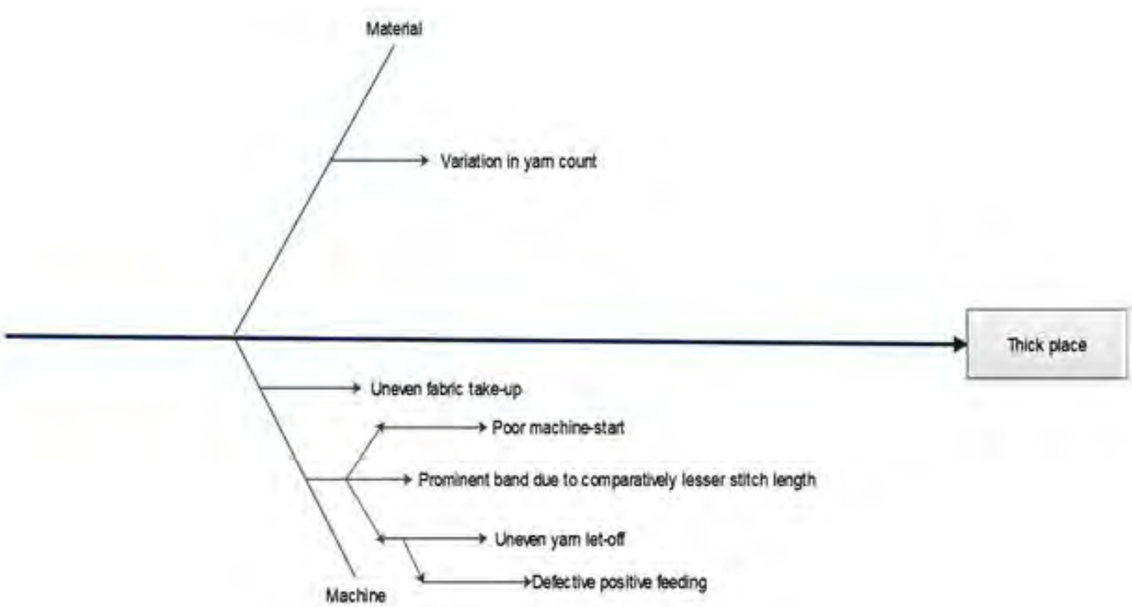


Figure **7.35**: Cause-and-effect diagram for „Thick Place"

***Thin Place*:**

An unintentional change in fabric appearance characterized by a small area of loosely spaced yarns or by a congregation of thin yarns as compared to the adjacent construction (ASTM D3990-12) as shown in Figure 7.36

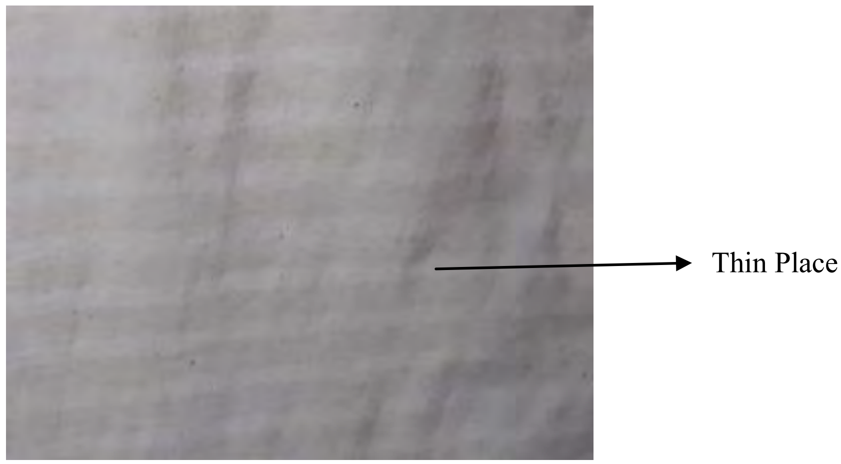


Figure **7.36**:„Thin Place" in knitted fabric

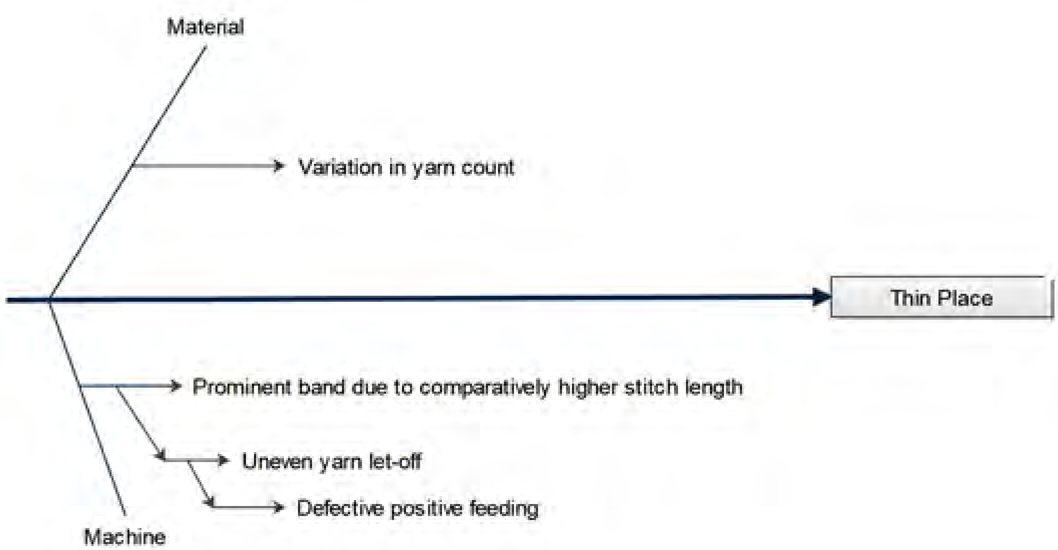


Figure **7.37**: Cause-and-effect diagram for „Thin Place"

***Streak/Streakiness*:**

An extended unintentional stripe of narrow width, often a single yarn (ASTM D3990-12) as shown in Figures 7.38 and 7.39.

Figure **7.38**:„Streak‟in knitted fabric (Streaky Grey Mellange Fabric, n.d.)

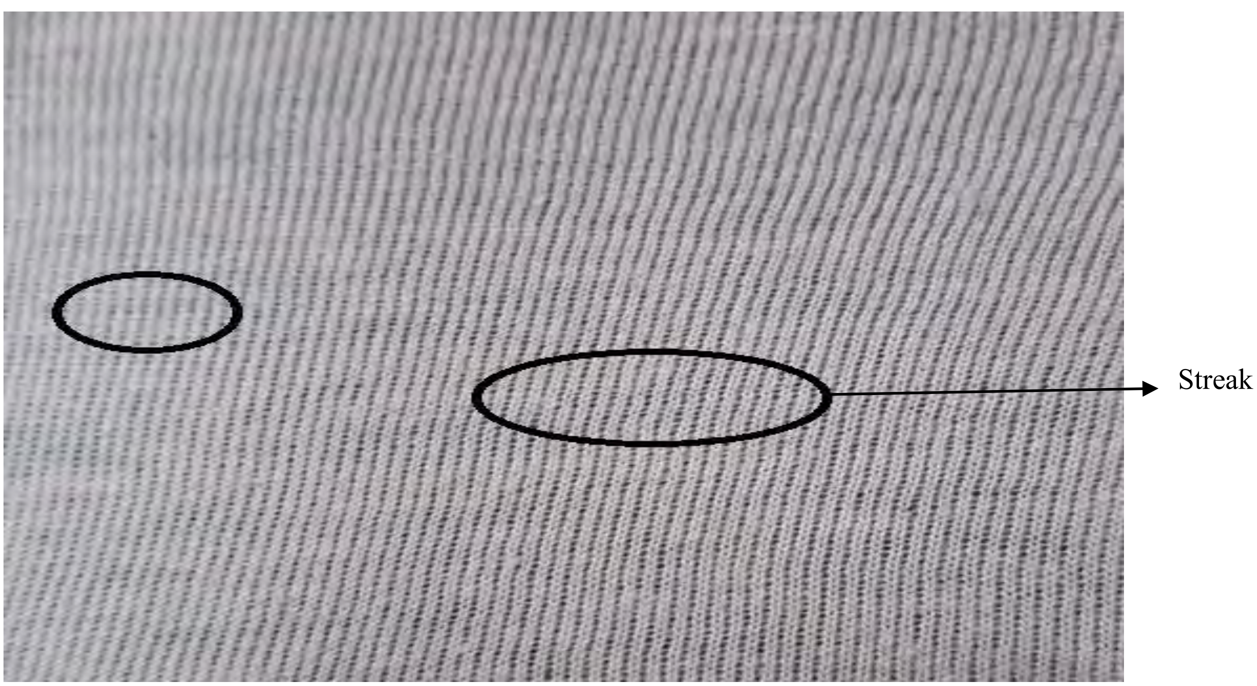


Figure **7.39**: „Streak‟ in knitted fabric –cotton knitted

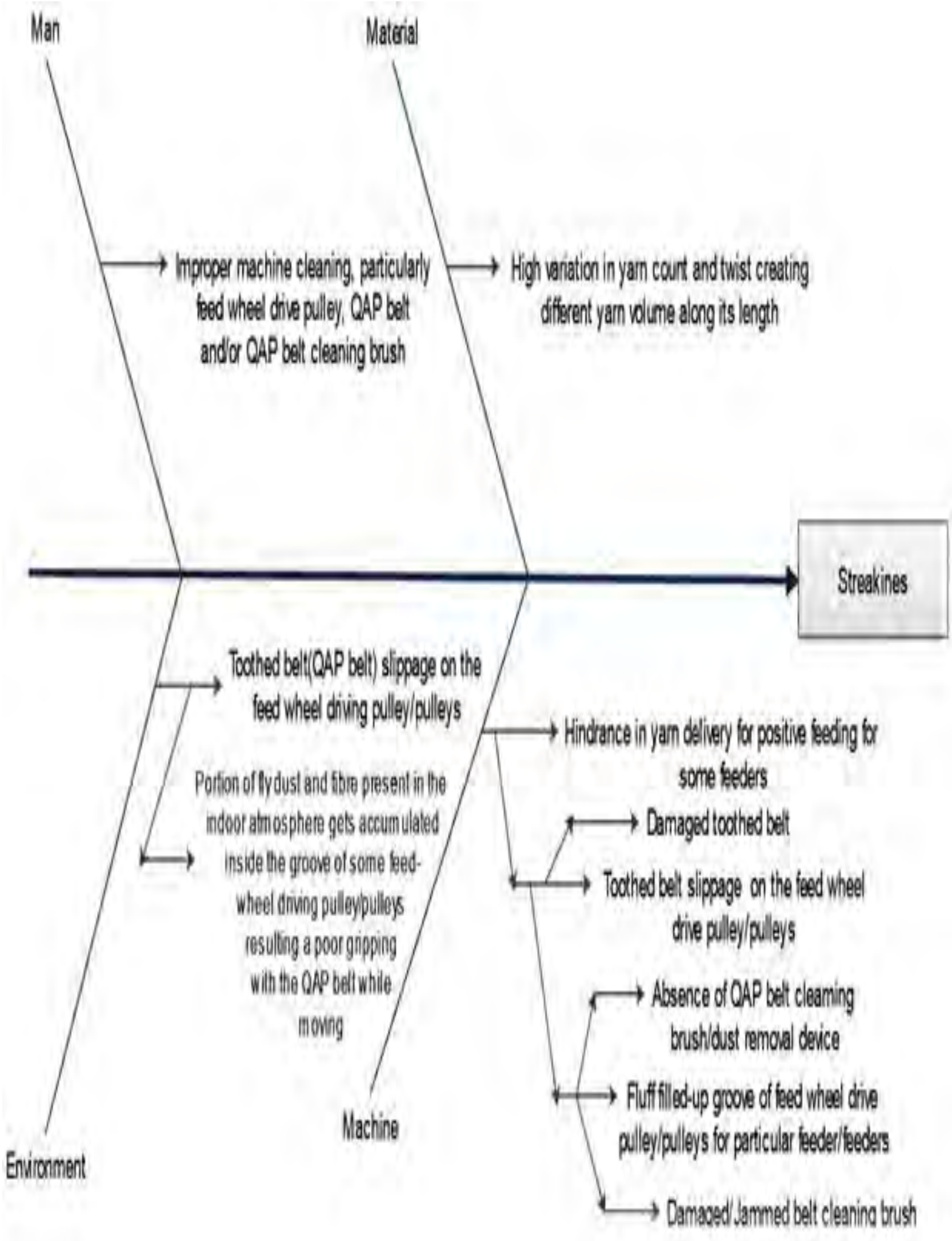


Figure **7.40**: Cause-and-effect diagram for „Streakiness"

GSM variation:

Areal density differs in different portions of a fabric.

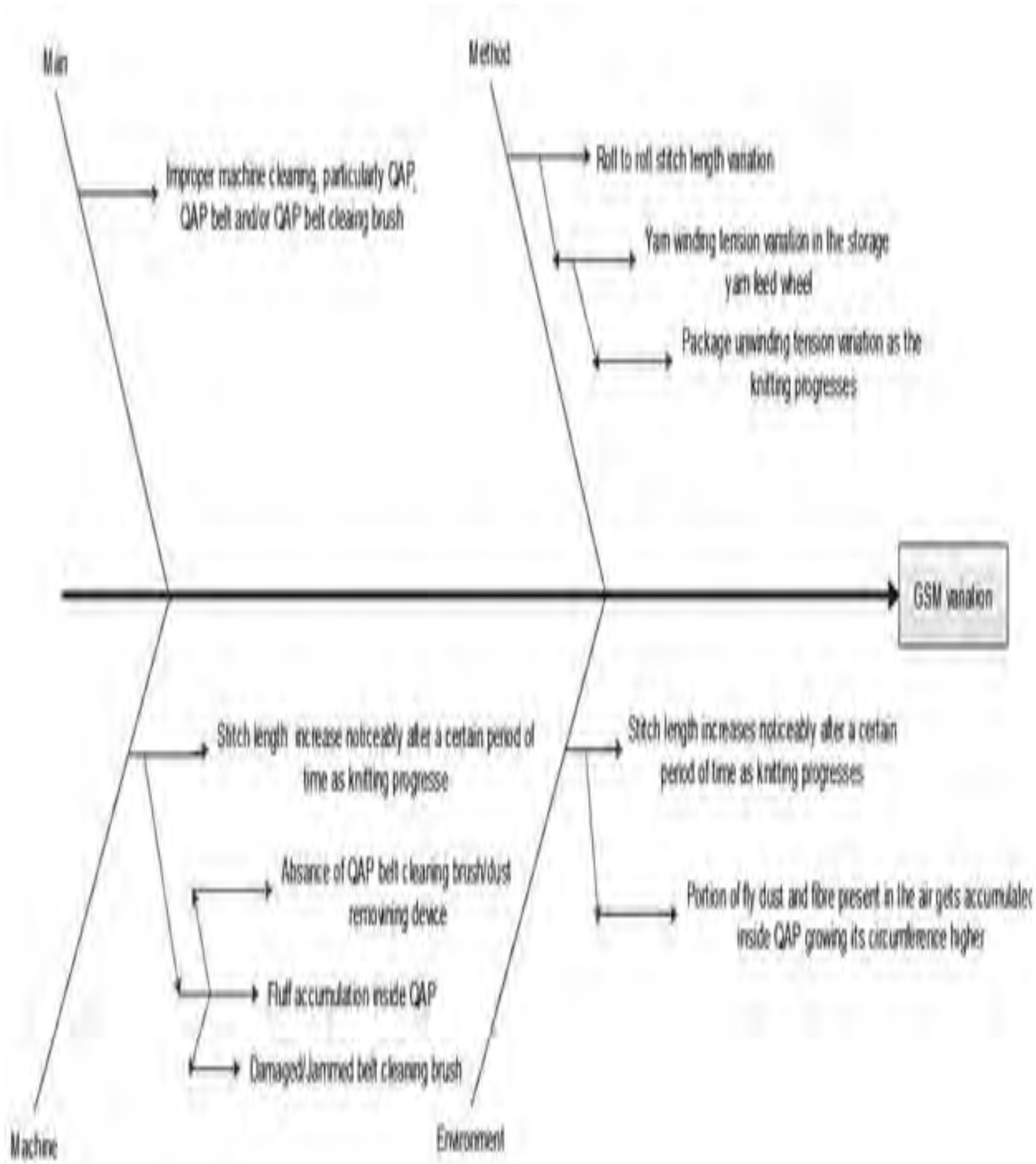


Figure **7.41**: Cause-and-effect diagram for „GSM variation"

7.5.3 A summary of root causes identified through pinpoint analysis of knitted fabric defects/flaws

The primary causes responsible for different circular weft-knitted fabric defects have been gathered in table 7.2.

Table **7.2**: Fundamental reasons that are responsible for different weft knitted fabric faults/flaws

Defect type	Root Causes				
	Man	**Machine**	**Material**	**Method**	**Environment**
Barre	-Unskilled operator -Carelessness -Lack of knowledge about defects	-Uneven cylinder height needles i.e. needle bed levelness with the horizontal line is not uniform (wavy barre) -Improper stitch cam setting -Damaged scrolled segments inside QAP -Damaged toothed belt -Loose fitting of toothed belt over QAP -Jammed feed wheel driving pulley/ pulleys for some feeder/ feeders -Jerky impulse from fabric take up due to defective take down mechanism	-Individual yarn difference (for count, properties or structure) -Package unwinding tension variation due to different sizes of yarn packages in creel -Package hardness variation from cone to cone	-Mixing of yarn lots or counts while loading package into creel -Defective plating	
Tucking			-Waxing/moisture / storage is improper	-Defective take down mechanism -Dirt in	

Defect type	Root Causes				
	Man	Machine	Material	Method	Environment
				trick wall -Defective needle -Improper stitch cam setting	
Bow		-Incorrect Take down tension during knitting.			
Crack Mark	-Improper lubrication	-Defective needle/ sinkers -Damaged trick slots/ sinker grooves -Dirt in trick slots/ sinker grooves	-Yarn count selected is too fine for the machine gauge	-Needles/ sinkers are of different origins/ brands	
Dropped Stitch/ Run		-Stitch cam is set too far back -Yarn feeder is not properly set -Defective needles -Fabric take off is insufficient	-Yarn is too stiff	-Yarn tension is not sufficient	
Float		-Defective needle		-Wrong selection of cam design.	
Gout			-Yarn containing dead fibers or other foreign materials.		-Foreign material/ dust in the air. -Dyed and other type of fiber flying from the nearby machine.

Defect type	Root Causes				
	Man	Machine	Material	Method	Environment
Hole	-Unskilled operator -Carelessness -Lack of knowledge about deeds	-Yarn guide is not properly set -Take down system is not functioning properly -The positive feed system operating improperly -Bad needle, sinker or yarn guide elements	-Hairiness in yarn -Weak places in yarn -Presence of knots, neps, slubs, thick places etc. -Waxing/ moisture/ storage is improper	-Badly tied knots -Stitched cams are adjusted too deep	
Press off	-Carelessness of the operator	-Faulty stop motion -Faulty needle detector -Bad needle with defective hook or latch -Wrong setting of yarn feeder	-Poor yarn strength -Hairiness in yarn.	-Knitting with high yarn input tension	
Loose Course		-Overlapped yarn coils in feed wheel resulting growing circumference of it			
Miss knit		-Defects in design elements -Wrong setting or differed machine parts for the desired fabric design	-Wrong yarn selection -Missing yarn (i.e. machine continuing to run e.g. with one yarn end at one feeder instead of two)	-Wrong threading (i.e. yarns do not conform to the intended feeding sequence)	
Skew		-Uneven take down during knitting	-Insufficient twist setting		

Defect type	Root Causes				
	Man	Machine	Material	Method	Environment
		-Inevitable consequences of the spiral arrangement of the courses in the fabric due to the fabric formation principle of a multi-feeder circular knitting machine			
Slub			-Fragments of undrafted roving or slubbing that have not been cleared during winding		
Snag	-Carelessness of the operator	-Worn/bent machine surface or material handling equipment			
Snarl			-Yarn twist liveliness		
Split Stitch		-Incorrectly set yarn feeder.			
Spot	-Handling of the fabric with soiled hands and stepping onto the stored fabric with dirty feet or shoes on				-Fabric touching the floor and other soiled places during transportation in the trolleys
Stain		-Contamination with extraneous substances such as dirt, oil or dust from the unguarded machine parts		-Too much lubrication -Bad lubrication technique	
Thick place		-Uneven fabric take-up	-Variation in yarn count		

Defect type	Root Causes				
	Man	Machine	Material	Method	Environment
		-Poor machine-start -Defective positive feeding			
Thin place		-Defective positive feeding	-Variation in yarn count		
Streakiness	-Improper machine cleaning, particularly feed wheel drive pulley, QAP belt and/or QAP belt cleaning brush	-Damaged toothed belt -Absence of QAP belt cleaning brush/dust removal device -Damaged /jammed belt cleaning brush	-High variation in yarn count and twist creating different yarn volume along its length		-Portion of fly dust and fiber present in the indoor atmosphere gets accumulated inside the groove of some feed wheel driving pulley/pulleys resulting a poor gripping with the QAP belt while moving
GSM variation	-Improper machine cleaning, particularly QAP, QAP belt and/or QAP belt cleaning brush	-Absence of QAP belt cleaning brush/ dust removing device -Damaged/ jammed belt cleaning brush		-Package unwinding tension variation as the knitting progresses	-Portion of fly dust and fiber present in the air gets accumulated inside QAP growing its circumference higher

7.6 Scope of Machine Development through Pinpoint Analysis of Knitted Fabric Defects

From the pinpoint analysis of different defects it may be observed that the absence or presence of the existing QAP belt cleaning system may contribute to the generation of two types of faults/flaws, i.e. Streakiness (Figure 7.39) and GSM variation on knitted fabric. The built-up eccentricity due to fly accumulation on QAP sometimes reflects as periodic pattern in yarn tension and thus gives warning for necessary correction.

Therefore A detail study over concerned machine related issue may open the door for a possible machine development.

7.6.1 A detail of QAP based positive storage feed system

In order to knit a fabric utilizing a multifeeder circular knitting machine, a no. of ends of yarn are supplied to the needles cylindrically disposed around the cylinder of the circular knitting machine. Knitting cams located around the cylinder define the travel path of the needles. The needles demand a certain quantity of yarn per revolution of the knitting machine when the machine is operating according to the stitch cam settings of the knitting machine.

The amount of yarn that is fed to the needles of a circular knitting machine determines the quality of the fabric being knitted. If it is desired to knit a denser fabric, the amount of yarn fed to the needles per revolution of the knitting machine is decreased and vice versa. Thus, in order to control the quality of a fabric, it is desirable to control the rate at which yarn is fed to a circular knitting machine.

In positive yarn feed systems (Figure 7.42), the rate at which yarn is fed to the needles is controlled by the rate of rotation of a plurality of positive feed units, usually driven by a motor, (Earl and Earl,2000).

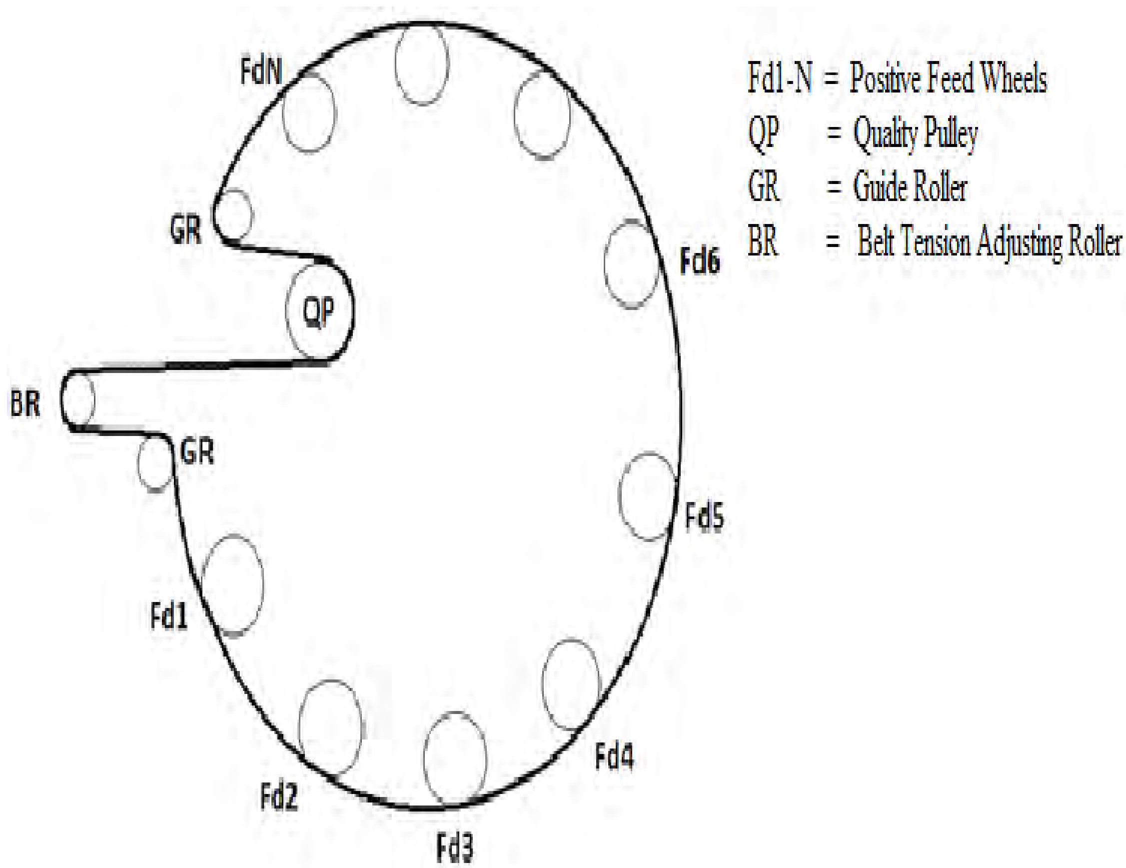


Figure **7.42**: Schematic diagram of positive storage feed system (Dias,Tang and Lanarolle,1998)

More specifically, the positive feed units rotate to extract yarn from the packages and deliver yarn to the needles. Yarn is positively fed from the positive feed units to the needles only when the positive feed units are rotating. The quality wheel is adjustable to vary the rate of rotation of the positive feed units, and consequently, the rate at which yarn is fed to the needles.

A quality wheel [Also known as Quality Adjusting Pulley (QAP)] is illustrated through Figures 7.43 to 7.45. The quality wheel comprises upper and lower plates with a plurality of movable segments between the upper and lower plates. The upper plate includes a helical groove, while the lower plate includes radial grooves. A lock nut connects the upper and lower plates. The inner diameter of the quality pulley is adjustable to vary yarn consumption. To increase fabric areal density (e.g. GSM), for example, it is necessary to decrease yarn consumption by reducing the inner diameter of the quality pulley through scrolled segments in order to obtain shorter stitches and denser fabric. Additionally couliering depth has to be controlled in order to reduce high yarn tension caused by decreased yarn delivery.

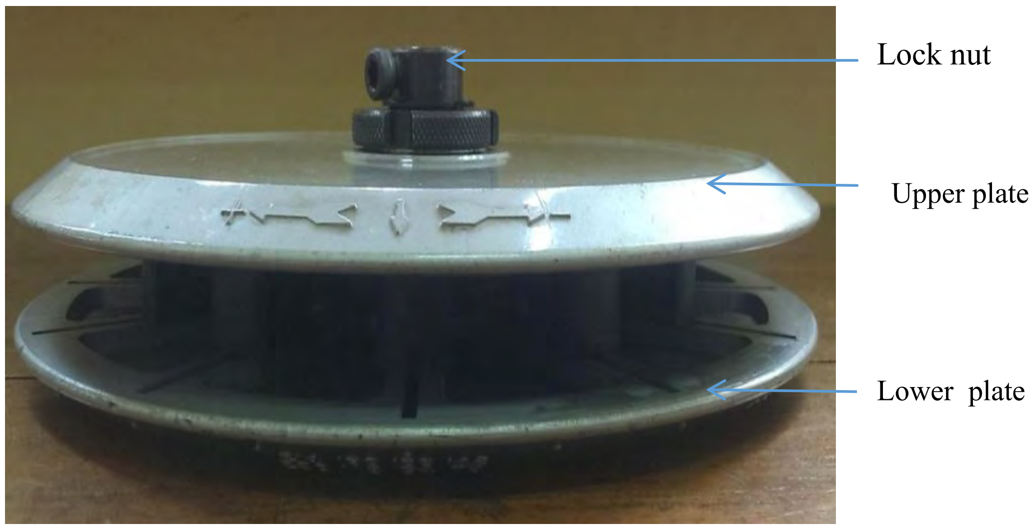


Figure **7.43**: QAP (Quality Adjusting Pulley)

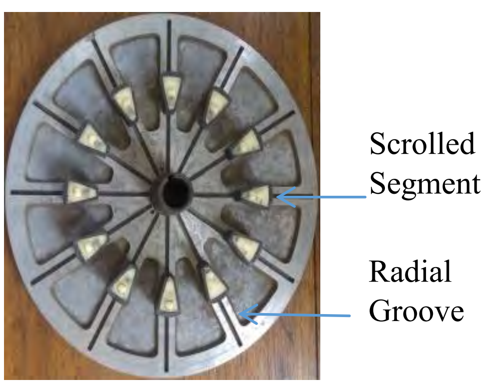


Figure **7.44**: Inside view of lower plate of QAP

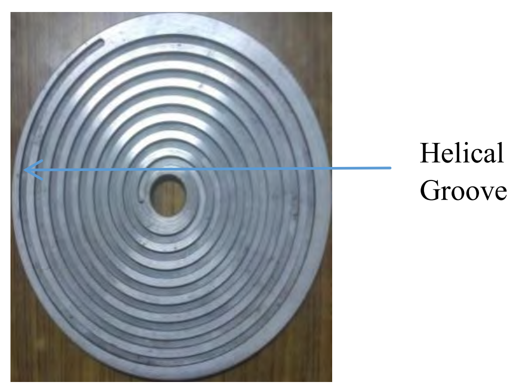


Figure **7.45**: Inside view of upper plate of QAP

7.6.2 Lint/ Fluff deposition related problem with QAP based positive storage feed system

Knitting environment is generally dusty with loose short fibres, i.e., lint, particularly when processing spun yarns, like Cotton. Friction between knitting yarns or threads in a knitting machine and those portions of the machine with which the yarn comes into contact, such as thread guides and the like, cause the fiber comprising the yarns to separate and accumulates as lint on these and adjacent areas of the machine This lint, sometimes known as fly, is sticky in nature, can be carried by the timing belt, even deposited and packed inside the grooves of toothed belt pulley ; eventually leading to slippage of toothed belt over toothed belt pulley resulting poor control of positive feeding, even negative feeding from that particular feeder. Moreover, dirt/fluff deposition inside the QAP through the belt and resulting change in the diameter may influence the stitch size (stitch length) even if the positive feed system operates at required speed (Assorted accessories for fabric quality improvement on fine gauge machines, n.d.). Periodic variation of yarn delivery rate due to the build-up eccentricity in QAP pulley for dust deposition (Figure 6.8 of chapter 6) may result fluctuation in yarn input tension thereby making the process unstable. Besides these, the increased tension in belt makes it prone to wear and tear reducing its desired lifetime. Therefore, lint accumulation on yarn delivery system must be avoided.

7.6.3 Traditional cleaning system (Brush cleaning) of QAP belt

To overcome such problems some knitting machine are provided with a brush-based cleaning system for removal of waste fibre or fly from the QAP belt (Figures7.46 ,7.47 and 7.48). Here two rotating brush are used to clean both sides of the QAP pulley belt. Being surface driven by the moving QAP belt, the brushes remove fly or dirt from the belt.

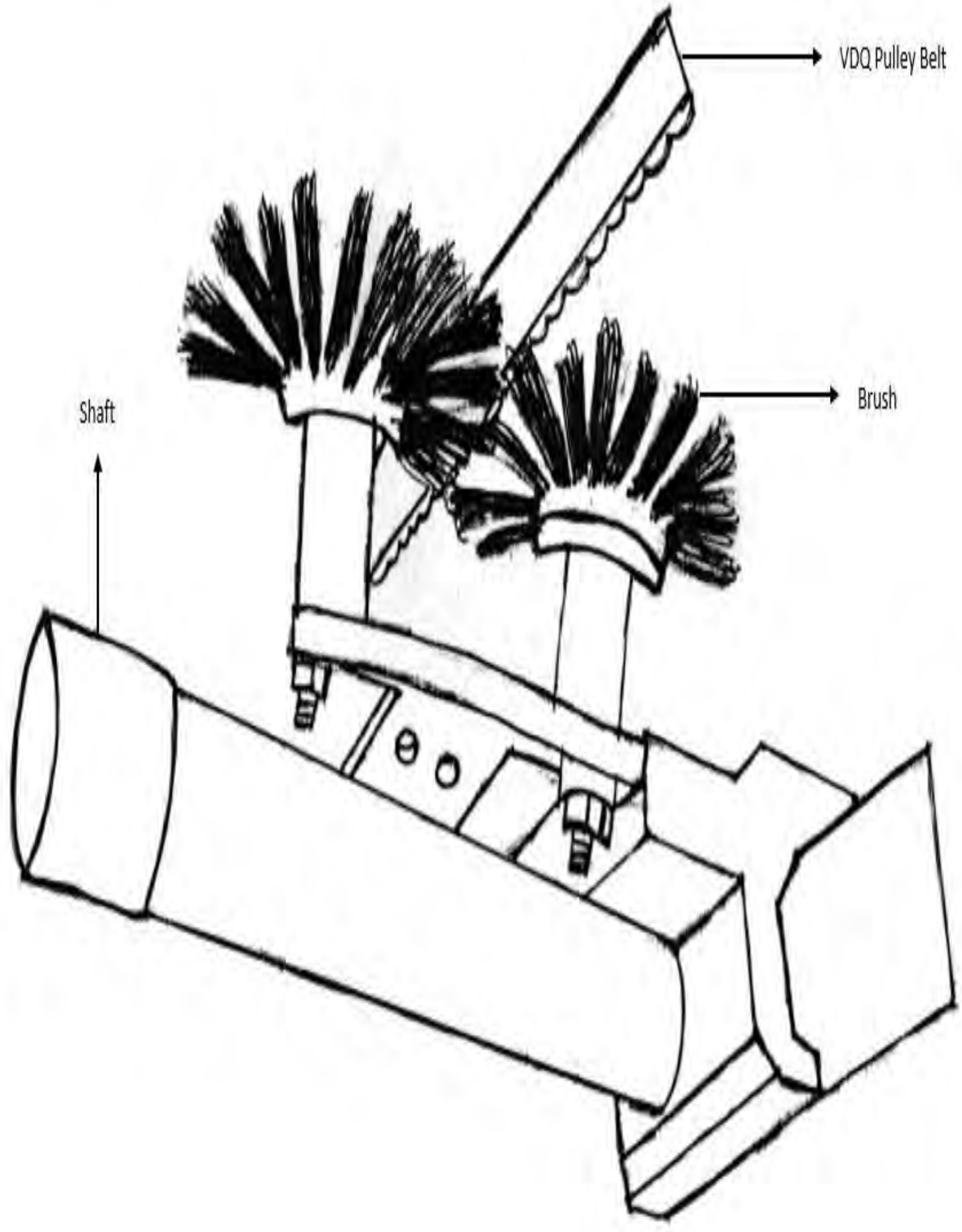


Figure **7.46**: A schematic diagram for a single brush-shelf with brushes for circular knitting machine

Figure **7.47**: An image of single brush-shelf based belt cleaning brush (*Courtesy:* Padma Polycotton Knit Fabrics Ltd.)

Figure **7.48**: An image of double brush-shelf belt cleaning brush (Belt cleaning brush,n.d.)

7.6.4 Justification for the development of an alternative cleaning device for the feed system

The typical brush-based cleaning apparatus for QAP system has some practical limitations. Firstly, the brushes are highly prone to wear on bristle side due to friction with moving belt (Figure 7.49). Secondly, the brushes get clogged frequently with dust//lint during operational hours and need frequent attention from the knitting machine

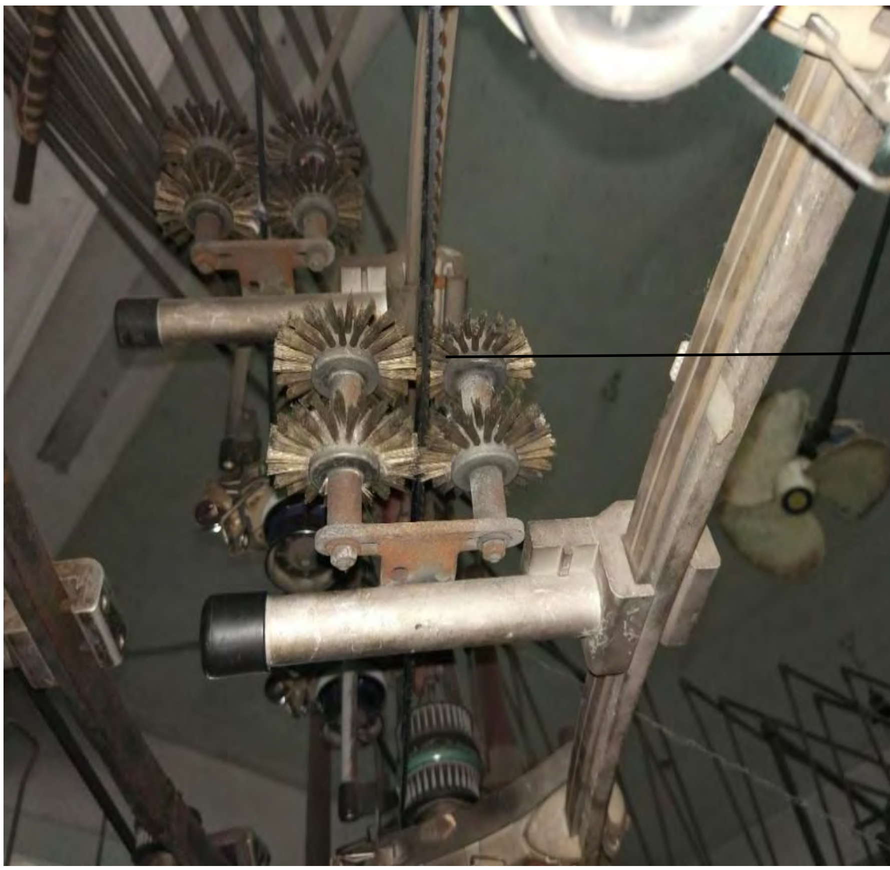


Figure **7.49**: A brush-shelf with worn brush

operator. Furthermore, the frequent manual handling of this cleaning aid might not fit ergonomically for all operators particularly those having comparatively shorter physical postures. Therefore, a need for an alternative cleaning apparatus is quite justified.

7.7 State of different cleaning systems for knitting machines

Numerous research works, mostly through patents, have been carried out over time to protect different parts of a knitting machine from environmental substances. Various dust/lint/fluff removing means (e.g., compressor and conduit, housings, fluid ejecting nozzle, air jet nozzle, filter, suction, blower, fan, airstream, etc.) were developed.

Shortland‟s (1958) invention comprises a compressor and some conduit means for transmission of compressed air. The compressor, synchronized with the machine drive, is designed to supply compressed air at a relatively low pressure. Conduit means are designed to transmit such air at the required point or points from which it can be directed in jet form to the machine parts need to be clean from lint or fluff.

Abrams and Tetrault (1966) showed a typical apparatus that was designed for blowing lint and other foreign objects away from the critical parts of the knitting machines having top creel arrangement.

Schmidt (1965) proposed some means for removing dust from circular knitting machines, consisting of one or more housings. The dust is raised and swirled up by an air steam inside the housing and then sucked of by a suction system. The deposited dust is further collected in a dust bag or thrown away into the open air. The invention was based on the principle of raising the dust by means of a blower at the spot where it collects, followed by sucking the dust off by means of a suction fixture. This method claims the advantage of taking air from the blow tubes directly to even relatively inaccessible spots without any damaging effects on the threads and stitch forming tools when the dust is moved from the spots where it collects.

Abrams(1969) invented a lint removing device having a plurality of fluid expelling nozzles which are adopted to be oscillated or reciprocated about portions of a circular knitting machine to prevent the accumulation of lint on such portion of the machine.

Nurk (1982) proposed a dust-collecting system for a circular knitting machine that has a needle cylinder and loop-forming instrumentalities which form loops along an annular loop-forming zone. A plurality of suction nozzles orbits about the annular loop-forming zone to collect dust and fluff from the zone.

Yorisue and Morimoto (1987) invented a waste fiber removing device that is provided with at least one air jet nozzle which is sufficiently flexible adjacent its outer free end for imparting a fluttering motion. The air jet nozzle is either stationary or may be rotated to prevent the accumulation of lint on various adjacent parts of the knitting machine.

Rovinsky and Meszaros (1989) described a knitting machine attachment using pressure air flow through, and discharging from, plural flutter tubes to control the accumulation of lint. Each individual tube construction consists of an inner circular bore encircling elliptical wall which causes a flutter or pivotal traverse in a specified plan or path where lint is likely to accumulate.

Igarashi and Lida (1993) described a collector/ remover of dust in knitting machine. Fibers generated adjacent the knitting section of the knitting machine and adjacent yarn feeding devices of the machine is blown to a filter adjacent at the top of the machine. The lint is removed from the filter by a rotatable filter cleaner and then is transported by suction to a vacuum device outside of the machine.

Igarashi and Lida (1994) also showed an impressive technique for dust collection /removal and controlling in knitting machine. During operation of the apparatus, the suction/blowing means overlying the knitting section of the knitting machine causes the fiber waste generated at the upper part of the knitting section to be moved upwardly through the suction duct associated with the suction-blowing means. Mutually spaced fiber waste collectors upon the knitting machine and creel of a knitting unit collect fiber waste which is then withdrawn by a fiber waste remover. The waste remover is selectively connectable to different ones of the fiber waste collectors. Sensors detect when the fiber waste collected by the collectors exceeds a predetermined amount.

Izumi (1995) invented an apparatus where an injection nozzle is located on a rotating cylinder of a circular knitting machine for removing dust, lint and waste fibers as well as lubricating the knitting unit. The nozzle, located between the sinker cap and sinker cam in general axial alignment with the sinker groove, includes a tip opening located adjacent the knitting unit. This nozzle also includes a receiving end located opposite the tip opening. Mist-oil and air is supplied to the injection nozzle. A holder is mounted between the mist-oil supply and the injection nozzle to enable the mist-oil and air to move through the receiving end of the injection nozzle to be discharged at the tip opening of the injection nozzle for cleaning as well as lubricating the knitting unit.

Tsay (1996) showed a dust blower, mounted at the centre of the circular knitting machine, for blowing dust and fluff away from the annular loop forming zone of the circular knitting machine. The dust blower includes a rigid guide tube and a swivel nozzle head. The rigid guide tube is connected to a compressed air source and rotates horizontally by a constant speed motion. The swivel nozzle head is mounted on one end of the rigid guide tube and rotates vertically when compressed air is driven out of its radial nozzles.

Baumann(1998) developed a fan-based cleaning apparatus for utilization in connection with circular knitting machines, and especially circular knitting machines which would otherwise not have the dimensions suitable for the use of fan-based cleaning apparatus having a rotating arm.

Gutschmit (1998) explained some means for deterring lint and debris accumulation on the knitting elements of the circular knitting machine, particularly having two needle beds. According to his claim the needle and dial slots of a circular knitting machine can be significantly cleaned by enclosing an annular air chamber spanning between the cylinder and dial, and delivering a pressurized air steam into the chamber. The air stream will blow lint, debris and contaminations away from the critical knitting elements (e.g. needles and sinkers) and prevent the accumulation of such materials within the cylinder and dial slots.

Willmar, Sickinger and Berwald (2006) introduced a dust removal device which contains air distribution channels. These channels are configured in segments and are connected to a compressed air source via radial air supply channels. The air distribution channels are designed to discharge into radial gaps. The radial gaps, present between the segments, are sealed outwardly with sealing means.

From above discussion, it can be concluded that researchers and/or inventors used mainly two basic techniques- lint collecting and lint blowing means to control lint. Lint collecting technique was basically a lint suction system whereas lint blowing technique involved a system that applies jet of compressed air. Though some existing technology (like brush cleaning) is available to keep QAP based feed system away from dust via cleaning of QAP belt but, none of these previous studies mentioned any means of keeping the said feed system clean directly using compressed air. It is quite expected that an apparatus using pressured air flow will be able to obviate the accumulation of lint or fluff in any critical point of the knitting machine efficiently.

7.8 Material and Method

7.8.1 Constructional elements

To develop a prototype compressed air-based cleaning apparatus, cheap and available material components have been used. Soft flexible plastic pipes with roller clamps have been used as conduit means. Polyvinyl Chloride (PVC) based board and channels have been utilized for housing. Hard plastic fittings like Tees and Elbows together with metal screws were used as joining aids. The device is developed in such a way that it can be mounted on the feed-units holder ring conveniently.

7.8.2 Constructional method

A sketch of the desired prototype device is shown in Figure 7.50. The width and total thickness the QAP toothed belt (not mentioned in the sketch) that would undergo cleaning, were considered as 10 mm and 3 mm respectively following the toothed belt dimensions of the renowned Memminger-IRO drive systems (Drive Systems: TOOTHED BELTS ,n.d.)

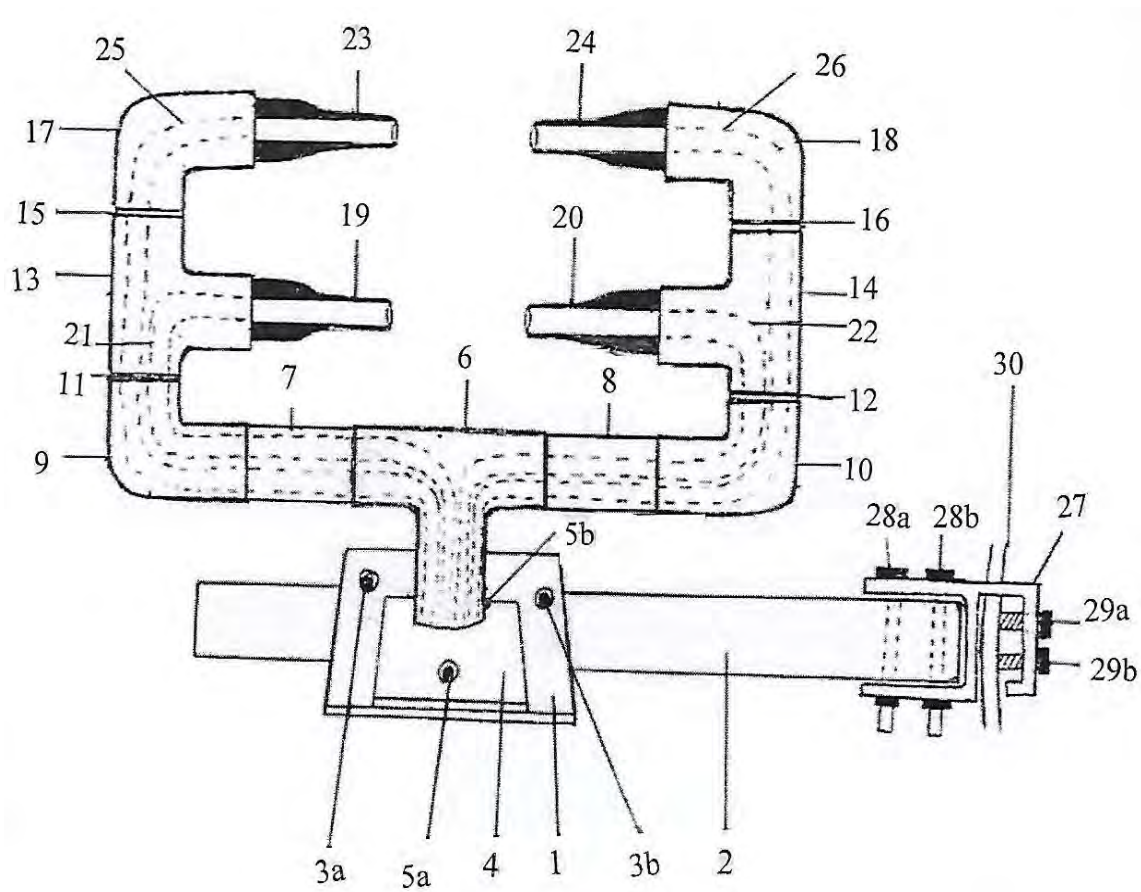


Figure **7.50**: A drawing of the proposed air nozzle based QAP belt cleaning apparatus

As in figure 7.50, a base plate (1) is attached to a shaft (2) by screw (3a,3b) to hold the rest parts of the device. An upper base plate (4) is attached by screw (5a,5b) above the first base plate (1) for reinforcement purpose. These base plates (1,4) are made of PVC composite board. A tee (6) is placed in the center of the upper base plate (4) to join pipe-segments (7,8). With the pipe-segments (7, 8), two 90° elbows (9, 10) are attached. Another two PVC pipe-segments (11, 12) were attached with other ends of the elbows (9,10). Two tees (13, 14)were joined on both open ends of the PVC pipe-segments (11,12). At the top openings of the tees (13,14), another two pipe-segments of PVC pipes (15,16) were attached. On the other end of these PVC pipe-segments (15,16), two elbows (17,18) were attached. Air nozzles (19, 20) attached with flow tubes (21,22) were incorporated with the side openings of tees (13,14) whereas air nozzles (23,24) attached with flow tubes (25,26) were incorporated with the openings of elbows (17,18). The tubes (21, 22, 25, 26) act as conduit means and are connected to the air distributor of the machine. A roller clamp was used with each flow tube (21, 22, 25, 26) to regulate the rate of air flow. Typical diameters of PVC pipe-segments and nozzles are around 12.5mm and 5mm. The distance between two face-to-face nozzles was kept at 23 mm so that belt to any corresponding nozzle distance remains at 10 mm. Compressed air pressure was maintained at around 210 KPa (around 2 bar) (Torlach, Safety Bulletin No.49, n.d.) through air regulator unit so that air jets directed to the belt passing between face-to-face nozzles are strong enough to blow away attached lint without any damaging effect to belt or making any deviation to the belt‟s running condition. The position of whole base plate (1) can be adjusted somewhat by tuning the position of screws (3a,3b). The shaft (2) is joined with feed unit holder ring (30) through a gripper (27). The gripper (27) is fixed with the shaft (2) by screws (28a,28b). Two other screws (29a,29b) are set at other side of the gripper (27), which are used for firm fitting of the gripper with the ring (30).

A typical diagrammatic set-up for this device on a circular knitting machine (Orizio-Johnan, E 24, 26-inch Dia.) is shown on Figure 7.51.

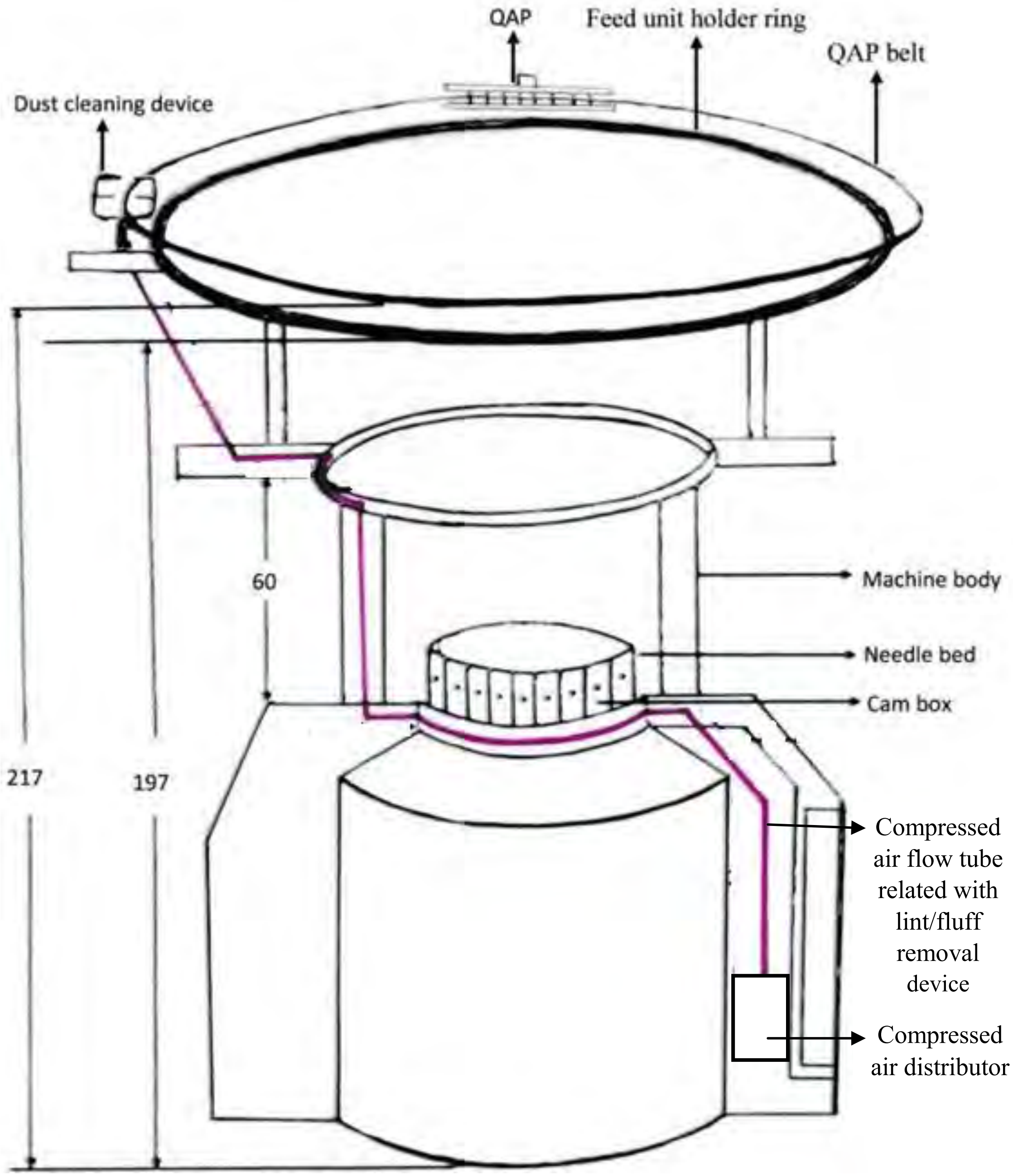


Figure **7.51**: Proposed attachment of a compressed air-based lint removal device on a circular knitting machine with QAP based positive feed system [all measurements are taken in centimeters for a commercial knitting machine (Orizio, Johnan)]

7.9 Device Installation with Corresponding Results and Discussion

7.9.1 Installation of the device

The device was first installed on a circular knitting machine (with an alternative gripper) in a lab setting for a trial run (Figure 7.52). A close look of the developed prototype apparatus is shown in Figure 7.53


The developed device

Figure **7.52**: The newly developed lint removal device attached to a knitting machine

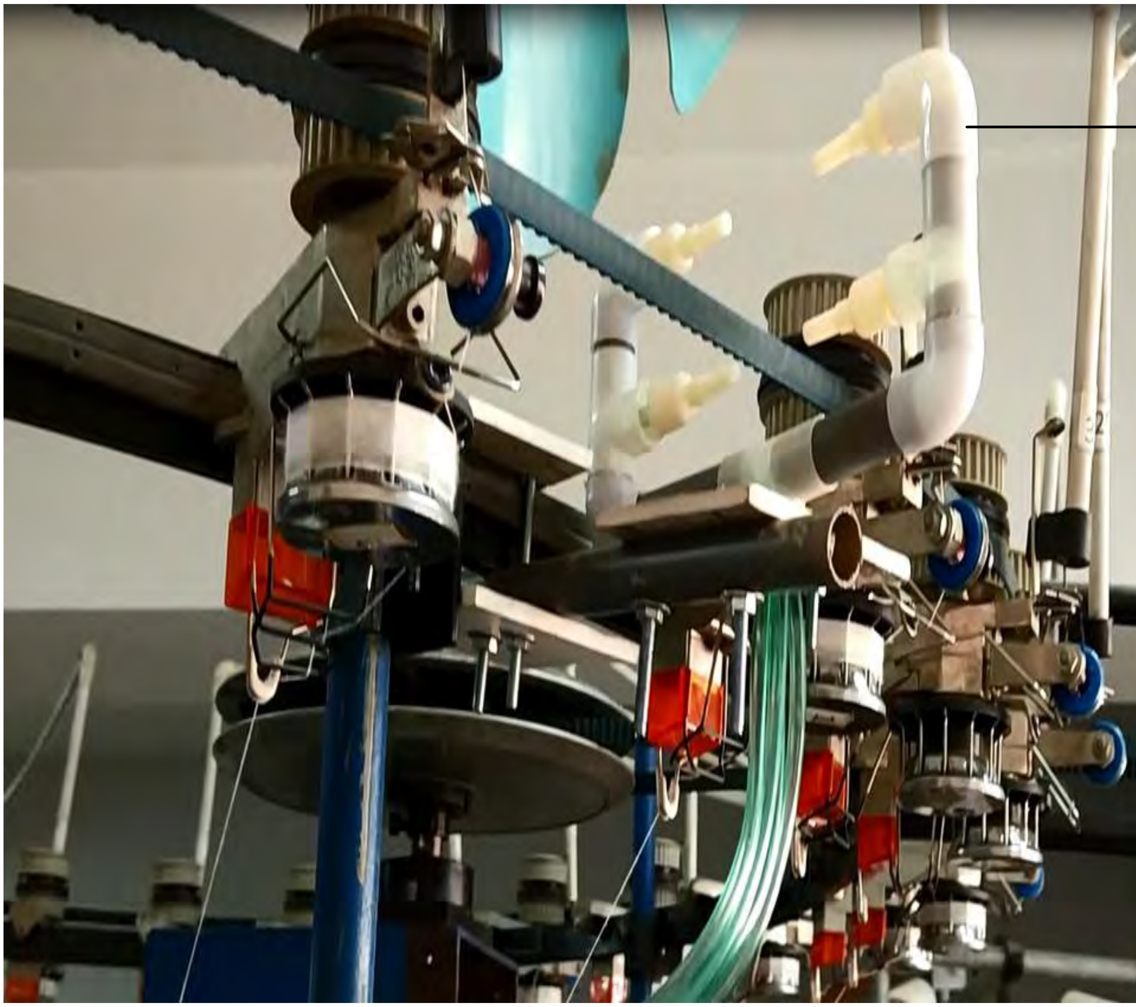


Figure **7.53**: A close view of the developed lint removal device for the QAP belt

7.9.2 Comparative cleaning performance between brush-based cleaning system and compressed air based cleaning system

In order to compare the cleaning performances, both the brush-based and compressed air-based cleaning devices were attached individually with same knitting machine for two consecutive days. The deposited dust from the QAP was collected and the mass of these were measured through a high precision SHIMADZU electronic balance (Type AY220) as shown in Figure 7.54. Related data with comments are included in Table 7.3.

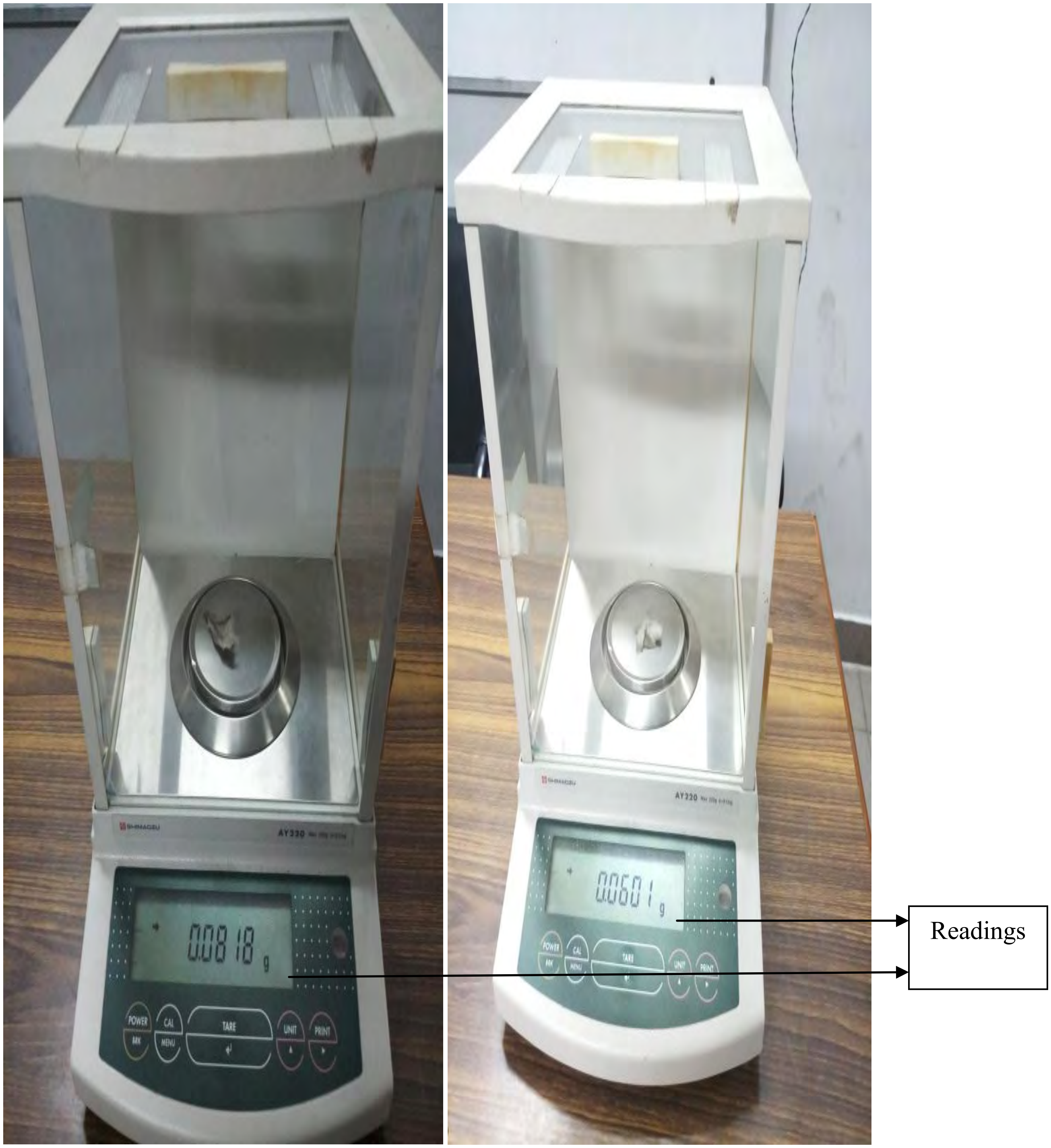


Figure **7.54**: Mass measurement of deposited dirt/fluff (Left- for brush-based cleaning device, Right- Compressed-air based cleaning device)

Table **7.3**: Comparative cleaning performance between brush-based cleaning device and compressed-air based cleaning device

Machine Specification	**Fabric Specification**	**Particulars obtained for Brush-based cleaning device**	**Particulars obtained for Compressed air based device**	**Difference between the cleaning performance**	**Comment**
Brand: JIA HAO Machine gauge=24 G Machine Dia= 34" No of needles=2556 No of feeder=102 Factory Name= Padma Poly Cotton Knit Fabrics Limited.	Type: Yarn: 30/1 Ne CVC (Cotton=60%,Viscose= 40%) Stitch length= 2.72 mm	Production date and time=23/12/18 to 24/12/18 (2pm to 2 pm) Total Production hours=24 Actual Production =312.5 kg Mass of dirt/ fluff collected over the scrolled segments inside QAP during the production hours = 0.0818 gm Mass of dirt/ fluff collected over the scrolled segments inside QAP for 1 kg production of knitted fabric= 0.00026176 gm	Production date and time=24/12/18 to 25/12/18 (2pm to 2 pm) Total Production hours=24 Actual Production =323 kg Mass of dirt/ fluf collected over the scrolled segments inside QAP during the production hours =0.0601 gm Mass of dirt/ fluff collected over the scrolled segments inside QAP for 1 kg production of knitted fabric= 0.000186068 gm	0.0000757 gm less dirt/fluff deposition inside QAP for 1 kg production of knitted fabric by the compressed air-based cleaning device over the selected time period of 24 hours	Due to installation of Compressed air-based cleaning device instead of brush-based cleaning device around 29 % less dust deposition was observed over the scrolled segments inside QAP.

7.9.3 Comparative cost analysis between brush-based cleaning system and compressed air based cleaning system for QAP belt

A typical cost calculation for the compressed air used by the proposed device is shown below. Here the calculation has been done on the perspective of the compressor (Brand:Gardner Denver,Model:ESM55-10A,Country of origin: Germany and Year of manufacturing:2016) used for the knitting floor of Padma Polycotton Knit Fabrics Limited. (Figure 7.55).

Figure **7.55**: Name plate of Gardner Denver compressor (Courtesy: PPCKFL)

7.9.3.1 Determining per unit cost of compressed air

To calculate the cost of compressed air, the following formula (modified) is used. Here maintenance and other operating costs have considered as marginal.

$$\text{Cost(Tk.)}=\left\{\frac{bhp\times 0.746\times operating\ \ hours\times(\frac{tk}{KW\,h})\times(\%time\ )\times(\%\,full\ \ load\ \ hp)}{Motor\ \ efficiency}\right\}(1)$$

(Hitchcox, Hydraulics and Pneumatics,n.d.)

Assuming motor efficiency as 100% and bhp to be equal to hp, equation (1) becomes

Cost (Tk.) $=hp\times 0.746\times operating\ hours\times(\frac{tk}{KWh})\times(\%time)\times(\%\,full\ load\ hp)$

Compressor shaft horse-power (hp) = $\frac{55}{0.746}$ [As, installed motor capacity = 55 KW] = 74

Total operating hours of the compressor per year

= (365−67) days [total holidays per year = weekly holidays +

Public holidays=52+15=67 (As per year 2017)]

= 298 days

= (298×24) hours

= 7,152 hours

Electricity charge = 8.15 Tk. / KWh (Bangladesh Energy Regulatory Comission,n.d.)

Compressor running in fully loaded state = 80% of time(Approx.)

Compressor running in unloaded state (25% full-load hp) condition = 20% of time (Approx.)

Cost when fully loaded = $(74\times 0.746\times 7{,}152\times 8.15\times 0.80\times 1.0$ Tk.

= 25, 74,219.93 Tk.

Cost when partially loaded = $74 \times 0.746 \times 7{,}152 \times 8.15 \times 0.20 \times .25$Tk.

= 1,60,888.74 Tk.

Cost of electricity consumed by the compressor per year or Cost of compressed air generated per year = (25, 74,219.93+1, 60,888.74) Tk.

= 27, 35,108.67Tk

.

Compressed air generated per year (estimated)

= 9.51 m^3/min [at 10 bar]

= 9.51×60 m^3/hour

= 9.51×60×7152 m^3/year

= 40, 80,931 m^3/year

∴ Cost/ m^3 of compressed air (at 10 bar) $= \frac{27{,}35{,}108.67}{40{,}80{,}931}$ Tk.

= 0.67 Tk.

7.9.3.2 Cost of compressed air consumed by the developed device

Let the knitting machine run at each working day on an average running time of 21 hours/day (indicating an efficiency of 87.5%).

Here, Air nozzle to belt distance = 10 mm, Air nozzle dia, d= 5mm and Incoming air pressure for nozzle = 2 bar

Average velocity of compressed year ejected from the nozzle, V= 22 m/s, {as found through an Anemometer(Figure 7.56)} (APPENDIX P)

Figure **7.56**: An anemometer

Compressed air consumption per nozzle per year,

$=V\pi\left(\frac{d}{2}\right)^2\times60\times60\times21\times298m^3$

$= 22\times\pi\times(\frac{5}{2\times1000})^2\times60\times60\times21\times298m^3$[As, 1000mm=1m]

$= 9{,}731.74\ m^3$

Now, $9{,}731.74m^3$ compressed air at 2 bar is equivalent to $1{,}946.35\ m^3$ at 10 bar [According to Boyle"s Law]

∴Cost of compressed air per nozzle per year = (1,946.35×0.67) tk

= 1,305 Tk.

∴Cost of compressed air per two nozzles per year = (1,305×2) Tk.

= 2,610 Tk.

∴Cost of compressed air per four nozzles per year = (1,305×4) Tk .

= 5,220Tk

So, Percentage of cost consumed by air nozzles considering total cost of the compressed air :

For single air nozzle $= \frac{1,305}{27,35,108.69}\times100\ \%$

$= 0.048\%$

For two air nozzles $= \frac{2{,}610}{27{,}35{,}108.69} \times 100\ \%$

$= 0.095\%$

For four air nozzles $= \frac{5{,}220}{2{,}735{,}108.69} \times 100\ \%$

$= 0.19\%$

Therefore, the developed device (with four nozzles for a two QAP system) will consume about 0.19% of total cost need to generate compressed air by the compressor.

7.9.3.3 Cost involved when using brush type cleaning apparatus

For a two QAP positive feed system four pieces of brush are required.

Now, price of single piece of brush (As per the quotation provided by the local agent of Memminger IRO, i.e., APPENDIX O) = 1,400Tk

∴ Price of four brushes = (1,400×4) Tk.

= 5,600 Tk.

Expected life time of each brush is about one year [as per supplier‟s warranty]

Therefore, expected cost consumption per year for a brush-self based cleaning apparatus with four brushes for a two QAP feed system = 5,600 Tk.

7.9.3.4 Manufacturing Cost (Cost of raw materials) for the developed device

As the device was built on prototype basis, the manufacturing components were purchased locally .The prices of different components involved (according to local market price in November 2018) are shown below.

Price of 1 plastic elbow = 4 Tk

Price of 1 plastic tee = 4 Tk

Price of 1 air nozzles with air/flow tube = 100 Tk

Price of base plates (Hardboard) = 20 Tk

Price of PVC pipe = 22 Tk

Price of 1 Screw = 5 Tk

Therefore, cost of raw materials associated with the device [without the gripper]

= Cost of component parts (4 elbows + 3 tees + 4 air nozzles with flow tube + Hard board +PVC pipe + 4 screws)+Labor charge

= (4×4+3×4+4×140+20+22+4×5) +1000 (estimated) Tk.

= 1650 Tk ≈ around 20.63 USD only [1USD=Tk.80 (average) in 2018]

Note: *The selling price is not considered here*

7.9.3.5 Price of a double brush-shelf cleaning device for QAP belt

The manufacturing cost of a brush type cleaning apparatus could not be obtained as the manufacturer was not willing to disclose it due to company"s policy. However the selling price was 15000 Tk. (around 185 USD) only (As per the quotation provided by the local agent of Memminger IRO, i.e., APPENDIX Q)

7.10 Comparative analysis between some prominent features of brush based cleaning system and compressed air based cleaning devices

Table 7.4 highlights some crucial differences between a Brush-based cleaning apparatus and the developed Compressed-air based cleaning apparatus

Table **7.4**: Some key differences between Traditional brush-based cleaning device and the developed compressed-air based cleaning device

Brush based cleaning apparatus	**Compressed air based cleaning apparatus**
Here the QAP belt comes in contact with two	QAP belt is contactless with the

Brush based cleaning apparatus	Compressed air based cleaning apparatus
moving brushes during operations	device.
Due to friction between moving belt and brushes, the belt, particularly the brushes are highly prone to wear on bristle side (as shown in Figure 7.55).	Damage due to friction is not possible here.
Frequent cleaning of brushes are required here as dust collected by the brush causes jamming inside bristles resulting reduced cleaning efficiency.	No need for frequent cleaning. Operator has to be aware of any leakage of compressed air.
It is ergonomically unfeasible for workers, particularly of Bangladesh origin, to clean the brush time to time while operating the machine as the average height of Bangladeshi male is around 167.7 cm(Islam,2014) and female is around 150.6 cm(Subramanian, Ozaltin and Finlay,2011) where the brush-shelf/feed unit holder ring of a large diameter circular knitting machine is more than 180cm high from the ground (for example 197 cm for Orizio circular knitting machine of model JOHNAN-FIHNAN as found on the knitting floor of Padma Polycotton Knit Fabrics Ltd.).	No need for frequent handling of this part as the device uses compressed air for its desired function.

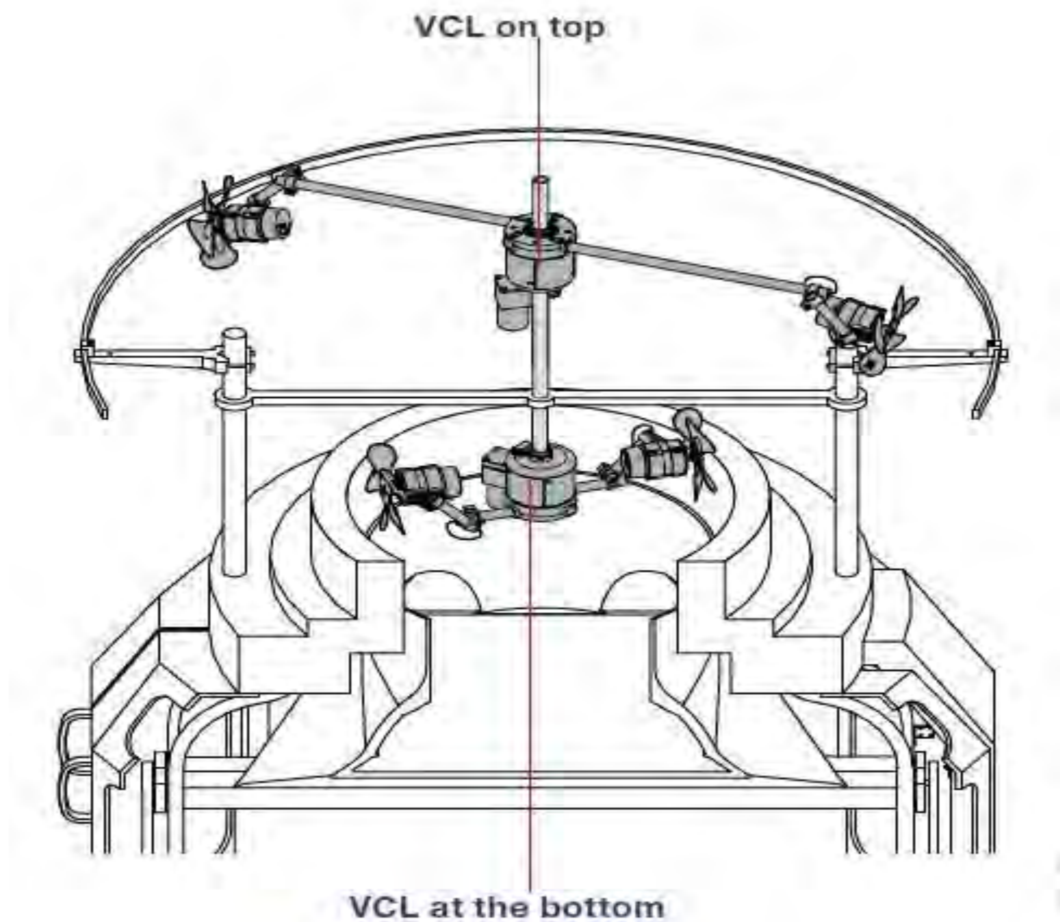
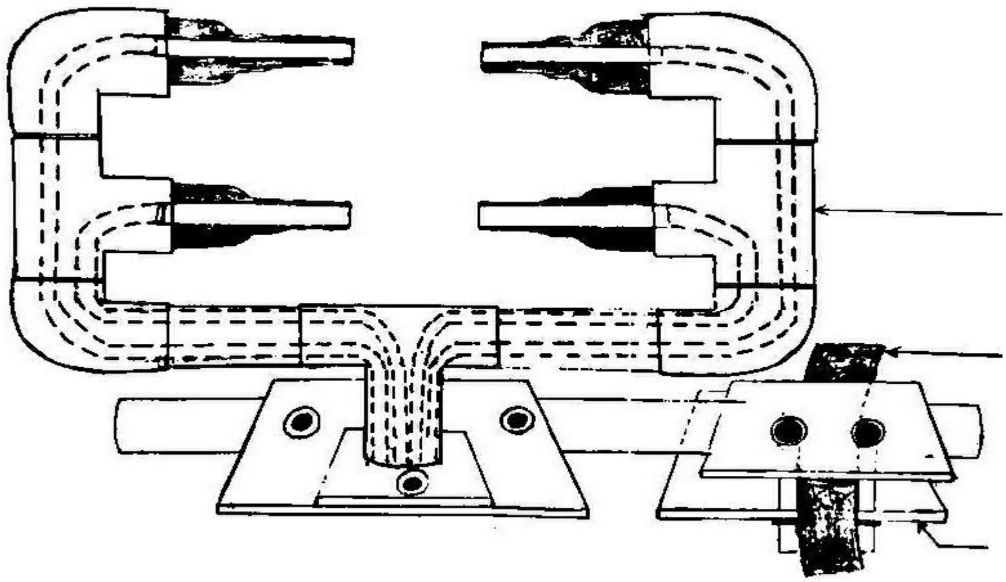


Figure **7.57:** Venti-cleaner (VCL 5 Venti-Cleaner,n.d.)

7.11 Limitations Faced through the Stages of Machine Modification

The findings of this study have to be seen in light of some limitations. Firstly, there is a paucity of research available on the performance of brush-based clean system for the circular knitting machine. Secondly, a reliable source for some compressor related information (e.g., motor efficiency, compressor loading, and unloading duration) was unavailable to the particular knitting mill used in this study. This information was collected from the maintenance department without cross verification, which may lead to some erroneous judgment while calculating the cost of generated compressed air. However, it can be realized that these limitations are not so potential to hamper the research outcome significantly. Additionally the gripper as per drawing could not be constructed due to some practical limitations. Therefore, an alternative was built with simple screws for attaching the device with the machine (Figure 7.58), which was also satisfactorily workable during machine running condition.



7.58: Developed device with alternative gripper

7.12 Recommendation

The compressed air based cleaning system for QAP belt is an alternative to the present available brush-based cleaning system. The prototype device developed here is cheaper (though the device was not evaluated in commercial scale and selling price was not considered, the calculated manufacturing cost is significantly lower!!) and user-friendly to install and operate. Moreover, it does not need any additional requirement of support device as the air distributor is already available in the machine as an essential part of it. The calculated operating cost is also not higher if the device is used as a replacement of brush based cleaning apparatus for QAP belt. Even the cleaning performance is better too. It is therefore, highly expected that circular knitting machine manufacturers can evaluate this device and its principle for adapting it in their machines.

CHAPTER-8

SUMMARIZED RESULTS AND DISCUSSION

The key tasks associated with this research study were executed through four different research approaches. These are:

1. Associating yarn tension with fabric quality,i.e. course length, during knitting production: *through a model derivation*.
2. Identifying the effect of machine speed over yarn input tension and corresponding yarn delivery: *through a predictive analysis*.
3. Evaluating a knitting machine performance: *through constructing a time series plot with some specific values of yarn input tension*.
4. Knitting machine modification: *through development of a typical machine accessories/device which will regulate yarn tension variation due to fly/dust deposition in the feed system as well as minimize associated fabric defects*.

The corresponding results and discussion have been summarized below.

8.1 A Predictive Model for Fabric Course Length

8.1.1 The model

A model in the form of an equation has been developed for predicting actual course length in grey knitted fabric from online reading of yarn tensile force and yarn delivery. The defined simple equation has the form:

$$L_0 = \left(\frac{{L_{T1}}^{T_2 L_{T2}}}{{L_{T2}}^{T_1 L_{T1}}}\right)^{1/\left(T_2 L_{T2} - T_1 L_{T1}\right)}$$

where

T_1 = A particular value of average yarn input tension measured on the yarn path during the dynamic knitting process

L_{T1}= Length of yarn delivered to the knitting zone per cylinder revolution at tension T1

T_2= Yarn tension (other than T_1) measured on the yarn path during the dynamic knitting process

L_{T2} = Length of yarn delivered to the knitting zone per cylinder revolution at tension T_2

L_0 = Course length = Actual length of yarn in a course on a relaxed fabric = Relaxed form (in length) of L_{T1} or L_{T2}.

8.1.2 Experimental verification of the model

The predicted course length through this model has been compared with that found from the actual fabric by a recognized apparatus i.e. HATRA Course Length Tester, as shown in Figure 8.1 (derived from Table 4.16). Simultaneously to check whether the

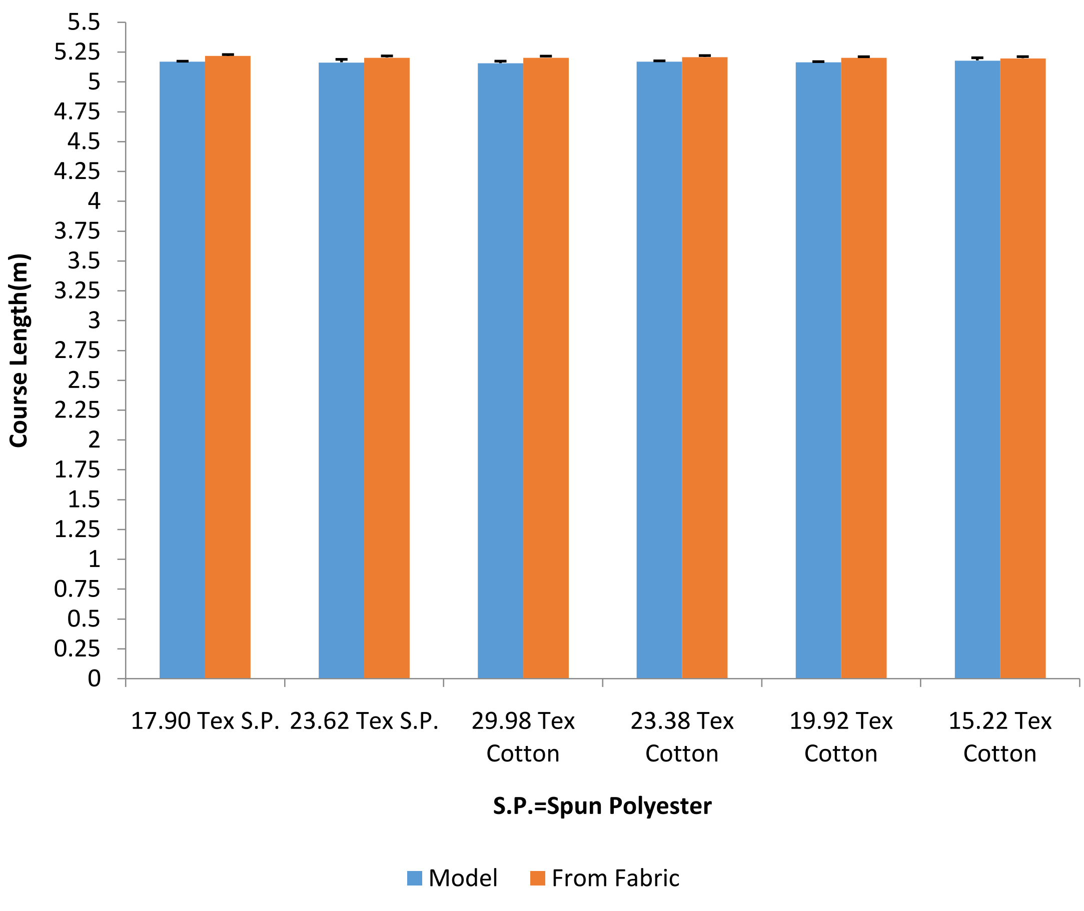


Figure **8.1**: Comparison between average values of actual and model predicted course lengths differences between predicted and measured course lengths are statistically significant or not, two sample t-tests were carried out for some specific fabric samples. The summary is shown in Table 8.1 (derived from Table 4.9, 4.10 and 4.14 respectively).

Table **8.1**: Summarised results of t-tests between model predicted and measured course lengths

<table>
<tr><th>Null Hypothesis</th><th>Statistical parameters for a two sample t-test</th><th>Fabrics knitted with 17.90 Tex Spun Polyester</th><th>Fabrics knitted with 23.62 Tex Spun Polyester</th><th>Fabrics knitted with 23.38 Tex Cotton</th><th>Comment</th></tr>
<tr><td rowspan="3">There is no statistically significant difference between model predicted and measured course lengths</td><td>Mean difference</td><td>0.0468m</td><td>0.040m</td><td>0.0385m</td><td rowspan="3">Null hypothesis can be rejected (based on 95 % confidence Level).</td></tr>
<tr><td>t-value</td><td>5.31080014</td><td>3.192661075</td><td>6.839379331</td></tr>
<tr><td>p-value</td><td>0.0000012894</td><td>0.000316741</td><td>0.00000264187</td></tr>
</table>

From Table 8.1 it may be concluded that the differences between the model predicted course length values and fabric course length values (measured by an „off-line" instrument like HATRA Course Length Tester). are statistically significant. However the model is quite effective enough [mean difference is less than 1% only, which translates a lesser stitch length of 0.02 mm in most cases !(Table 4.16)] to predict course length of the fabric from the readings of yarn input tension and corresponding yarn delivery/machine rev. during machine running state.

8.2 Empirical Relation between Machine Rotational Speed and Yarn Tension as well as Yarn Delivery to Needles:

The effect of machine speed over yarn input tension and corresponding online yarn length /machine rev. is statistically observed via predictive analysis through linear regression at two different levels of yarn input tension (adjusted by cam setting points). Figure 8.2 shows the corresponding trend lines and Table 8.2 summarizes the key

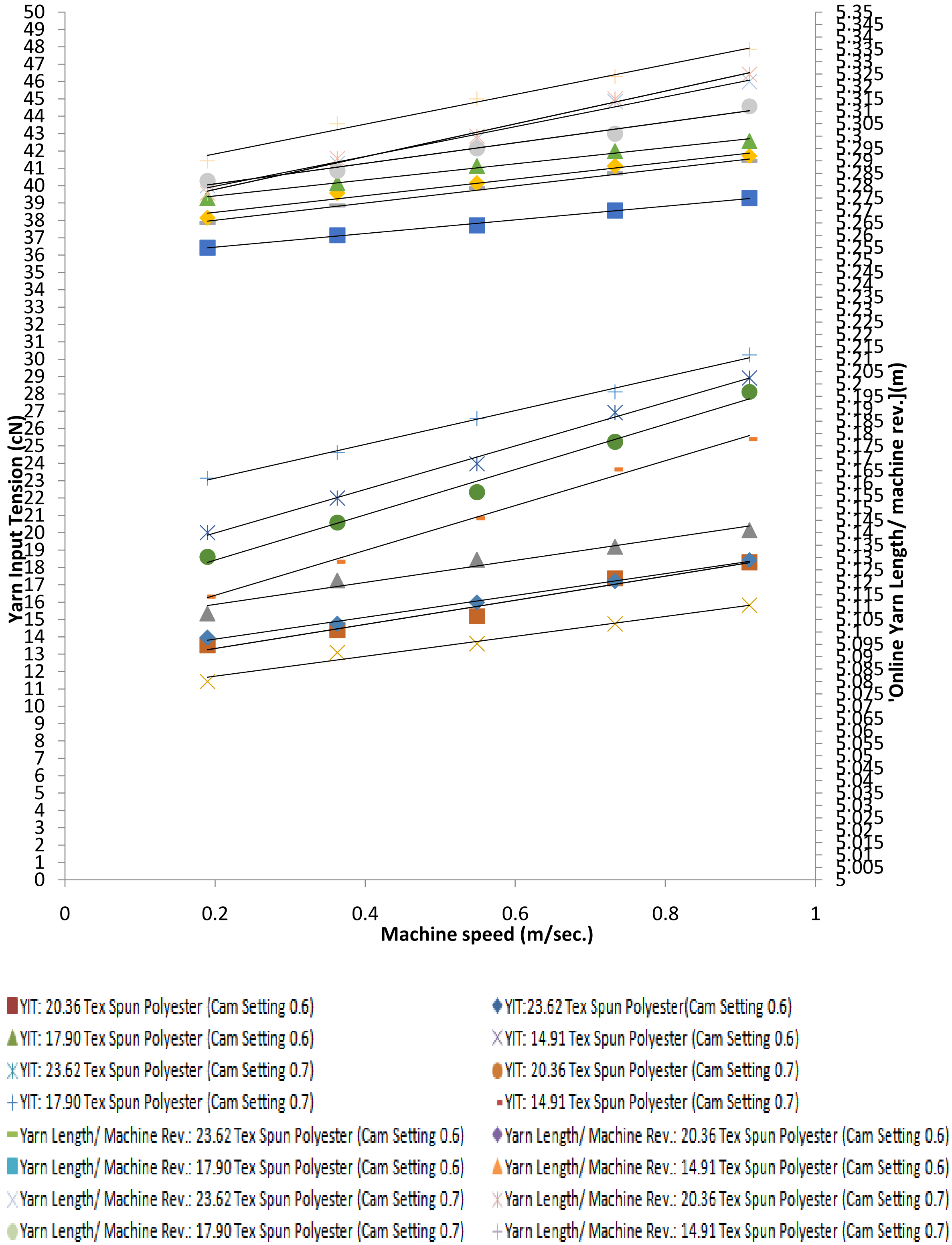


Figure **8.2**: Effect of machine speed on yarn input tension and online yarn length/machine rev. with trend lines outputs from the regression analysis.

Table **8.2** : Regression summary obtained for Machine Speed (MS) and Yarn Input Tension(YIT) and Machine Speed (MS) and online Yarn Length/Machine Rev.(YL).

Variables of interest	**Cam setting point**	**Regression summary**	**23.62 Tex**	**20.36 Tex**	**17.90 Tex**	**14.91 Tex**
Machine speed (MS) and Yarn Input Tension (YIT)	0.6	R Square	0.995768528	0.96896060	0.96176513	0.97622757
		Regression Equation	YIT(cN)= 6.299132303 *MS +12.6032567	YIT(cN)= 6.93610962 *MS +11.943301	YIT(cN)= 6.35086107 *MS +14.592836	YIT(cN)= 5.74050170 *MS +10.588168
	0.7	R Square	0.995441313	0.98780043	0.99685277	0.99618690
		Regression Equation	YIT(cN)= 12.54554526 *MS +17.475477	YIT(cN)= 13.0507880 *MS +15.809897	YIT(cN)= 9.75293921 *MS +21.189735	YIT(cN)= 12.9386644 *MS +13.801497
Machine speed (MS) and online yarn length/machine rev.	0.6	R Square	0.994831284	0.97142735	0.99677211	0.99254872
		Regression Equation	YL(m)= 0.034720627 *MS +5.2591244	YL(m)= 0.03357933 *MS +5.2625515	YL(m)= 0.02756112 *MS +5.2496579	YL(m)= 0.03252677 *MS +5.2693297
	0.7	R Square	0.992332851	0.99442382	0.98000286	0.98902556
		Regression Equation	YL(m)= 0.06012254 *MS +5.267768677	YL(m)= 0.066127987 *MS +5.26526928	YL(m)= 0.041372076 *MS +5.27247018	YL(m)= 0.032526773 *MS +5.26932979

From Figure 8.2 it may be observed that strong linear correlation exists between machine speed and yarn input tension as well as machine speed and corresponding yarn delivery/machine revolution with R-Square (Co-efficient of determination) values of greater than 0.9 (Table 8.2) .Therefore using the regression equations (from Table 8.2), different empirical relations could be established, like, forecasted change in Yarn Input Tension(YIT) and Online Yarn Length/ Machine rev. for some change in machine speed (MS),Some examples are depicted through Figure 8.3 and Figure 8.4 respectively.

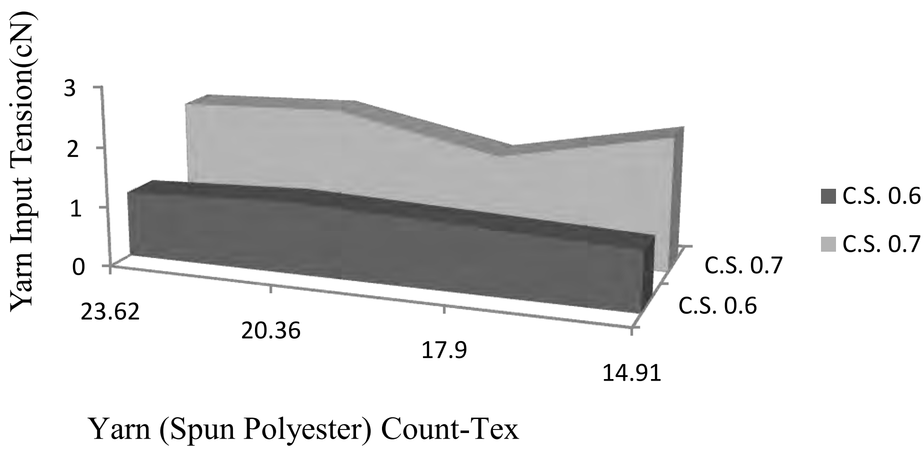


Figure **8.3**: Predicted approximate change in YIT for change in machine speed by rpm of 05 (0.173 m/sec)

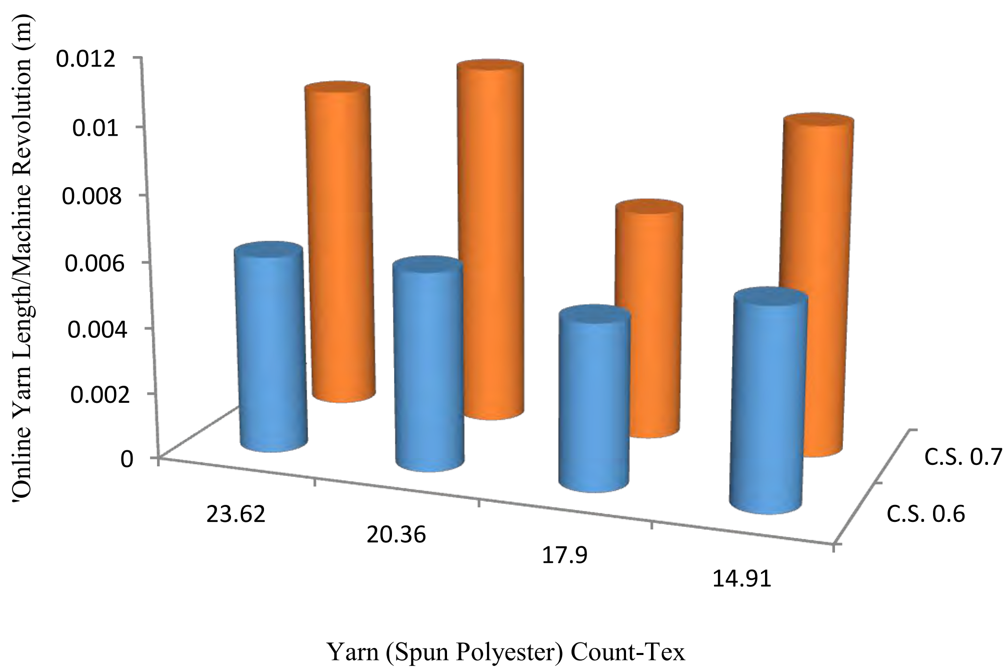


Figure **8.4**: Predicted approximate change in online yarn length/machine revolution for change in machine speed by rpm of 05 (0.173 m/sec

8.3 Performance Evaluation of a Knitting Machine through YIT Analysis

An industrial circular weft knitting machine having positive storage feed system has been observed for its performance evaluation. Run charts have been built using second wise highest yarn input tesion (YIT) t values for some production runs to detect different patterns of non-randomness in YIT waveforms. By evaluating the p-values for different special cause variations the selected production runs have been identified as normal or abnormal. The p value is the evidence **against** the null hypothesis ,i.e. there exists no non-randomness pattern in the data. The smaller the p-value, the stronger the evidence for rejecting the null hypothesis. Sidewise a check for astronomical data points was also carried out. The result is shown through a pie chart in Figure 8.5, which has been synthesized from Table 6.1

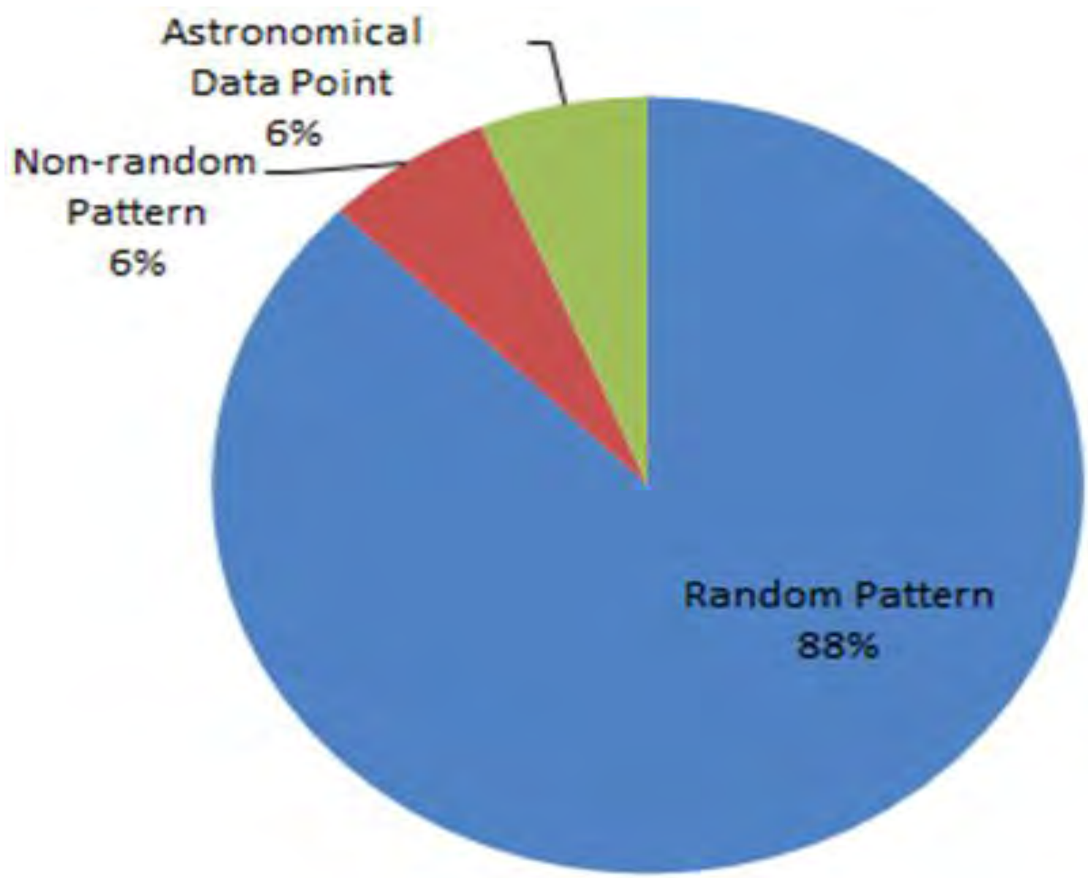


Figure **8.5**: Graphical representation of evaluated production runs for performance evaluation

As the non-randomness patterns were absent in more than 85% of the evaluated production runs, the experimental knitting machine may be considered having satisfactory operational performance

8.4 Knitting Machine Modification: An Innovative Approach

To mitigate the tension fluctuation in running yarn caused by dirt/dust deposition inside the positive storage feed system, a compressed –air based lint removal system has been developed as shown in Figure 8.6.

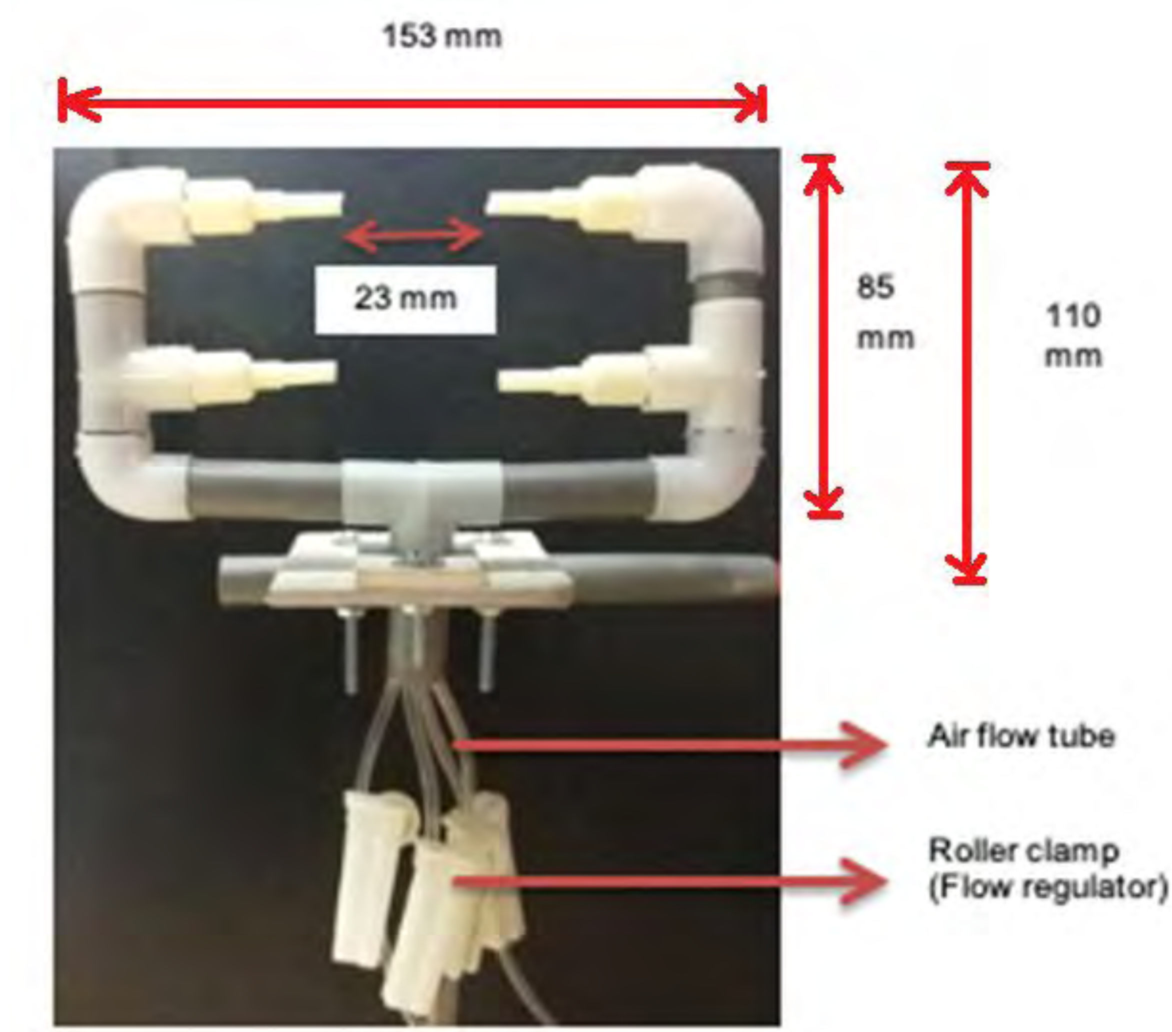


Figure **8.6**: An image of the developed lint removal device for the drive belt ,i.e., QAP belt of the positive storage feed system

Through a comparative analysis (particularly on the basis of performance and cost), as shown in Figure 8.7, it may be found that the developed device is a better alternative to its counterpart, i.e. the currently available brush-based cleaning device for the drive belt of the positive storage feed system.

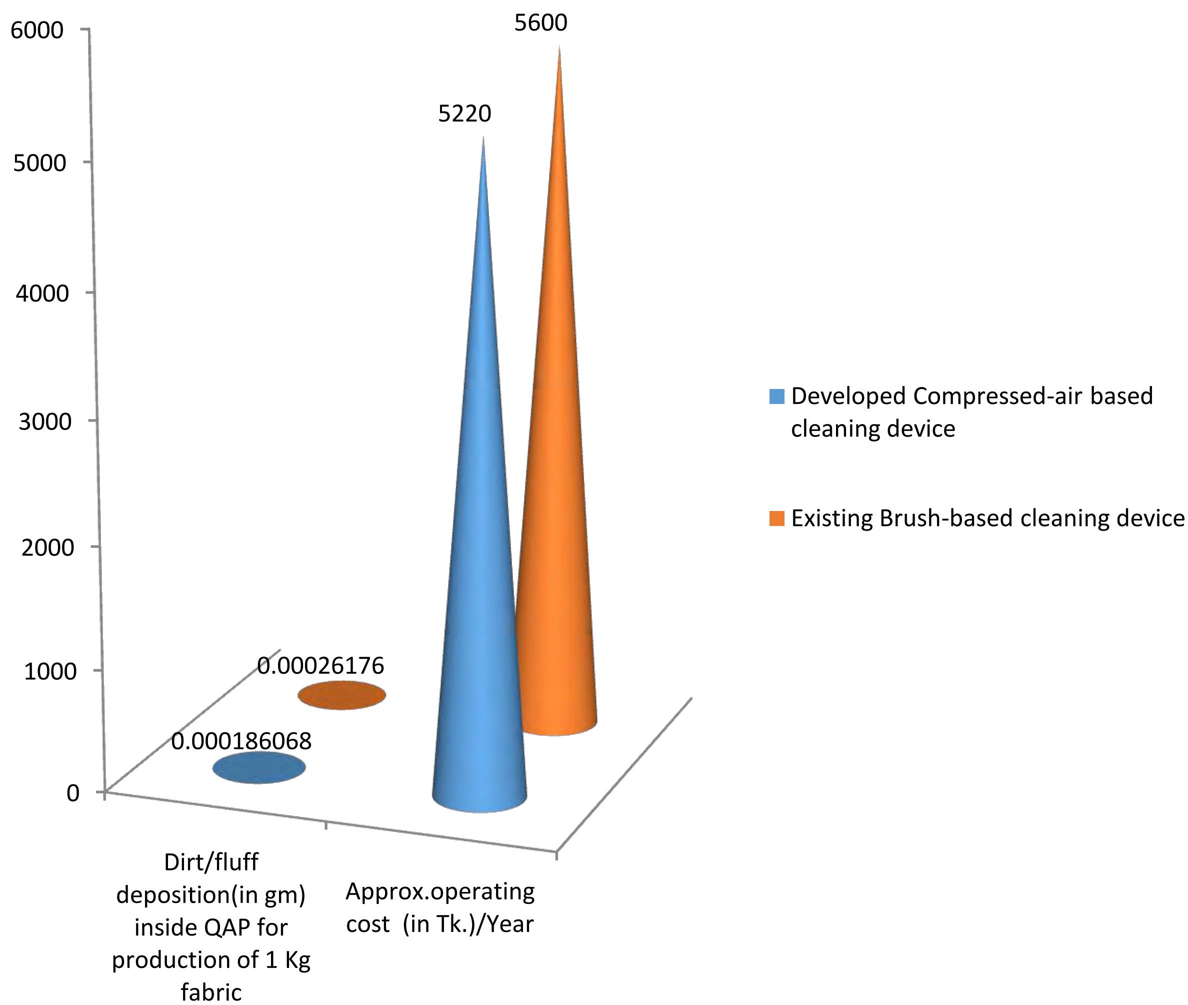


Figure **8.7**: Comparative analysis between developed compressed-air based cleaning device and traditional brush-based cleaning device based on cleaning performance and running cost

CHAPTER-9
CONCLUSION

9.1 Summary:

The mechanical action of knitting generates tensile force on yarn throughout its running path and the most critical yarn input tension has been analyzed in the form of correlating it with fabric quality, machine speed and machine performance. To relate yarn input tension with fabric quality, i.e., loop length precisely an attempt has been carried out to derive a model for prediction of actual course length in grey knitted fabric from online reading of yarn tensile force and yarn delivery. Correlation to machine speed as well as „on-machine" course length was carried out through regression analysis. To judge the machine performance YIT waveforms obtained through some production runs were analyzed statistically for checking non-random patterns. Furthermore a modification of the circular knitting machine has been proposed through the pinpoint analysis of knitted fabric. Based on the related theoretical and experimental research activities, the following conclusions are drawn:

1.Yarn tension analysis is very much significant to precisely determine knitted fabric basic quality from the machine running state .Fabric quality, in the term of course length, can be mathematically derived from the running yarn tension and corresponding yarn delivery on a positive storage feeding based circular knitting machine. A noble analytical model has been developed for the said purpose. The model established through two different yarn input tensions and associated yarn feedings was quite effective enough to precisely determine course length (mean differences are less than 1% when compared with practically measured course lengths) of acceptable quality fabric knitted with common knitting yarns like cotton and polyester .Consequently it was also found that the model also supports the justification about the influence of different parameters on the variable of interest.

This model, as per the author"s knowledge, is of its first kind for numerical expression of fabric quality or course length from pre-knitting parameters for a circular knitting machine with positive storage feeding. No comparison for this model could be done due to lack of any alternative one. However the developed model will not only save time but also bring credible savings on fabric cost in day-to-day dynamic production system of knitting factories.

2. Machine rotational speed, more correctly needle bed or cylinder speed –a very common production controlling parameter, does have minor influence on yarn input tension and corresponding yarn length. The verification lead to the conclusion that the changing patterns of yarn input tension and online yarn length may be overlooked as long as the generated tensile force in yarn does no damage its elastic property and result non-conformity in fabric quality.

3. The circular weft knitting machine used for the research works was quite flawless during the experimental production hours. Based on a critical evaluation of Yarn input Tension for some randomly production runs it was observed that the small disruptions in machine performance were due to outside factors rather than its inherent imperfection.

4. As a part of machine modification, an extensive root-cause analysis was carried out primarily for all recognized circular weft knitted fabric defects. Afterwards to minimize the propensity of two particular flaws/faults, i.e. GSM variation and Streakiness, a lint removal device for QAP belt has been developed .The developed device has been proven effective, convenient showing better cleaning performance. With a simple cost analysis it was also proven that the developed device is economically feasible too.

9.2 Noble Findings Simplified

1. The present technology for measurement of „fabric quality‟ are either deceptive (online yarn length/machine rev.) or imperfect (Offline measurement through a course length tester) . The developed model through tension analysis is the better alternative for precision measure of course length / loop length.
2. Machine speed has some positive influence on yarn tension. The correlation can be numerically established for further decision making on machine running rpm.

3. Yarn tension may be used as an excellent tool for judging the operational performance of a knitting machine. The strategy used here through run charts is quite instantaneous and can be applied on running machine, rather than checking the produced fabric quantity or quality.
4. YIT analysis for performance assessment opens the door to possible machine/modification development through evaluation of special cause variations. Through this study a compressed air based cleaning tool has been developed as an approach to improve the drive belt cleaning system for the positive feed mechanism of a circular weft knitting machine, which is claimed to be an excellent alternative to the currently available brush-based cleaning system

9.3 Recommendations for Future Work

The research works carried out here are entirely original and believed to contribute significantly for answering some critical research questions on circular weft knitting mechanism. However recommendations for further investigations are as follows.

1. The current model on fabric course length or loop length prediction from „on-machine" measurements may be justified, and if necessary, may be modified for stretch yarns like Nylon, Spandex etc. Moreover initiatives should be taken to establish recognized standards for measurement of Yarn Input Tension and Online Yarn Length.

2. Machine/Needle bed speed may be further evaluated to find out the optimum running speed for generating acceptable quality of fabrics with different textile yarns without damaging the elastic property.

3. Performance evaluation for a circular knitting machine may be further extended to examine the influence of temperature and relative humidity on production process.

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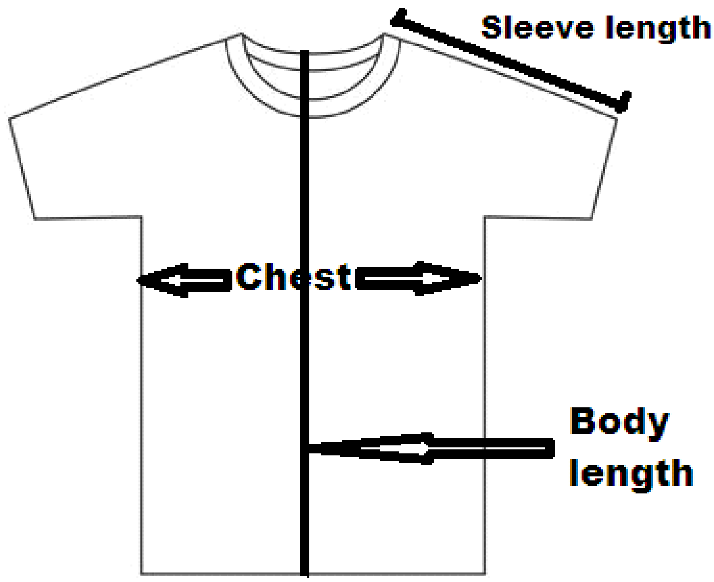
APPENDICES

APPENDIX A: A typical example of fabric consumption for a basic t shirt according to different GSM



Let,

Body Length = 72 cm

Sleeve length =28.5 cm

Chest Spread =62 cm

Seam & other allowances (lengthwise) = 10 cm

Seam & other allowances (widthwise) = 06 cm

Fabric GSM =180

Now, $Fabric\ Consumption\ per\ dozen\ Tshirt$=

$$\frac{(\text{Body length} + \text{Sleeve length} + \text{Allowance}) \times (\text{Chest spread} + \text{Allowance}) \times 2) \times \text{GSM}}{100 \times 100 \times 10000} x12\text{kg}$$

$$= \frac{(72 + 28.5 + 10) \times (62 + 06) \times 2) \times 180}{100 \times 100 \times 1000} \times 12 \text{ kg}$$

= 3.246 kg

If fabric GSM is increased by 01 or fabric GSM becomes 181, then fabric consumption changes as

$$Fabric\ Consumption\ per\ dozen\ Tshirt =$$

$$\frac{(\text{Body length} + \text{Sleeve length} + \text{Allowance}) \text{ x } (\text{Chest spread} + \text{Allowance}) \text{ x } 2) \text{ x GSM}}{100 \text{x } 100 \text{ x } 10000} x12\text{kg}$$

$$= \frac{(72 + 28.5 + 10) \text{ x } (62 + 06) \text{ x } 2) \text{ x } 181}{100 \text{x } 100 \text{ x } 1000} \text{x12 kg}$$

$$= 3.264 \text{ kg}$$

Therefore, fabric consumption grows due to increase in GSM by 01 = 0. 55%

APPENDIX B: Determination of actual yarn count

Table **B1**: Determination of Actual Yarn Count (Yarn: Spun Polyester; Nominal Count 26/1Ne)

Observation No.	Yarn Length (yds.)	Yarn Weight (g)	Avg. Yarn Count (Ne)	Avg. Yarn Count (Tex)
1	120	2.745	24.999836	23.62015495
2		2.723		
3		2.374		
4		2.508		
5		2.639		
6		2.773		
7		2.682		
8		2.546		
9		2.548		
10		2.382		
Average		2.592		
SD		0.143902745		
CV%		5.551803431		

Table **B2**: Determination of Actual Yarn Count (Yarn: Spun Polyester; Nominal Count 34/1Ne)

Observation No.	**Yarn Length (yds.)**	**Yarn Weight (g)**	**Avg. Yarn Count (Ne)**	**Avg. Yarn Count (Tex)**
1	120	1.936	32.98359713	17.90283812
2		1.886		
3		1.895		
4		2.105		
5		1.927		
6		2.201		
7		1.853		
8		1.912		
9		1.979		
10		1.952		
Average		1.9646		
SD		0.107723102		
CV%		5.483207871		

Table **B3**: Determination of Actual Yarn Count (Yarn: Cotton; Nominal Count: 20/1Ne)

Observation No.	**Yarn Length (yds.)**	**Yarn Weight (g)**	**Avg. Yarn Count (Ne)**	**Avg. Yarn Count (Tex)**
1	120	3.468	19.69712	29.97901
2		3.375		
3		3.235		
4		3.278		
5		3.243		
6		3.385		
7		3.352		
8		3.272		
9		3.143		
10		3.147		
Average		3.2898		
SD		0.105165267		
CV%		3.196706996		

Table **B4**: Determination of Actual Yarn Count (Yarn: Cotton; Nominal Count: 26/1Ne)

Observation No.	**Yarn Length (yds.)**	**Yarn Weight (g)**	**Avg. Yarn Count (Ne)**	**Avg. Yarn Count (Tex)**
1		2.648		
2		2.613		
3		2.487		
4		2.576		
5		2.569		
6		2.756		
7	120	2.608	25.25807	23.37867
8		2.535		
9		2.547		
10		2.316		
Average		2.5655		
SD		0.11400122		
CV%		4.44362574		

Table **B5**: Determination of Actual Yarn Count (Yarn: Cotton; Nominal Count: 30/1Ne)

Observation No.	**Yarn Length (yds.)**	**Yarn Weight (g)**	**Avg. Yarn Count (Ne)**	**Avg. Yarn Count (Tex)**
1	120	2.175	29.63757	19.92404
2		2.106		
3		2.253		
4		2.103		
5		2.111		
6		2.142		
7		2.271		
8		2.242		
9		2.217		
10		2.244		
Average		2.1864		
SD		0.066786892		
CV%		3.054651097		

Table **B6**: Determination of Actual Yarn Count (Yarn: Cotton; Nominal Count: 40/1Ne)

Observation No.	**Yarn Length (yds.)**	**Yarn Weight (g)**	**Avg. Yarn Count (Ne)**	**Avg. Yarn Count (Tex)**
1	120	1.655	38.79284897	15.22188
2		1.712		
3		1.674		
4		1.782		
5		1.721		
6		1.754		
7		1.601		
8		1.612		
9		1.581		
10		1.612		
Average		1.6704		
SD		0.069613536		
CV%		4.167477033		

APPENDIX C: Determination of yarn twist

Table **C1**: Determination of yarn twist for different counts of cotton and spun polyester yarns

No. of Obser-vation	Cotton								Spun Polyester			
	20 Ne		26 Ne		30Ne		40Ne		26		34	
	Twist/50cm	Avg. Actual TPI	Twist/50cm	Avg. Actual TPI	Twist/50cm	Avg. Actual TPI	Twist/50cm	Avg. Actual TPI	Twist/50cm	Avg. Actual TPI	Twist/50cm	Avg. Actual TPI
1	337	17.37	377	20.04	429	21.97	500	25.41	402	20.5	476	23.95
2	339		410		428		506		406		468	
3	337		395		418		495		411		469	
4	345		417		441		505		406		470	
5	341		390		436		503		404		471	
6	350		391		450		504		410		469	
7	342		389		435		491		407		478	
8	349		384		431		489		400		474	
9	333		393		425		499		402		471	
10	347		399		432		510		405		469	
Total	3420		3945		4325		5002		4053		4715	
Average	342		394.5		432.5		500.2		405.3		471.5	
S.D	5.66		11.78		8.81		6.78		3.37		3.37	

APPENDIX D: Raw materials (spun polyester and cotton yarn) quality reports from the supplier

34/1 Ne Spun Polyester

USTER® TESTER 5 - S800 R 5.7 Wed 08.06.16 07:40 Operator @@AL AMIN SHEIKH@@ Page 1

TU	UT5-1	Catalog	U1	Temp		Rel.H	
Style	RING	Sample ID	96834	Nom. count	Nec 34	Nom. twist	0 T/inch
Tests	10 / 1	v= 400 m/min	t= 1 min	Meas. slot	4	Short staple	

Std. Table & Spectogram

Article UNIT:SYL Material class Yarn Mach. Nr. R/F:01

Uster Statistics

Fiber Cotton 0%

34P/463(PSF-100%),SHIFT:A,SP:12-21,NEW LOT.

Total tests : 10 / 10 Single test(s)

Nr	U% %	CVm %	CVm 1m %	CVm 3m %	CVm 10m %	Index	Rel. Cnt ± %	H	sh	Thin -30% /km	Thin -40% /km	Thin -50% /km
1	10.79	13.48	4.43	3.51	2.90		-1.8	4.80	1.01	1343	187.5	12.5
2	9.85	12.40	3.83	3.02	2.41		0.9	4.71	0.95	913	62.5	2.5
3	10.21	12.85	4.29	3.43	2.76		-0.6	4.74	0.97	993	100.0	0.0
4	10.23	12.95	4.26	3.47	2.62		0.2	5.05	1.16	1053	95.0	5.0
5	10.39	13.05	4.35	3.56	2.88		-0.3	5.55	1.44	1155	145.0	0.0
6	10.24	13.00	3.88	3.12	2.24		-0.6	5.82	1.52	1308	120.0	2.5
7	9.60	12.13	4.19	3.40	2.88		2.1	4.53	0.90	723	67.5	2.5
8	10.66	13.40	4.83	4.08	3.52		0.1	4.64	0.92	1188	97.5	5.0
9	10.48	13.18	4.14	3.24	2.53		1.1	4.79	1.03	1148	97.5	2.5
10	10.65	13.37	4.20	3.38	2.55		-1.2	5.03	1.16	1220	115.0	7.5
Mean	10.31	12.98	4.24	3.42	2.73		0.0	4.96	1.11	1104	108.8	4.0
CV	3.6	3.4	6.6	8.5	12.9		1.2	8.4	19.7	17.1	33.6	94.1
Max	10.79	13.48	4.83	4.08	3.52		2.1	5.82	1.52	1343	187.5	12.5
Min	9.60	12.13	3.83	3.02	2.24		-1.8	4.53	0.90	723	62.5	0.0
USP™												

Nr	Thin -60% /km	Thick +35% /km	Thick +50% /km	Thick +70% /km	Thick +100% /km	Neps +140% /km	Neps +200% /km	Neps +280% /km
1	0.0	227.5	15.0	0.0	0.0	65.0	10.0	2.5
2	0.0	137.5	10.0	0.0	0.0	42.5	10.0	5.0
3	0.0	167.5	7.5	0.0	0.0	50.0	15.0	2.5
4	0.0	227.5	30.0	10.0	2.5	80.0	22.5	10.0
5	0.0	212.5	15.0	0.0	0.0	130.0	22.5	7.5
6	0.0	242.5	27.5	0.0	0.0	110.0	15.0	0.0
7	0.0	122.5	12.5	7.5	2.5	40.0	22.5	2.5
8	0.0	220.0	17.5	0.0	0.0	40.0	10.0	0.0
9	0.0	212.5	10.0	2.5	0.0	75.0	17.5	2.5
10	0.0	260.0	22.5	2.5	0.0	90.0	20.0	2.5
Mean	0.0	203.0	16.8	2.3	0.5	72.3	16.5	3.5
CV		22.3	45.6	161.0	210.8	42.9	32.1	90.4
Max	0.0	260.0	30.0	10.0	2.5	130.0	22.5	10.0
Min	0.0	122.5	7.5	0.0	0.0	40.0	10.0	0.0
USP™								

34/1 Spun Polyester

26/1 Ne SpunPolyeste

STER® TESTER 5 - S800 R 5.7 Tue 19.04.16 14:51 Operator @@AL AMIN SHEIKH@@ Page 1
SQUARE TEXTILES LTD. Saradagonj,Kashimpur Gazipur.

TU	UT5-1	Catalog	U1	Temp		Rel.H	
Style	RING	Sample ID	94414	Nom. count	Nec 26	Nom. twist	0 T/inch
Tests	10 / 1	v= 400 m/min	t= 1 min	Meas. slot	3	Short staple	

Std. Table & Spectogram

Article UNIT:SYL Material class Yarn Mach. Nr. R/F:01
Uster Statistics
Fiber Cotton 0% 0% 0%
R/F:01,,26P/429,(PSF-100%),SHIFT:B,SP:93,94,159,160,345,346,411,412,597,598,NEW LOT .

Total tests : 10 / 10 Single test(s)

Nr	U%	CVm	CVm 1m	CVm 3m	CVm 10m	Index	Rel. Cnt ±	H	sh	Thin -30%	Thin -40%	Thin -50%
	%	%	%	%	%		%			/km	/km	/km
1	9.77	12.32	4.23	3.43	2.50		-4.3	5.28	1.02	835.0	50.0	0.0
2	8.90	11.21	3.66	2.96	2.26		0.2	5.13	0.97	447.5	25.0	2.5
3	8.96	11.30	4.14	3.56	3.04		1.4	5.07	1.04	367.5	15.0	0.0
4	8.94	11.29	3.61	2.85	1.95		0.1	5.92	1.55	507.5	20.0	0.0
5	9.20	11.54	3.48	2.63	1.94		1.3	4.94	0.99	500.0	20.0	0.0
6	9.10	11.45	4.01	3.24	2.36		0.3	5.17	1.01	480.0	32.5	0.0
7	9.21	11.57	4.04	3.15	2.51		0.2	5.22	1.09	505.0	25.0	0.0
8	8.97	11.29	3.48	2.76	2.03		0.8	4.99	0.98	482.5	20.0	0.0
9	9.11	11.42	4.21	3.50	2.72		0.1	5.66	1.15	410.0	25.0	0.0
10	8.78	11.06	3.48	2.61	1.72		-0.2	5.06	0.98	452.5	22.5	0.0
Mean	9.09	11.44	3.83	3.07	2.30		0.0	5.24	1.08	498.8	25.5	0.3
CV	3.0	3.0	8.4	11.6	17.6		1.6	5.9	16.3	25.3	38.3	316.2
Max	9.77	12.32	4.23	3.56	3.04		1.4	5.92	1.55	835.0	50.0	2.5
Min	8.78	11.06	3.48	2.61	1.72		-4.3	4.94	0.97	367.5	15.0	0.0
USP™												

Nr	Thin -60%	Thick +35%	Thick +50%	Thick +70%	Thick +100%	Neps +140%	Neps +200%	Neps +280%
	/km	/km	/km	/km	/km	/km	/km	/km
1	0.0	122.5	2.5	0.0	0.0	72.5	7.5	2.5
2	0.0	42.5	5.0	5.0	0.0	12.5	5.0	5.0
3	0.0	55.0	12.5	7.5	2.5	32.5	15.0	10.0
4	0.0	75.0	5.0	0.0	0.0	60.0	7.5	2.5
5	0.0	85.0	2.5	0.0	0.0	30.0	2.5	0.0
6	0.0	47.5	0.0	0.0	0.0	40.0	7.5	0.0
7	0.0	65.0	7.5	0.0	0.0	25.0	5.0	0.0
8	0.0	67.5	2.5	0.0	0.0	20.0	10.0	2.5
9	0.0	87.5	7.5	0.0	0.0	67.5	22.5	2.5
10	0.0	55.0	2.5	0.0	0.0	15.0	2.5	0.0
Mean	0.0	70.3	4.8	1.3	0.3	37.5	8.5	2.5
CV		33.7	76.3	216.0	316.2	58.4	72.3	124.7
Max	0.0	122.5	12.5	7.5	2.5	72.5	22.5	10.0
Min	0.0	42.5	0.0	0.0	0.0	12.5	2.5	0.0
USP™								

26/1 spun Polyester

20/1 Ne Cotton

USTER® TESTER 5 - S800 R 5.7 Sat 28.05.16 09:18 Operator SUMON Page 1

TU	UT5-1	Catalog	U1	Temp		Rel.H	
Style	RNIG	Sample ID	96219	Nom. count	Nec 20	Nom. twist	0 T/inch
Tests	10 / 1	v= 400 m/min	t= 1 min	Meas. slot	3	Short staple	

Std. Table & Spectogram

Article UNIT:2 Material class Yarn Mach. Nr. R/F:A14
Uster Statistics
Fiber Cotton 0%
20CH/72W,SHIFT"A"SP:1-10,NEW LOT.

Total tests : 10 / 10 Single test(s)

Nr	U% %	CVm %	CVm 1m %	CVm 3m %	CVm 10m %	Index	Rel. Cnt ± %	H	sh	Thin -30% /km	Thin -40% /km	Thin -50% /km
1	7.79	9.81	3.15	2.68	2.02		0.7	4.92	0.88	167.5	7.5	0.0
2	8.00	10.07	2.80	2.21	1.62		0.0	5.07	0.93	200.0	5.0	0.0
3	7.72	9.71	2.78	2.14	1.47		0.9	5.18	0.97	150.0	0.0	0.0
4	7.85	9.89	2.96	2.34	1.62		-0.4	5.11	0.92	187.5	2.5	0.0
5	8.15	10.29	3.05	2.38	1.70		0.6	5.02	0.90	270.0	2.5	0.0
6	7.64	9.62	2.90	2.34	1.81		1.2	5.21	0.97	147.5	0.0	0.0
7	7.80	9.83	2.84	2.26	1.70		-1.0	5.04	0.91	160.0	2.5	0.0
8	7.87	9.83	3.04	2.45	1.72		-0.1	4.94	0.89	177.5	5.0	0.0
9	7.78	9.77	2.92	2.34	1.74		1.9	4.97	0.91	172.5	0.0	0.0
10	8.08	10.23	2.84	2.24	1.38		-3.7	5.12	0.94	297.5	7.5	0.0
Mean	7.87	9.90	2.93	2.34	1.68		-0.0	5.06	0.92	193.0	3.3	0.0
CV	2.1	2.2	4.1	6.4	10.5		1.5	1.9	3.3	26.3	89.2	
Max	8.15	10.29	3.15	2.68	2.02		1.9	5.21	0.97	297.5	7.5	0.0
Min	7.64	9.62	2.78	2.14	1.38		-3.7	4.92	0.88	147.5	0.0	0.0
USP™												

Nr	Thin -60% /km	Thick +35% /km	Thick +50% /km	Thick +70% /km	Thick +100% /km	Neps +140% /km	Neps +200% /km	Neps +280% /km
1	0.0	45.0	5.0	0.0	0.0	32.5	2.5	0.0
2	0.0	55.0	5.0	2.5	0.0	15.0	2.5	2.5
3	0.0	42.5	2.5	0.0	0.0	15.0	2.5	0.0
4	0.0	50.0	5.0	5.0	5.0	42.5	7.5	2.5
5	0.0	75.0	7.5	2.5	0.0	40.0	10.0	0.0
6	0.0	37.5	0.0	0.0	0.0	27.5	2.5	0.0
7	0.0	40.0	2.5	0.0	0.0	30.0	5.0	0.0
8	0.0	45.0	2.5	0.0	0.0	32.5	5.0	0.0
9	0.0	42.5	2.5	0.0	0.0	40.0	12.5	0.0
10	0.0	65.0	2.5	2.5	0.0	17.5	0.0	0.0
Mean	0.0	49.8	3.5	1.3	0.5	29.3	5.0	0.5
CV		24.1	60.2	141.4	316.2	35.6	78.2	210.8
Max	0.0	75.0	7.5	5.0	5.0	42.5	12.5	2.5
Min	0.0	37.5	0.0	0.0	0.0	15.0	0.0	0.0
USP™								

20/1 Cotton

26/1 Ne Cotton

USTER 5 - S800 R 5.7 Thu 16.06.16 08:42 Operator ABED ALI Page 1

TU	UT5-1	Catalog	U1	Temp		Rel.H	
Style	RING	Sample ID	95002	Nom. count	Nec 26	Nom. twist	0 T/inch
Tests	10 / 1	v= 400 m/min	t= 1 min	Meas. slot	3	Short staple	

Std. Table & Spectogram

Article UNIT:02 Material class Yarn Mach. Nr. R/F:A1
Uster Statistics
Fiber Cotton 0%
26CH/18G SHIFT:A

Total tests : 10 / 10 Single test(s)

Nr	U% %	CVm %	CVm 1m %	CVm 3m %	CVm 10m %	Index	Rel. Cnt ± %	H	sh	Thin -30% /km	Thin -40% /km	Thin -50% /km
1	9.14	11.51	3.32	2.34	1.72		-4.4	4.52	0.92	585.0	27.5	2.5
2	8.87	11.15	4.42	3.16	2.26		1.4	4.80	0.95	462.5	5.0	0.0
3	8.21	10.37	3.05	2.39	1.80		1.8	4.34	0.86	242.5	5.0	0.0
4	8.18	10.32	2.88	2.08	1.60		1.8	4.54	0.90	250.0	7.5	0.0
5	8.76	10.99	3.18	2.13	1.53		-3.3	4.38	0.93	442.5	20.0	0.0
6	8.78	11.06	4.05	2.56	1.62		1.7	4.40	0.89	395.0	17.5	0.0
7	8.54	10.75	3.34	2.35	1.66		0.5	4.46	0.90	355.0	5.0	0.0
8	8.38	10.55	2.91	2.21	1.55		2.1	4.47	0.90	352.5	10.0	2.5
9	8.51	10.72	3.22	2.64	1.91		-1.4	4.42	0.88	350.0	10.0	0.0
10	8.51	10.71	3.30	2.43	1.74		-0.1	4.51	0.91	310.0	2.5	0.0
Mean	8.59	10.81	3.37	2.43	1.74		-0.0	4.48	0.90	374.5	11.0	0.5
CV	3.5	3.4	14.6	12.8	12.5		2.3	2.9	2.8	27.5	73.6	210.8
Max	9.14	11.51	4.42	3.16	2.26		2.1	4.80	0.95	585.0	27.5	2.5
Min	8.18	10.32	2.88	2.08	1.53		-4.4	4.34	0.86	242.5	2.5	0.0
USP™												

Nr	Thin -60% /km	Thick +35% /km	Thick +50% /km	Thick +70% /km	Thick +100% /km	Neps +140% /km	Neps +200% /km	Neps +280% /km
1	0.0	147.5	15.0	2.5	0.0	80.0	22.5	2.5
2	0.0	102.5	5.0	2.5	0.0	70.0	5.0	2.5
3	0.0	80.0	7.5	5.0	2.5	50.0	10.0	7.5
4	0.0	92.5	12.5	0.0	0.0	32.5	2.5	0.0
5	0.0	90.0	2.5	0.0	0.0	72.5	5.0	0.0
6	0.0	102.5	7.5	0.0	0.0	65.0	27.5	2.5
7	0.0	80.0	2.5	0.0	0.0	62.5	17.5	0.0
8	0.0	90.0	5.0	0.0	0.0	50.0	12.5	7.5
9	0.0	97.5	5.0	0.0	0.0	40.0	10.0	0.0
10	0.0	87.5	7.5	0.0	0.0	57.5	7.5	5.0
Mean	0.0	97.0	7.0	1.0	0.3	58.0	12.0	2.8
CV		20.0	57.8	174.8	316.2	25.8	67.9	108.8
Max	0.0	147.5	15.0	5.0	2.5	80.0	27.5	7.5
Min	0.0	80.0	2.5	0.0	0.0	32.5	2.5	0.0
USP™								

26/1 cotton

30/1 Ne Cotton

JSTER® TESTER 5 - S800 R 5.7 Thu 19.05.16 00:56 Operator SUMON Page 1

TU	UT5-1	Catalog	U1	Temp		Rel.H	
Style	RING	Sample ID	95758	Nom. count	Nec 30	Nom. twist	0 T/inch
Tests	10 / 1	v= 400 m/min	t= 1 min	Meas. slot	4	Short staple	

Std. Table & Spectogram

Article UNIT:2 Material class Yarn Mach. Nr. R/F-A3
Uster Statistics
Fiber Cotton 0%
30CH/52G,SHIFT-C,SP:1-10,NEW LOT.

Total tests : 10 / 10 Single test(s)

Nr	U%	CVm	CVm 1m	CVm 3m	CVm 10m	Index	Rel. Cnt ±	H	sh	Thin -30%	Thin -40%	Thin -50%
	%	%	%	%	%		%			/km	/km	/km
1	9.40	11.80	3.45	2.51	1.96		-0.4	4.52	0.88	615.0	25.0	0.0
2	8.92	11.25	2.95	2.25	1.61		0.7	4.52	0.85	485.0	15.0	0.0
3	9.18	11.58	3.71	2.88	2.29		-1.8	4.60	0.87	597.5	25.0	0.0
4	9.10	11.46	3.48	2.53	1.63		1.8	4.61	0.89	597.5	35.0	0.0
5	9.00	11.37	3.23	2.57	1.89		0.2	4.50	0.85	547.5	27.5	0.0
6	9.34	11.76	3.95	2.75	1.83		-2.1	4.50	0.87	712.5	22.5	0.0
7	9.23	11.64	3.66	3.09	2.63		1.2	4.57	0.87	570.0	22.5	2.5
8	9.06	11.42	3.31	2.40	1.57		0.5	4.58	0.89	577.5	17.5	0.0
9	9.29	11.69	3.69	2.65	1.77		-0.4	4.48	0.85	630.0	17.5	0.0
10	8.94	11.24	3.53	2.86	2.30		0.4	4.63	0.89	505.0	10.0	0.0
Mean	9.15	11.52	3.50	2.65	1.95		-0.0	4.55	0.87	583.8	21.8	0.3
CV	1.8	1.8	8.1	9.5	18.1		1.2	1.2	1.7	11.1	32.5	316.2
Max	9.40	11.80	3.95	3.09	2.63		1.8	4.63	0.89	712.5	35.0	2.5
Min	8.92	11.24	2.95	2.25	1.57		-2.1	4.48	0.85	485.0	10.0	0.0
USP™												

Nr	Thin -60%	Thick +35%	Thick +50%	Thick +70%	Thick +100%	Neps +140%	Neps +200%	Neps +280%
	/km	/km	/km	/km	/km	/km	/km	/km
1	0.0	165.0	0.0	0.0	0.0	102.5	30.0	2.5
2	0.0	130.0	25.0	0.0	0.0	162.5	32.5	12.5
3	0.0	182.5	15.0	2.5	0.0	132.5	30.0	7.5
4	0.0	140.0	10.0	0.0	0.0	95.0	30.0	5.0
5	0.0	160.0	10.0	0.0	0.0	120.0	17.5	0.0
6	0.0	167.5	10.0	0.0	0.0	105.0	20.0	5.0
7	0.0	175.0	12.5	2.5	2.5	127.5	22.5	2.5
8	0.0	202.5	15.0	5.0	0.0	85.0	22.5	5.0
9	0.0	155.0	7.5	0.0	0.0	82.5	10.0	0.0
10	0.0	115.0	0.0	0.0	0.0	92.5	12.5	5.0
Mean	0.0	159.3	10.5	1.0	0.3	110.5	22.8	4.5
CV		16.2	69.9	174.8	316.2	22.7	34.5	82.0
Max	0.0	202.5	25.0	5.0	2.5	162.5	32.5	12.5
Min	0.0	115.0	0.0	0.0	0.0	82.5	10.0	0.0
USP™								

30/1 Cotton

40/1 Ne Cotton

USTER® TESTER 5 - S800 R 5.7 Tue 21.06.16 06:49 Operator SUMON Page 1

TU	UT5-1	Catalog	U1	Temp		Rel.H	
Style	RING	Sample ID	95274	Nom. count	Nec 40	Nom. twist	0 T/inch
Tests	10 / 1	v= 400 m/min	t= 1 min	Meas. slot	4	Short staple	

Std. Table & Spectogram

Article UNIT:02 Material class Yarn Mach. Nr. R/F-A22
Uster Statistics
Fiber Cotton 0%
40CH/38C,SHIFT:A,SP:(1-10)NEW LOT.

Total tests : 10 / 10 Single test(s)

Nr	U% %	CVm %	CVm 1m %	CVm 3m %	CVm 10m %	Index	Rel. Cnt ± %	H	sh	Thin -30% /km	Thin -40% /km	Thin -50% /km
1	9.20	11.59	3.69	2.87	2.31		-1.3	3.11	0.67	722.5	42.5	0.0
2	9.12	11.47	3.52	2.52	1.85		-1.6	3.12	0.68	810.0	30.0	0.0
3	9.11	11.47	3.20	2.51	1.75		0.1	3.34	0.71	735.0	30.0	0.0
4	9.10	11.47	3.07	2.14	1.65		0.2	3.33	0.71	732.5	40.0	5.0
5	9.24	11.64	3.29	2.32	1.63		1.7	3.34	0.70	852.5	60.0	5.0
6	9.23	11.61	3.36	2.58	1.95		0.5	3.33	0.71	710.0	22.5	0.0
7	9.13	11.54	3.53	2.81	2.20		2.7	3.42	0.72	600.0	12.5	0.0
8	9.42	11.84	3.54	2.57	1.90		-0.4	3.14	0.68	715.0	20.0	0.0
9	9.48	11.94	3.50	2.55	1.79		-1.1	3.12	0.67	857.5	52.5	0.0
10	9.53	12.03	3.62	2.53	1.65		-0.7	3.10	0.66	910.0	45.0	0.0
Mean	9.26	11.66	3.43	2.54	1.87		0.0	3.24	0.69	764.5	35.5	1.0
CV	1.8	1.8	5.7	8.3	12.5		1.3	3.9	3.2	12.0	42.5	210.8
Max	9.53	12.03	3.69	2.87	2.31		2.7	3.42	0.72	910.0	60.0	5.0
Min	9.10	11.47	3.07	2.14	1.63		-1.6	3.10	0.66	600.0	12.5	0.0
USP™												

Nr	Thin -60% /km	Thick +35% /km	Thick +50% /km	Thick +70% /km	Thick +100% /km	Neps +140% /km	Neps +200% /km	Neps +280% /km
1	0.0	132.5	7.5	2.5	0.0	175.0	37.5	7.5
2	0.0	90.0	5.0	0.0	0.0	117.5	22.5	10.0
3	0.0	140.0	32.5	0.0	0.0	235.0	62.5	12.5
4	0.0	110.0	7.5	0.0	0.0	145.0	12.5	2.5
5	0.0	100.0	7.5	0.0	0.0	127.5	22.5	5.0
6	0.0	110.0	2.5	0.0	0.0	135.0	32.5	0.0
7	0.0	130.0	10.0	2.5	2.5	195.0	27.5	10.0
8	0.0	105.0	10.0	5.0	2.5	177.5	45.0	7.5
9	0.0	115.0	15.0	0.0	0.0	162.5	30.0	10.0
10	0.0	137.5	10.0	2.5	2.5	160.0	35.0	5.0
Mean	0.0	117.0	10.8	1.3	0.8	163.0	32.8	7.0
CV		14.6	77.6	141.4	161.0	21.5	42.2	55.3
Max	0.0	140.0	32.5	5.0	2.5	235.0	62.5	12.5
Min	0.0	90.0	2.5	0.0	0.0	117.5	12.5	0.0
USP™								

40/1 Cotton

APPENDIX E:Some tensile properties of experimental Spun Polyester yarns

Tensile properties of experimental Spun Polyester yarns (before knitting stage) were derived through the data obtained from Titan[5] Universal Strength Tester and TestWise™ Test Analysis Software following ASTMD2256 / D2256M - 10(2015) {Courtesy : Textile Testing and Quality Control laboratory, Department of Textile Engineering, Ahsanullah University of Science and Technology}

Table **E1**: Determination of Initial Modulus (cN/Tex) for spun polyester yarns

No. of Observation	23.62 Tex	20.36 Tex	17.90 Tex	14.91 Tex
1	138.00	140.37	166.72	126.25
2	151.00	144.69	130.20	142.00
3	142.15	133.00	163.16	124.50
4	130.00	123.21	134.00	137.16
5	144.00	133.00	148.00	134.84
6	136.63	146.22	146.38	128.64
7	141.48	147.13	159.00	132.65
8	130.76	146.64	152.00	140.42
9	152.06	141.19	170.00	128.23
10	141.05	131.98	152.00	142.99
Average	140.71	138.74	152.15	133.77
S.D.	7.35	8.07	13.17	6.75
C.V.%	5.22	5.82	8.66	5.05

Table **E2**: Determination of Breaking Force/ Tenacity (cN/Tex) for spun polyester yarns

No. of Observation	23.62 Tex	20.36 Tex	17.90 Tex	14.91 Tex
1	12.23	14.14	13.31	12.67
2	13.63	14.07	11.86	12.89
3	14.13	13.65	12.96	12.94
4	13.60	13.48	12.66	14.49
5	13.93	12.82	15.45	13.21
6	14.29	14.64	15.44	12.68
7	13.91	13.40	13.44	13.47
8	13.47	13.19	14.61	12.38
9	14.26	13.57	14.06	13.00
10	14.24	13.04	13.09	14.00
Average	13.77	13.60	13.69	13.17
S.D.	0.62	0.55	1.19	0.65
C.V.%	4.50	4.04	8.69	4.94

Table **E3**: Determination of Extension at break (%)) for spun polyester yarns

No. of Observation	23.62 Tex	20.36 Tex	17.90 Tex	14.91 Tex
1	11.35	11.62	11.44	11.57
2	11.59	12.12	11.55	11.69
3	12.57	12.12	11.21	11.96
4	13.04	11.32	11.22	12.54
5	11.58	12.14	12.32	12.36
6	12.43	12.38	12.32	11.75
7	12.24	11.76	11.16	11.72
8	12.02	11.65	11.37	10.85
9	11.71	11.99	11.19	11.80
10	12.67	11.37	10.94	12.05
Average	12.12	11.85	11.47	11.83
S.D.	0.56	0.35	0.48	0.46
C.V.%	4.62	2.95	4.18	3.89

Table **E4**: Determination of Proportional limit (cN/Tex) for spun polyester yarns

No. of Observation	23.62 Tex	20.36 Tex	17.90 Tex	14.91 Tex
1	2.06	1.63	1.62	1.79
2	2.06	1.68	1.71	1.87
3	1.96	1.61	1.61	1.90
4	1.91	1.62	1.50	1.98
5	2.08	1.62	1.74	1.81
6	1.94	1.81	1.77	1.92
7	1.94	1.70	1.61	1.86
8	1.85	1.90	1.89	1.84
9	1.92	1.89	1.80	1.90
10	1.87	1.92	1.91	1.97
Average	1.96	1.74	1.72	1.88
S.D.	0.08	0.13	0.13	0.06
C.V.%	4.08	7.47	7.56	3.19

APPENDIX F:Some tensile properties of experimental Cotton yarns

Tensile properties of experimental Cotton yarns (before knitting stage) were derived through the data obtained from Titan^5 Universal Strength Tester and TestWise^{TM} Test Analysis Software following ASTMD2256 / D2256M - 10(2015) {Courtesy : Textile Testing and Quality Control laboratory, Department of Textile Engineering, Ahsanullah University of Science and Technology}

Table **F1** : Determination of Initial Modulus (cN/Tex) for Cotton yarns

No. of Observation	**29.98 Tex**	**23.38 Tex**	**19.92 Tex**	**15.22 Tex**
1	142.70	155.60	161.60	175.10
2	144.70	119.00	179.16	197.10
3	151.20	163.70	163.10	197.20
4	160.70	152.20	132.00	176.20
5	141.10	154.10	141.00	191.90
6	149.60	136.60	143.20	206.30
7	143.30	142.20	141.00	183.00
8	163.90	138.60	163.31	184.90
9	146.96	148.30	139.00	220.80
10	136.63	129.60	155.10	202.40
Average	148.08	143.99	151.85	193.49
S.D.	8.60	13.46	14.83	14.30
C.V.%	5.81	9.35	9.77	7.39

Table **F2** : Determination of Breaking Force/ Tenacity (cN/Tex)for Cotton yarns

No. of Observation	**29.98 Tex**	**23.38 Tex**	**19.92 Tex**	**15.22 Tex**
1	6.94	5.55	5.32	6.98
2	6.81	6.66	5.46	7.53
3	7.20	7.40	5.31	7.10
4	7.42	7.41	5.22	6.44
5	7.10	7.34	5.30	7.35
6	7.04	7.15	5.33	6.97
7	6.92	6.91	5.13	6.53
8	7.00	6.85	5.85	6.75
9	7.26	7.43	5.20	7.52
10	7.52	7.48	5.23	7.23
Average	7.12	7.02	5.33	7.04
S.D.	0.23	0.59	0.20	0.38
C.V.%	3.23	8.40	3.75	5.40

Table **F3**: Determination of Extension at break (%) for Cotton yarns

No. of Observation	**29.98 Tex**	**23.38 Tex**	**19.92 Tex**	**15.22 Tex**
1	5.76	7.00	4.27	4.40
2	5.48	7.09	4.74	4.73
3	5.91	5.92	4.42	4.39
4	5.56	6.08	4.99	4.43
5	6.16	5.75	4.39	4.58
6	5.82	6.03	4.42	4.08
7	5.70	5.86	4.18	4.16
8	5.12	5.78	5.11	4.28
9	5.99	5.84	4.76	4.30
10	6.21	6.33	4.55	4.30
Average	5.77	6.17	4.58	4.36
S.D.	0.33	0.49	0.31	0.19
C.V.%	5.72	7.94	6.55	4.36

Table **F4**: Determination of Proportional limit (cN/Tex)for Cotton yarns

No. of Observation	**29.98 Tex**	**23.38 Tex**	**19.92 Tex**	**15.22 Tex**
1	1.67	1.71	1.55	1.98
2	1.54	1.98	1.48	1.90
3	1.53	1.72	1.32	1.87
4	1.41	1.51	1.17	1.92
5	1.48	1.62	1.61	1.95
6	1.34	1.63	1.50	1.88
7	1.47	1.49	1.37	1.76
8	1.28	1.76	1.51	1.93
9	1.59	1.68	1.48	1.94
10	1.52	1.83	1.32	1.83
Average	1.48	1.69	1.43	1.90
S.D.	0.12	0.15	0.13	0.07
C.V.%	8.11	8.88	9.09	3.68

APPENDIX G: Examples of true specific stress-strain and engineering specific stress-strain curves for yarn

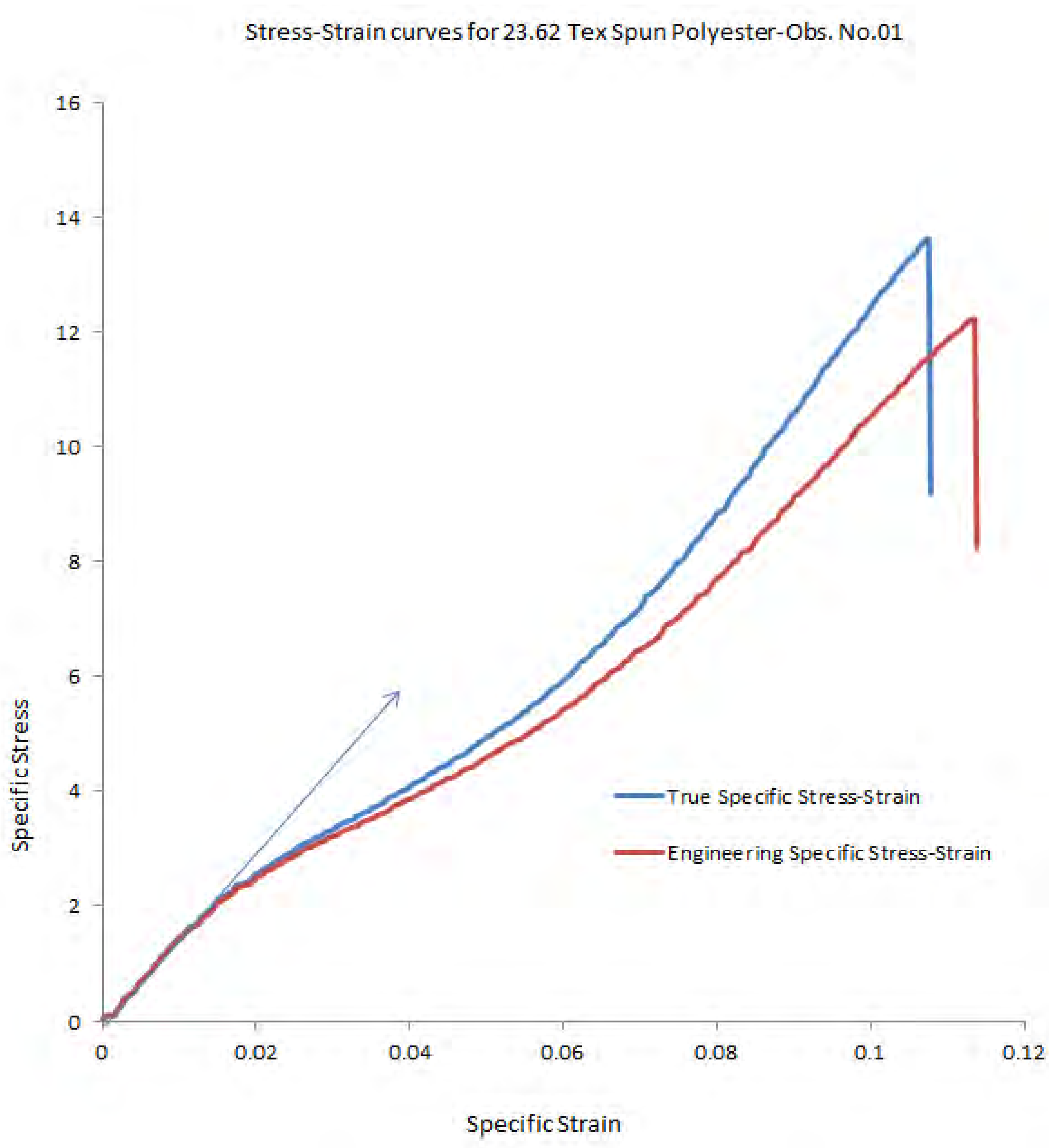


Figure **G1**: Example of True and Engineering specific stress-strain curves for experimental spun polyester yarn

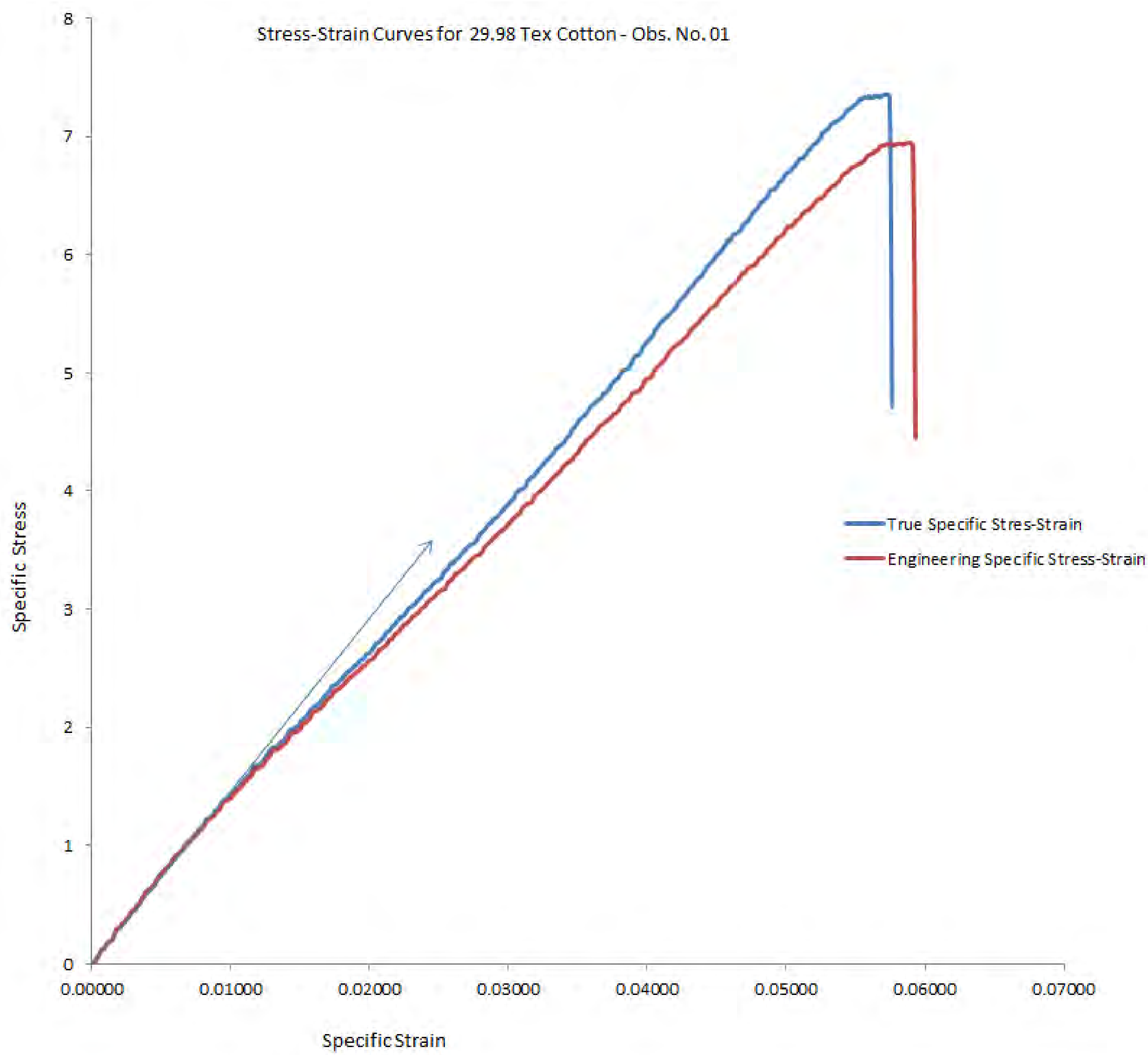


Figure **G2**: Example of True and Engineering specific stress-strain curves for experimental cotton yarn

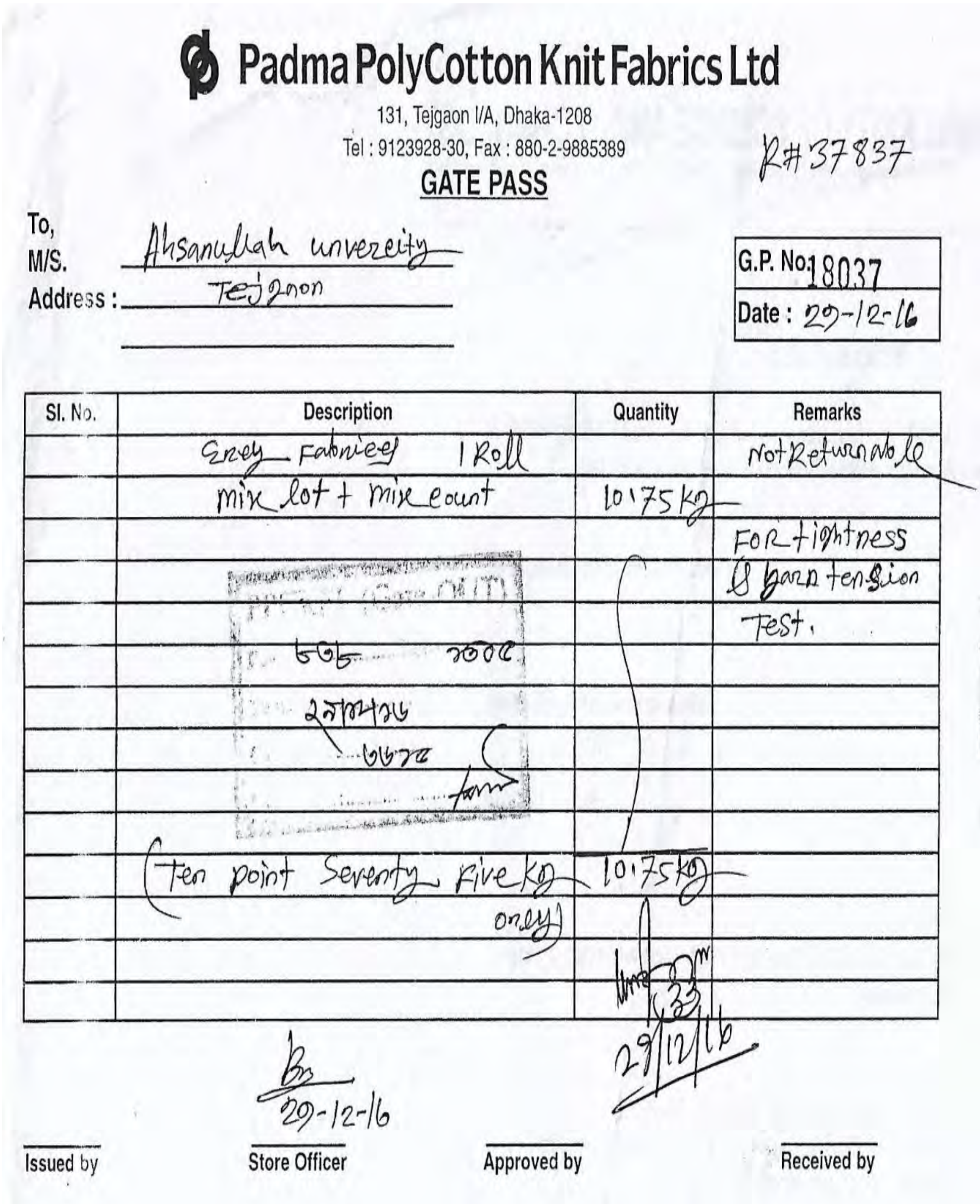
APPENDIX H: 'On-Machine' readings obtained through MLT Wesco yarn tension and rate meter for justification of the developed model

Table **H1**: Values of Yarn Input Tension and Yarn Delivery Obtained through MLT Wesco Yarn Meter

Yarn	Proportional Limit	Reading No.	Cam Setting Point	Average Yarn Input Tension(cN)	Tension Peak (cN)	Average Yarn Length / Rev. (m)
23.62 Tex Spun Polyester	1.96 cN/Tex or 46.29cN	1	0.4	2.60	7.1	5.164
		2	0.5	7.80	13.5	5.199
		3	0.6	11.00	19.1	5.231
		4	0.65	20.33	30.5	5.260
		5	0.7	27.58	40.8	5.285
17.90Tex Spun Polyester	1.72 cN/Tex or 30.79cN	1	0.4	1.53	4.5	5.180
		2	0.5	5.48	9.5	5.200
		3	0.6	11.02	17.3	5.235
		4	0.65	16.40	25.2	5.252
		5	0.7	20.30	30.2	5.283
29.98 Tex Cotton	1.48 cN/Tex or 44.37cN	1	0.4	8.3	14.3	5.174
		2	0.5	15.48	22.6	5.203
		3	0.6	25.7	38.2	5.222
		4	0.7	41.87	57.8	5.253
23.38 Tex Cotton	1.69 cN/Tex or 39.51	1	0.4	4.58	8.5	5.187
		2	0.5	11.07	17	5.214
		3	0.6	19.24	28.7	5.242
		4	0.7	26.07	36.1	5.272
19.92 Tex Cotton	1.43cN/Tex or 28.48 cN	1	0.4	3.7	8.1	5.181
		2	0.5	9.91	16.5	5.203
		3	0.6	15.54	23.8	5.226
		4	0.7	27.65	38.1	5.262
15.22 Tex Cotton	1.90 cN/Tex or 28.92 cN	1	0.4	4.41	9.3	5.186
		2	0.5	10.2	16.4	5.219
		3	0.6	17	24.7	5.229
		4	0.7	27.66	38.7	5.266

APPENDIX I: Fabric delivery and quality related documents from Padma Polycotton Knit Fabrics Limited

Gate Pass



Padma PolyCotton Knit Fabrics Ltd

131, Tejgaon I/A, Dhaka-1208

Tel : 9123928-30, Fax : 880-2-9885389

R#37837

GATE PASS

To,
M/S. Ahsanullah univerecity
Address : Tejgaon

G.P. No. 18037
Date : 29-12-16

Sl. No.	Description	Quantity	Remarks
	Grey Fabrics 1 Roll		Not Returnable
	mix lot + mix count	10.75 kg	
			For tightness
			& yarn tension
			Test.
	(Ten point Seventy Five kg only)	10.75 kg	

29-12-16

29/12/16

Issued by | Store Officer | Approved by | Received by

APPENDIX J: Grey Fabric Inspection Report

Padma PolyCotton Knit Fabrics Ltd.

131, Tejgaon I/A, Dhaka-1208

Knitting Section

Grey Fabrics Inspection Report

Date: 29-12-16	M/C NO: OR170	M/C DIA & Gauge: 26"×24 GG

Name of the Inspector:		
A.	Buyer:	Grey Gsm: 155/160
B. JULHAS	Order No:	Finish Gsm:
C.	Fabrics Type: S/J	Finish Witdh:
	Yarn Type: MIX	Sticth Length:

	Shift-A						Shift-B						Shift-C					
TYPE OF DEFECT	R-1	R-2	R-3	R-4	R-5	R-6	R-1	R-2	R-3	R-4	R-5	R-6	R-1	R-2	R-3	R-4	R-5	R-6
SLUB/KNOT																		
HOLE/LOOP							1											
NEDDLE/SINKER LINE																		
BROKEN NEDDLE/2"																		
THICK/THIN YARN																		
BARRE/STRIPE																		
DIRT/FLY																		
OIL SPOT/OIL LINE																		
PRESS OFF																		
LYCRA OUT/DROP																		
OTHERS SPECIFY / D.S.							1+1+1											
TOTAL POINT (P)							4											
GREY WIDTH							53"											
ROLL WEIGHT (W)							10.75 kg											
REJECTS QTY IN KG																		
LENGTH,MTR																		
QUALITY=(PXGSM) ÷ (W ÷ 10)																		

QUALITY CLASSIFICATION (POINTS/ 100 SQ. METER):

1	2	3
<20	20-30	>30

SIGNATURE OF Q.C INCHARGE

ASTM D5430-13:Standard Test Methods for Visually Inspecting and Grading Fabrics

Table **J1**: Point Assignment Option A, i.e. 4-Point System

Size of Defect	**Penalty Points**
Length of defects in fabric (either length or width)	
Defects up to 3 inches	1
Defects > 3 inches ≤ 6 inches	2
Defects > 6 inches ≤ 9 inches	3
Defects > 9 inches	4

Table J2: Sample wise breakdown for the inspected defects

Yarn	**Cam Setting Point**	**Average Yarn Input Tension(cN)**	**Produced Fabric Length (inch)**	**Defect observed**	**Points assigned**	**Accepted/ Rejeced**
23.62 Tex Spun Polyester	0.4	2.60	86.5 (App.)/ Sample	Drop Stitch	1	Accepted
	0.5	7.80		-	-	Accepted
	0.6	11.00		-	-	Accepted
	0.65	20.33		-	-	Accepted
	0.7	27.58		-	-	Accepted
17.90Tex Spun Polyester	0.4	1.53		Drop Stitch	1	Accepted
	0.5	5.48		-	-	Accepted
	0.6	11.02		-	-	Accepted
	0.65	16.40		-	-	Accepted
	0.7	20.30		-	-	Accepted
29.98 Tex Cotton	0.4	8.3		-	-	Accepted
	0.5	15.48		-	-	Accepted
	0.6	25.7		-	-	Accepted
23.38 Tex Cotton	0.4	4.58		Drop Stitch	1	Accepted
	0.5	11.07		-	-	Accepted
	0.6	19.24		-	-	Accepted
	0.7	26.07		-	-	Accepted
19.92 Tex Cotton	0.4	3.7		-	-	Accepted
	0.5	9.91		-	-	Accepted
	0.6	15.54		-	-	Accepted
15.22 Tex Cotton	0.4	4.41		-	-	Accepted
	0.5	10.2		-	-	Accepted
	0.6	17		Hole	1	Accepted

APPENDIX K: Some examples of measured course length values from fabrics (through HATRA Course Length Tester) that were knitted with different yarn input tension

Table **K1**: Examples of measured course lengths through HATRA equipment for different yarn input tension values

Reading No	Measurement side (Courses knitted at the starting or end portions of the fabric sample)	Course lengths (cm) measured from fabrics knitted with 23.62 Tex Spun Polyester yarn at YIT of 2.60 cN	Course lengths (cm)measured from fabrics knitted with 23.62 Tex Spun Polyester yarn at YIT of 27.58 cN	Course lengths (cm) measured from fabrics knitted with 23.38 Tex Cotton yarn at YIT of 4.58 cN	Course lengths (cm) measured from fabrics knitted with 23.38 Tex Cotton yarn at YIT of 26.07 cN
1	Staring side	519	521	520.5	520
2	Staring side	518.5	520	518.5	521
3	Staring side	520.5	519.5	522	519.5
4	Staring side	519	519	520	520.5
5	Staring side	520	521	522	521
6	End side	519	518.5	522	520.5
7	End side	521	521.5	520.5	521
8	End side	520	520.5	521	521.5
9	End side	521.5	523	519	522.5
10	End side	522	522.5	521.5	521.5
Average		520.05	520.65	520.7	520.9
CV (%)		0.23	0.28	0.24	0.84

APPENDIX L:Two Tailed Student's t-Distribution Table

Table **L1**: T values for Two-sample T-test

α / df	0.01	0.03	0.05	0.1	0.2
1	63.66	31.82	12.71	6.31	3.08
2	9.92	6.96	4.30	2.92	1.89
3	5.84	4.54	3.18	2.35	1.64
4	4.60	3.75	2.78	2.13	1.53
5	4.03	3.36	2.57	2.02	1.48
6	3.71	3.14	2.45	1.94	1.44
7	3.50	3.00	2.36	1.89	1.41
8	3.36	2.90	2.31	1.86	1.40
9	3.25	2.82	2.26	1.83	1.38
10	3.17	2.76	2.23	1.81	1.37
11	3.11	2.72	2.20	1.80	1.36
12	3.05	2.68	2.18	1.78	1.36
13	3.01	2.65	2.16	1.77	1.35
14	2.98	2.62	2.14	1.76	1.35
15	2.95	2.60	2.13	1.75	1.34
16	2.92	2.58	2.12	1.75	1.34
17	2.90	2.57	2.11	1.74	1.33
18	2.88	2.55	2.10	1.73	1.33

APPENDIX M: Two sample t-tests between actual course lengths obtained with Cotton yarns of different linear densities

Table **M1**: Results of t-test of course length values measured through HATRA apparatus for fabric knitted with 29.98Tex Cotton and19.92Tex Cotton yarns

Statistical parameters for a two samples t-test	HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 29.98Tex Cotton	HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 19.92 Tex Cotton
No. of observations	10	10
Mean	5.2035	5.2025
Mean Difference	0.001 m	
Variance	0.000128056	0.0000569444
t-Value	0.167706181	
p-value	0.81877636	

Table **M2**: Results of t-test of course length values measured through HATRA apparatus for fabric knitted with 29.98Tex Cotton and 15.22Tex Cotton yarns

Statistical parameters for a two samples t-test	HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 29.98Tex Cotton	HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 15.22 Tex Cotton
No. of observations	10	10
Mean	5.2035	5.1975
Mean Difference	0.006 m	
Variance	0.000128056	0.000168056
t-Value	0.795114101	
p-value	0.284718953	

Table **M3**: Results of t-test of course length values measured through HATRA apparatus for fabric knitted with 23.38Tex Cotton and 19.92Tex Cotton yarns

Statistical parameters for a two samples t-test assuming equal variance	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 23.38 Tex Cotton**	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 19.92 Tex Cotton**
No. of observations	10	10
Mean	5.208	5.2025
Mean Difference	0.0055 m	
Variance	0.000134444	0.0000569444
t-Value	0.907134166	
p-value	0.224749763	

Table **M4**: Results of t-test of course length values measured through HATRA apparatus for fabric knitted with 23.38Tex Cotton and 15.22Tex Cotton yarns

Statistical parameters for a two samples t-test	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 23.38 Tex Cotton**	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 15.22Tex Cotton**
No. of observations	10	10
Mean	5.208	5.1975
Mean Difference	0.0105m	
Variance	0.000134444	0.000168056
t-Value	1.376951115	
p-value	0.072323874	

Table **M5**: Results of t-test of course length values measured through HATRA apparatus for fabric knitted with 19.92Tex Cotton and 15.22Tex Cotton yarns

Statistical parameters for a two samples t-test	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 19.92Tex Cotton**	**HATRA Course Length Tester Measurement for Course lengths from fabrics knitted with 15.22 Tex Cotton**
No. of observations	10	10
Mean	5.2025	5.1975
Mean Difference	0.005m	
Variance	0.0000569444	0.000168056
t-Value	0.760026646	
p-value	0.305785052	

APPENDIX N : Course length values (Actual and model predicted) for justification of cam setting

Table **N1**: Comparison between model predicted course lengths and measured course lengths (from fabric) using separate set of cam setting points

Yarn	Cam Setting Point	Average Yarn Input Tension (cN)	Model prediction for course length through Matlab (m)	Collected readings for course lengths from fabric (m)	Average couse length from fabrics when knitted at two different cam setting points(m)	Difference between model predicted course length and measured course lengths from fabric(m)
17.90 Tex	0.4	1.53	5.1723[Using cam setting point 0.4 &0.5]	5.200 &5.205 [when knitting was done at cam setting point 0.4] 5.210 &5.230 [when knitting was done at cam setting point 0.5]	5.2112	0.0389
	0.5	5.48	5.1713[Using cam setting point 0.4 &0.6]	5.200&5.205 [when knitting was done at cam setting point 0.4] 5.220 &5.230 [when knitting was done at cam setting point 0.6]	5.2137	0.0424
	0.6	11.02	5.1728[Using cam setting point 0.4 &0.65]	5.200 &5.205 [when knitting was done at cam setting point 0.4] 5.225&5.225 [when knitting was done at cam setting point 0.65]	5.2137	0.0409

	0.65	16.40	5.1719[Using cam setting point 0.4 &0.7]	5.200 &5.205 [when knitting was done at cam setting point 0.4] 5.220 &5.210 [when knitting was done at cam setting point 0.7]	5.2087	0.0368
	0.7	20.30				
23.62 Tex	0.4	2.60	5.1468[Using cam setting point 0.4 &0.5]	5.190 &5.190 [when knitting was done at cam setting point 0.4] 5.195 &5.230 [when knitting was done at cam setting point 0.5]	5.2012	.0544
	0.5	7.80	5.1438[Using cam setting point 0.4 &0.6]	5.190 &5.190 [when knitting was done at cam setting point 0.4] 5.205 &5.210 [when knitting was done at cam setting point 0.6]	5.1987	.0549
	0.6	11.00	5.1504[Using cam setting point 0.4 &0.65]	5.190 &5.190 [when knitting was done at cam setting point 0.4] 5.215 &5.200 [when knitting was done at cam setting point 0.65]	5.1987	0.0483
	0.65	20.33	5.1519[Using cam setting point 0.4 &0.7]	5.190 &5.190 [when knitting was done at cam setting point 0.4] 5.210 &5.185 [when knitting was done at cam setting point 0.7]	5.1937	0.0418
	0.7	27.58				

APPENDIX O: YIT waveforms and run charts for different production runs

Production Run No. 01

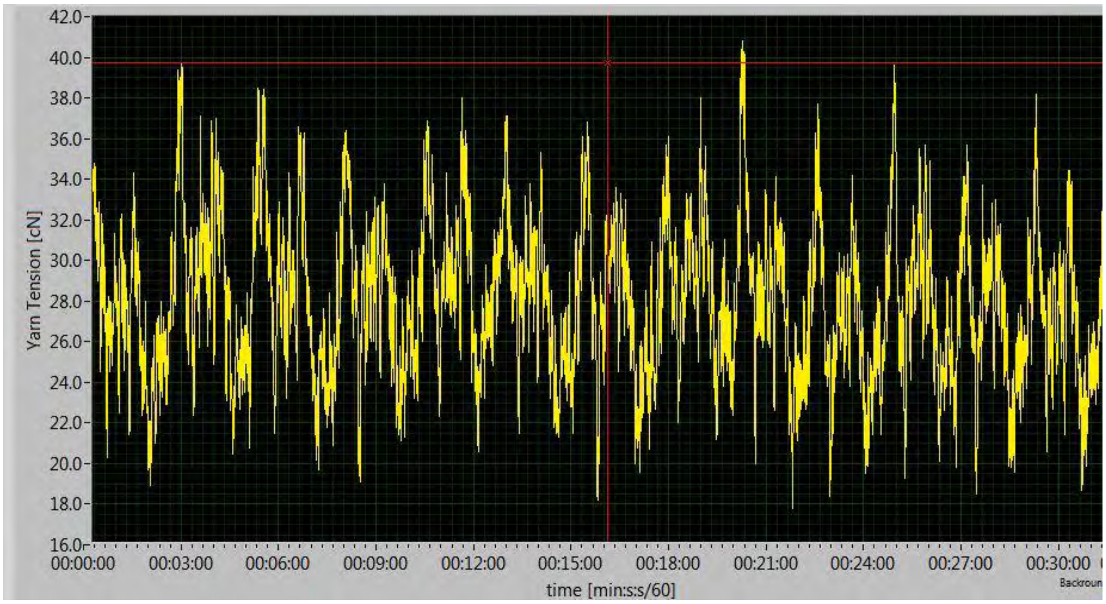


Figure **O1**: YIT waveform obtained for knitting production with 23.62 Tex Spun Polyester at cam setting 0.7

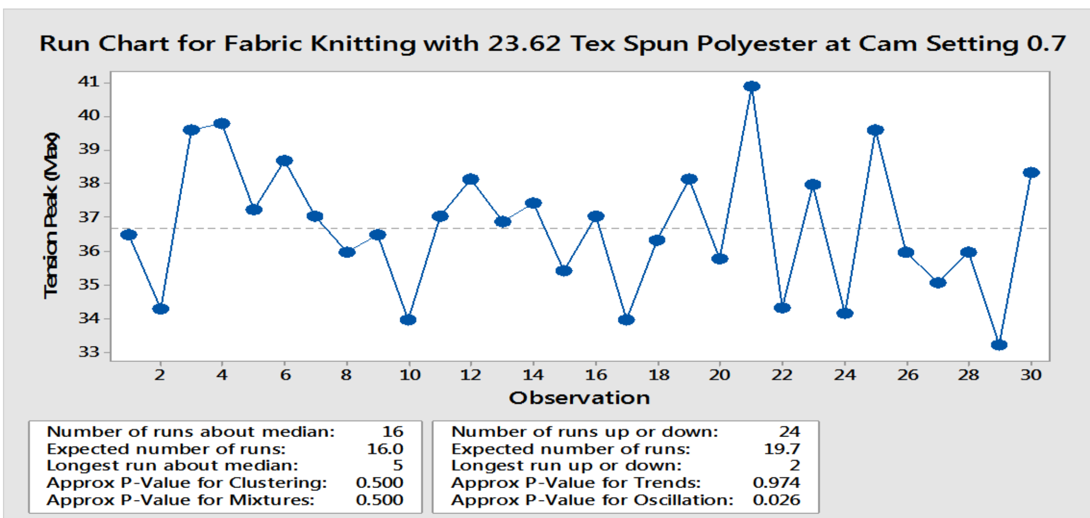


Figure **O2**: Run chart for production run no.01 (30 second)

Production Run No. 02

Figure **O3**: YIT waveform obtained for knitting production with 23.62 Tex Spun Polyester at cam setting 0.6

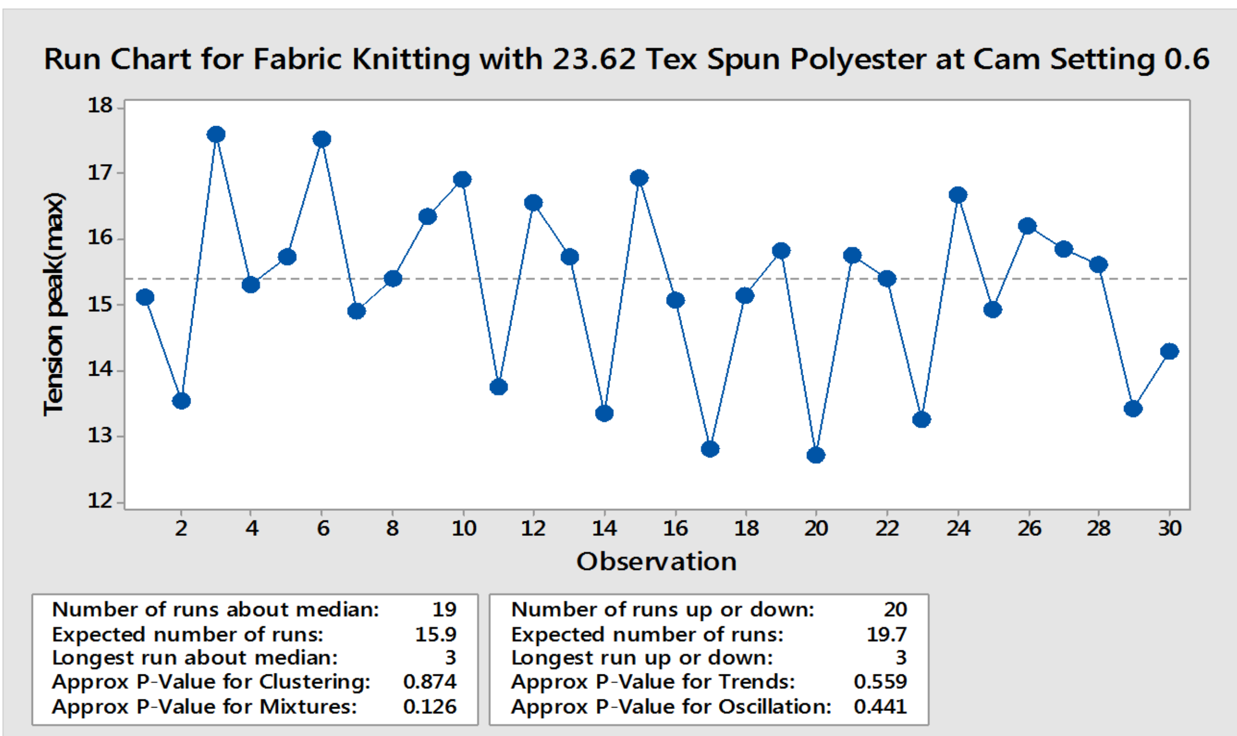


Figure **O4**: Run chart for production run no.02 (30 second)

Production Run No.03

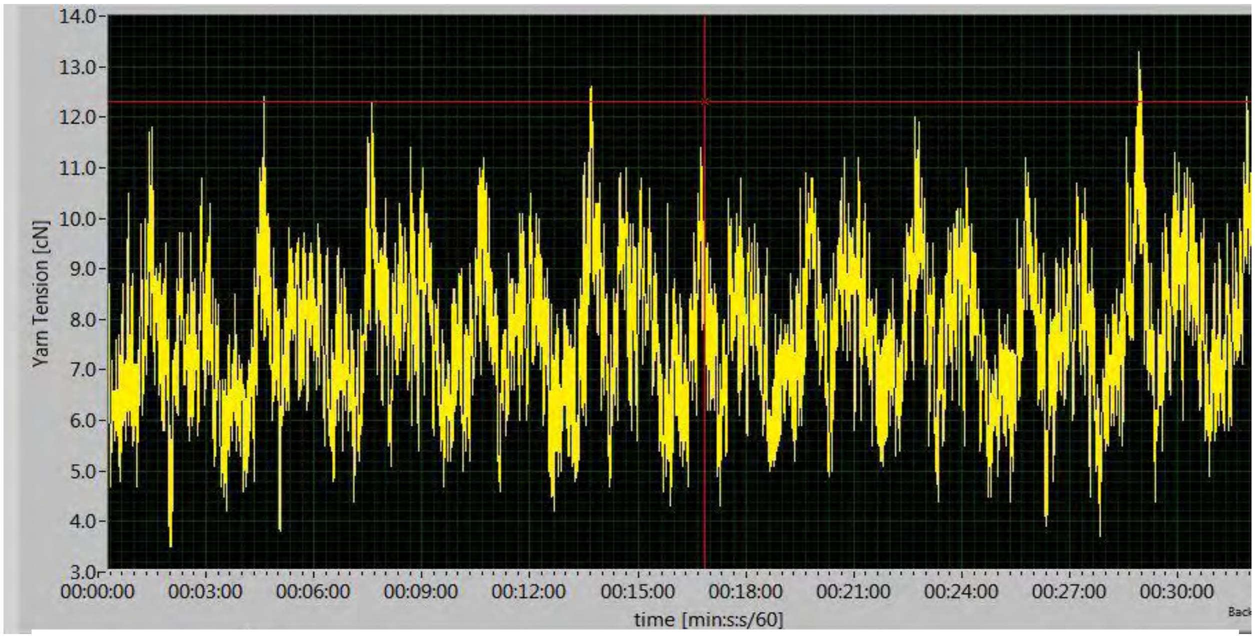


Figure **O5**: YIT waveform obtained for knitting production with 23.62 Tex Spun Polyester at cam setting 0.5

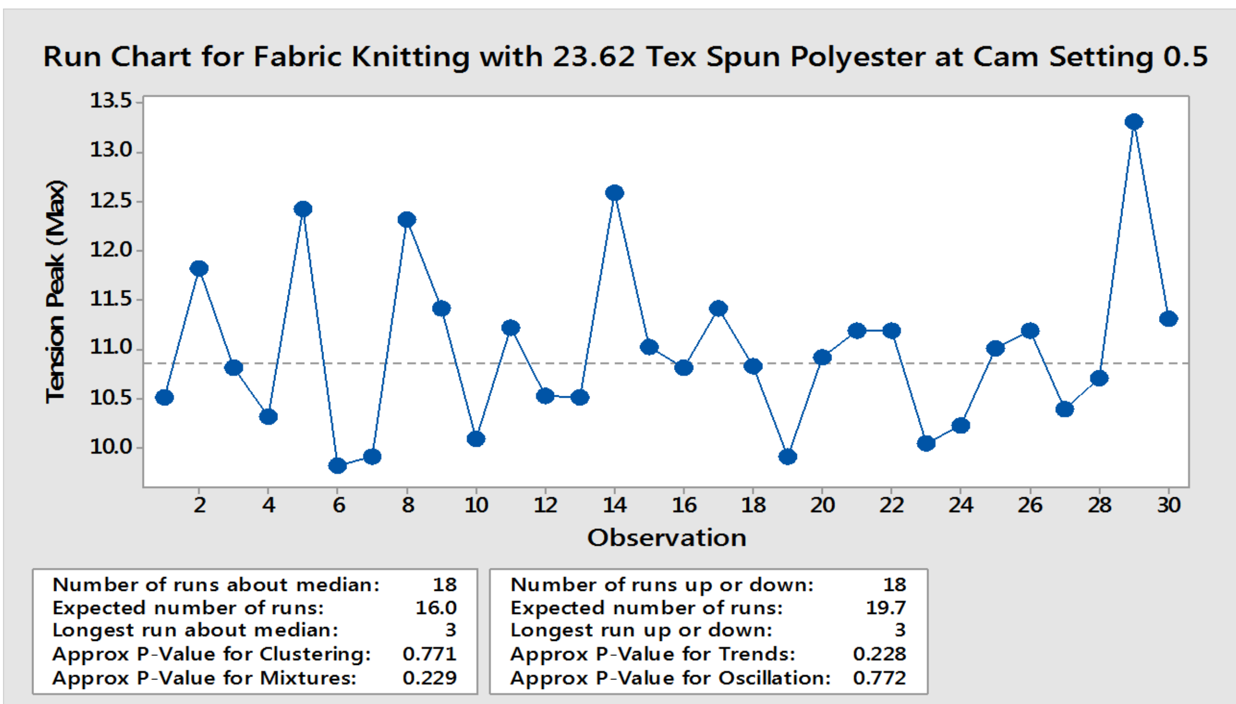


Figure **O6**: Run chart for production run no. 03 (30 second)

Production Run No. 04

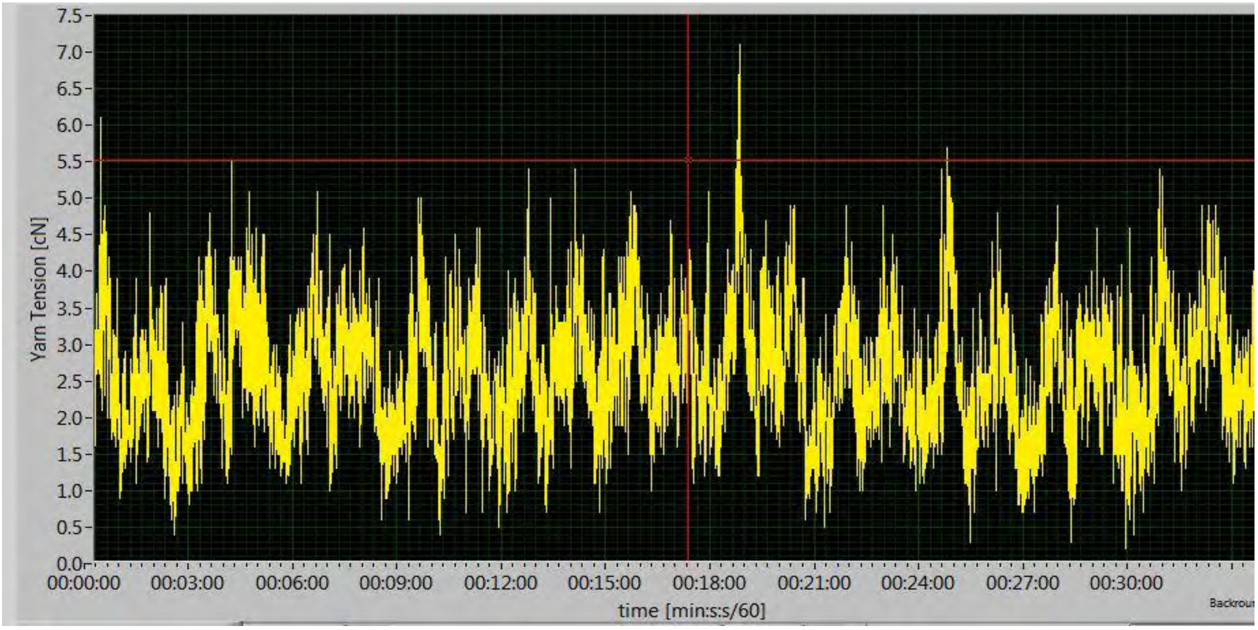


Figure **O7**: YIT waveform obtained for knitting production with 23.62 Tex Spun Polyester at cam setting 0.4

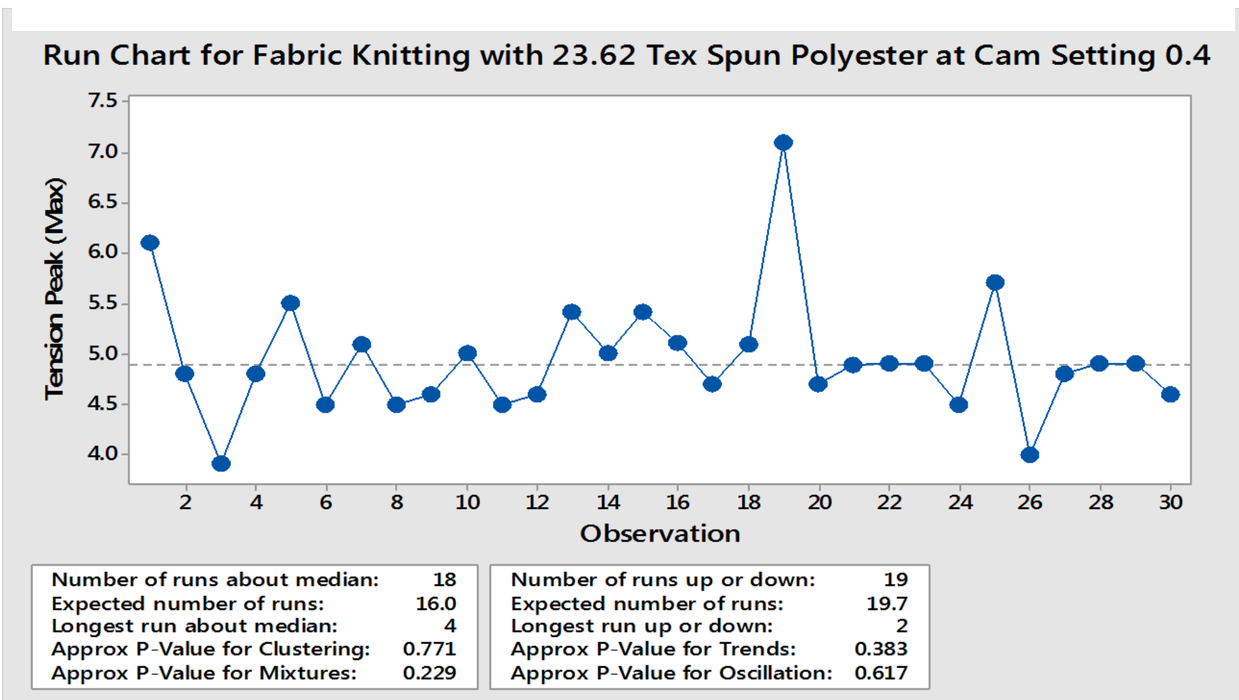


Figure **O8**: Run chart for production run no. 04 (30 second)

Production Run No. 05

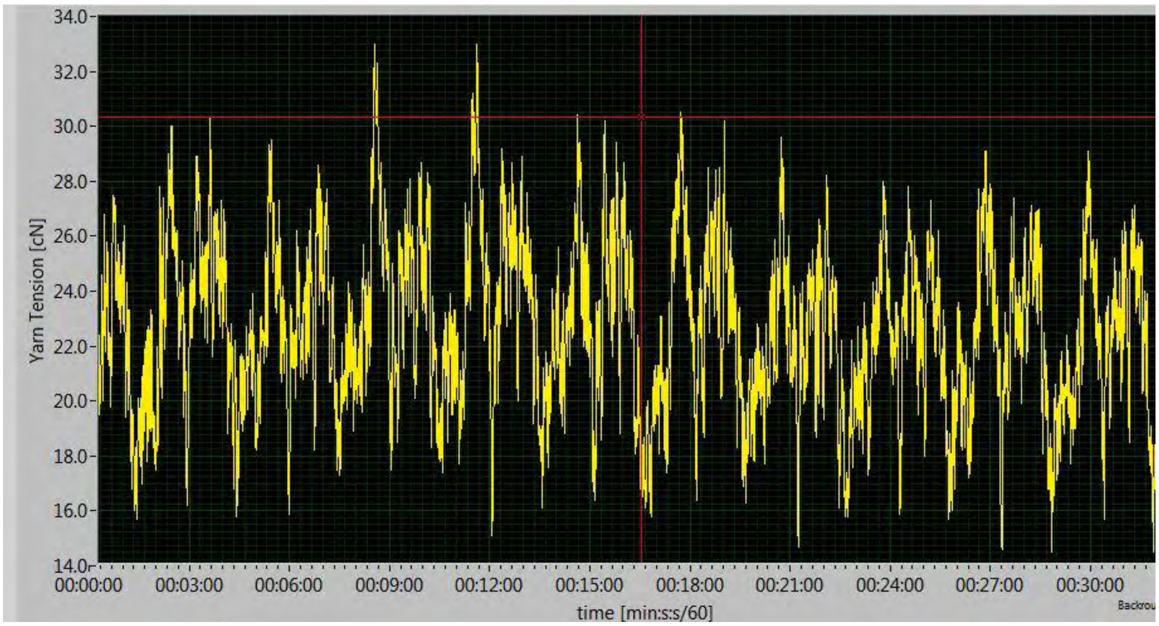


Figure **O9**: YIT waveform obtained for knitting production with 20.36 Tex Spun Polyester at cam setting 0.7

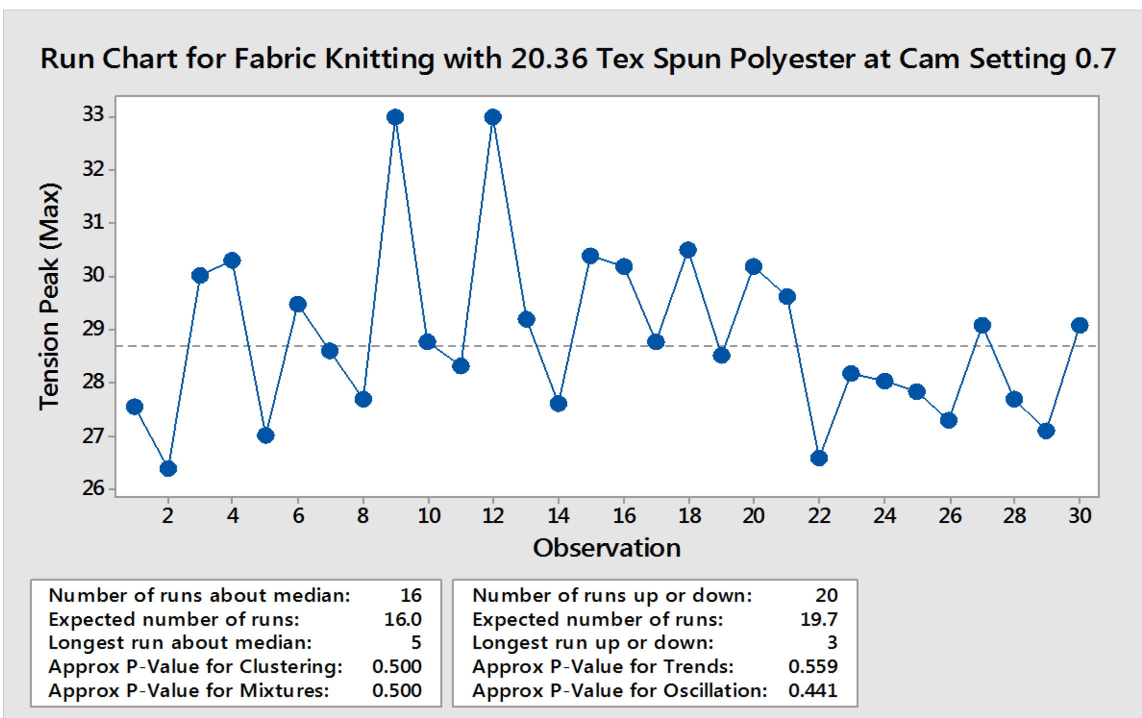


Figure **O10**: Run chart for production run no. 05 (30 second)

Production Run No. 06

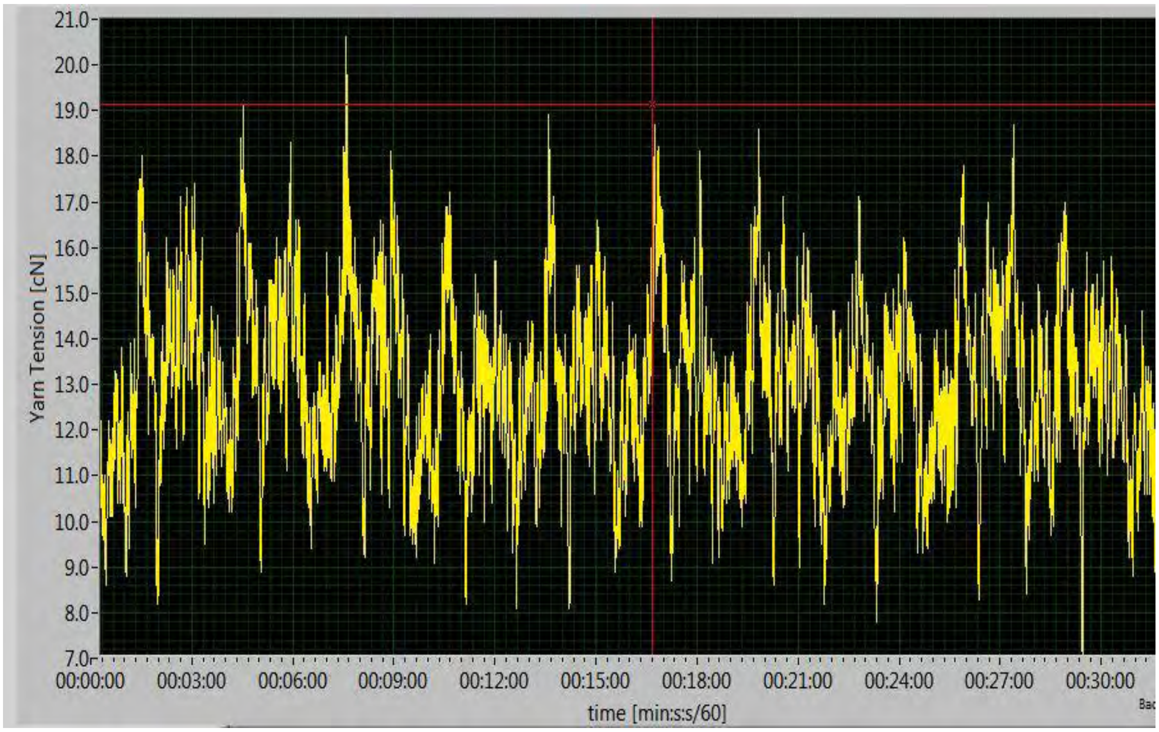


Figure **O11**: YIT waveform obtained for knitting production with 20.36 Tex Spun Polyester at cam setting 0.6

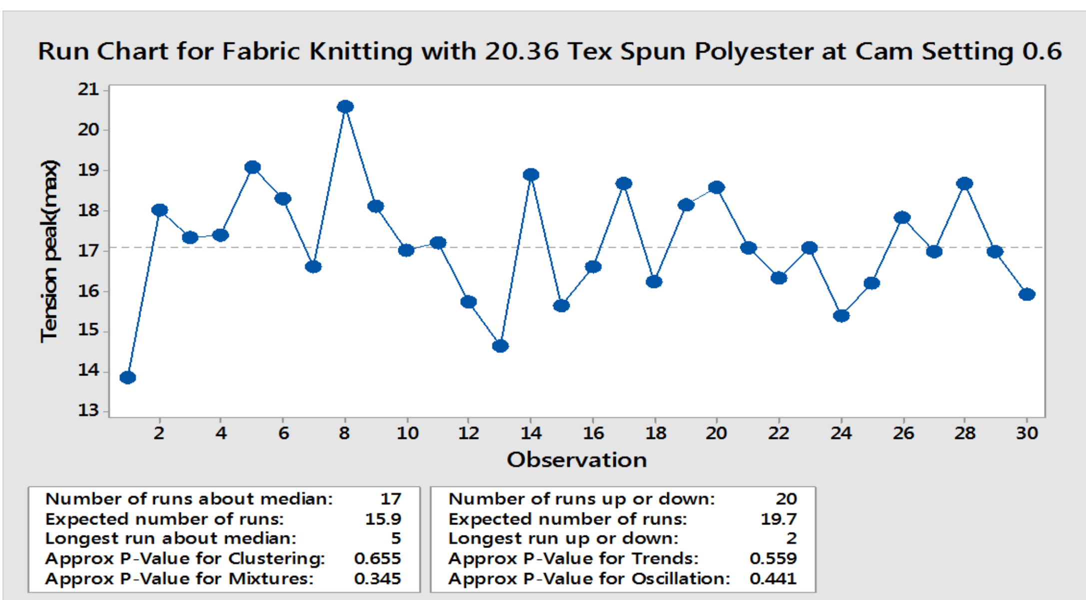


Figure **O12**: Run chart for production run no. 06 (30 second)

Production Run No. 07

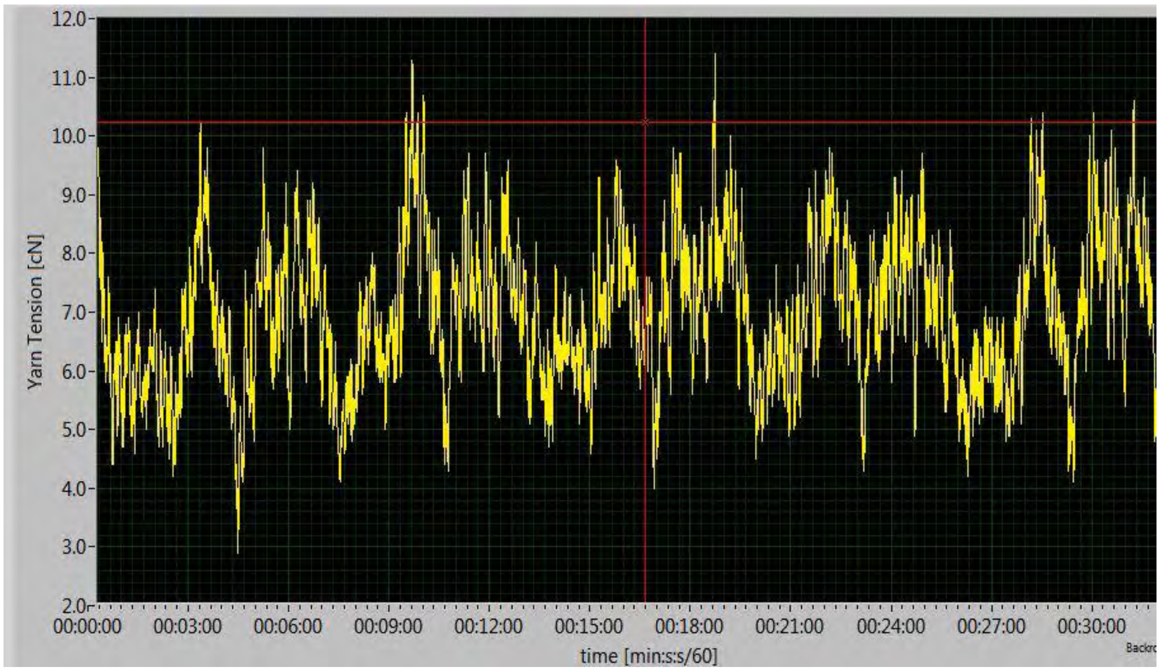


Figure **O13**: YIT waveform obtained for knitting production with 20.36 Tex Spun Polyester at cam setting 0.5

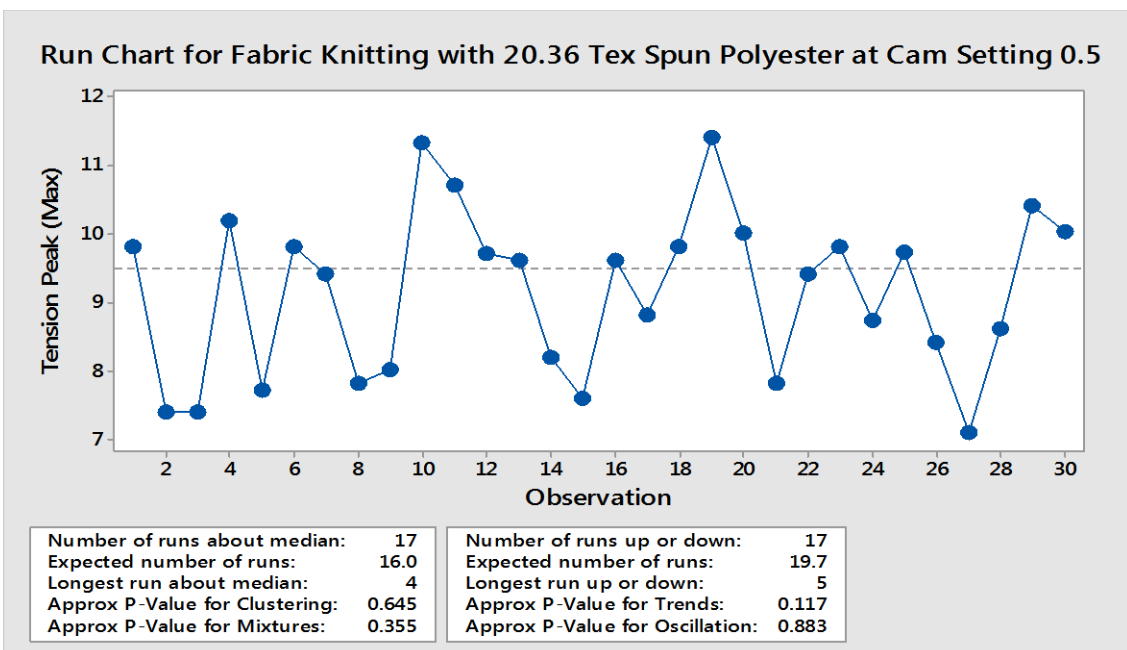


Figure **O14** : Run chart for production run no. 07 (30 second)

Production Run No. 08

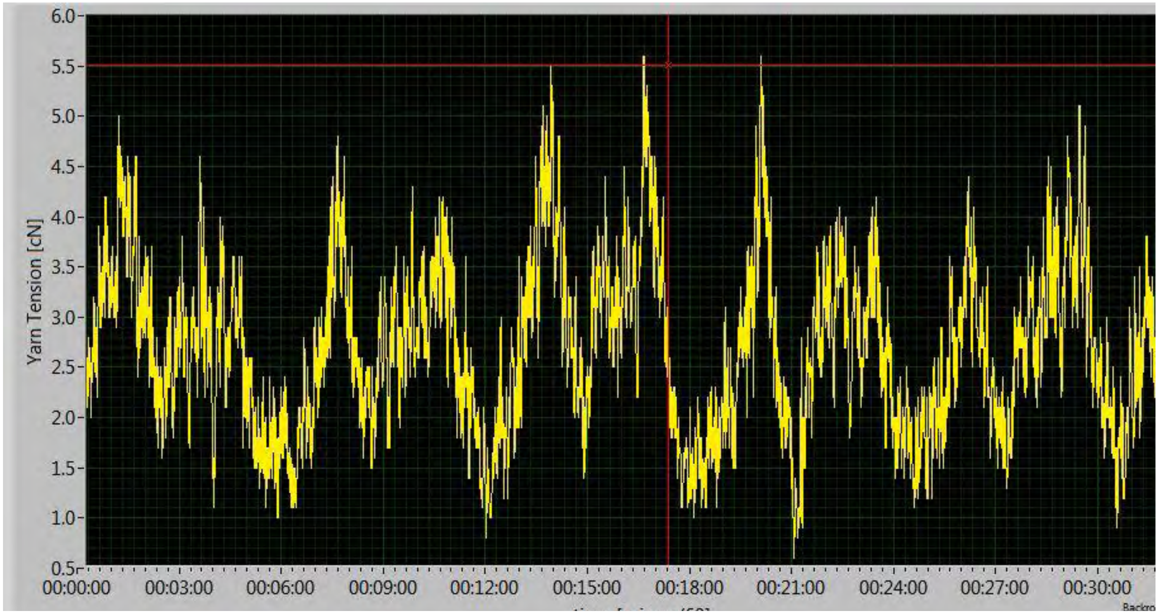


Figure **O15**:YIT waveform obtained for knitting production with 20.36 Tex Spun Polyester at cam setting 0.4

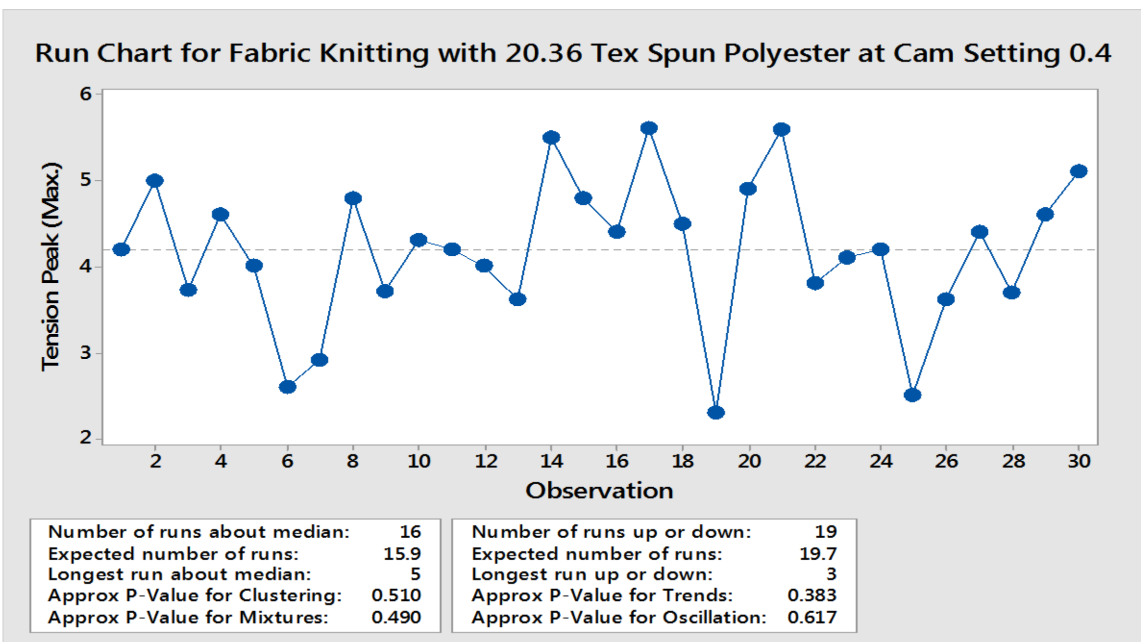


Figure **O16**: Run chart for production run no. 08 (30 second)

Production Run No. 09

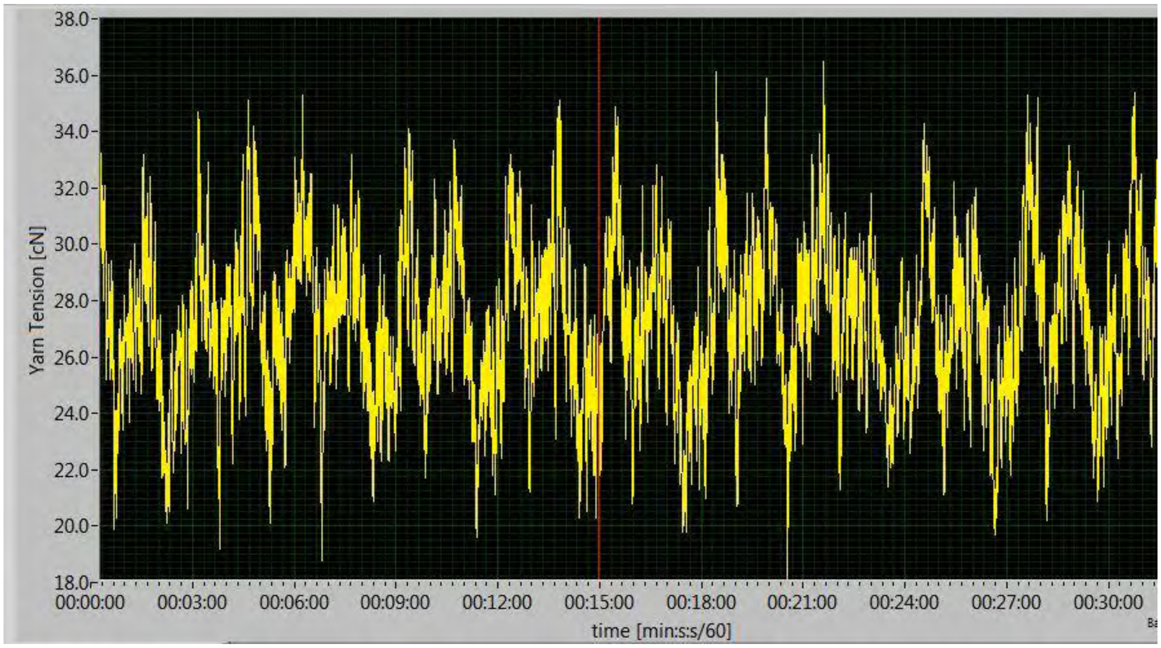


Figure **O17**: YIT waveform obtained for knitting production with 19.92 Tex Cotton at cam setting 0.7

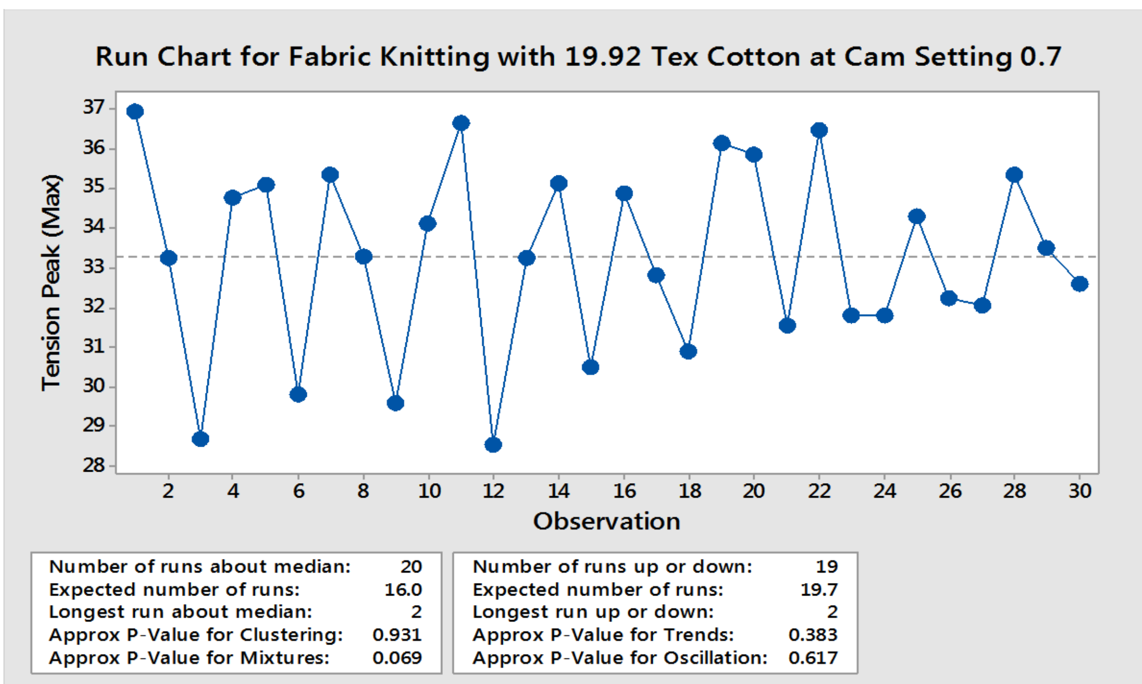


Figure **O18**: Run chart for production run no. 09 (30 second)

Production Run No. 10

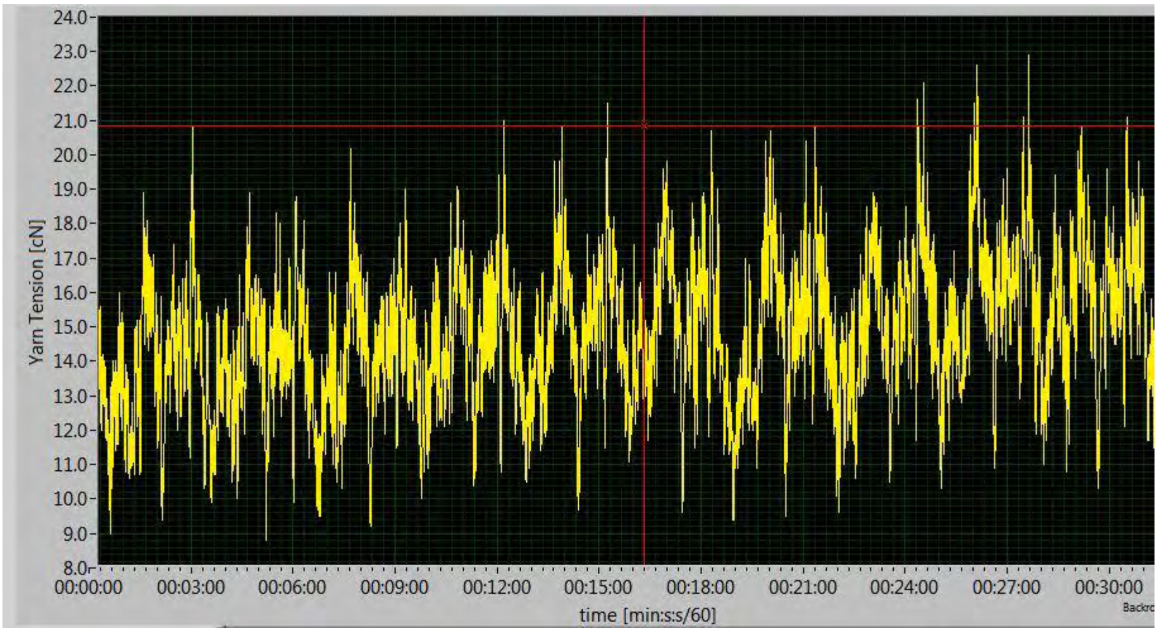


Figure **O19**: YIT waveform obtained for knitting production with 19.92 Tex Cotton at cam setting 0.6

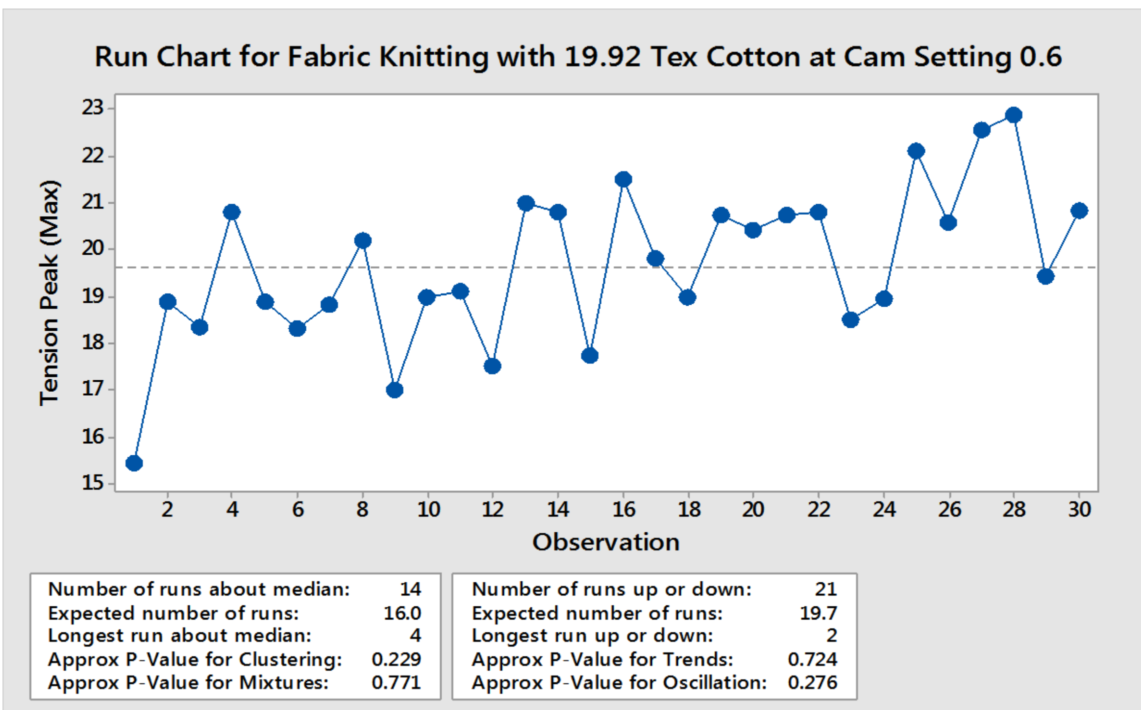


Figure **O20**: Run chart for production run no. 10 (30 second)

Production Run No. 11

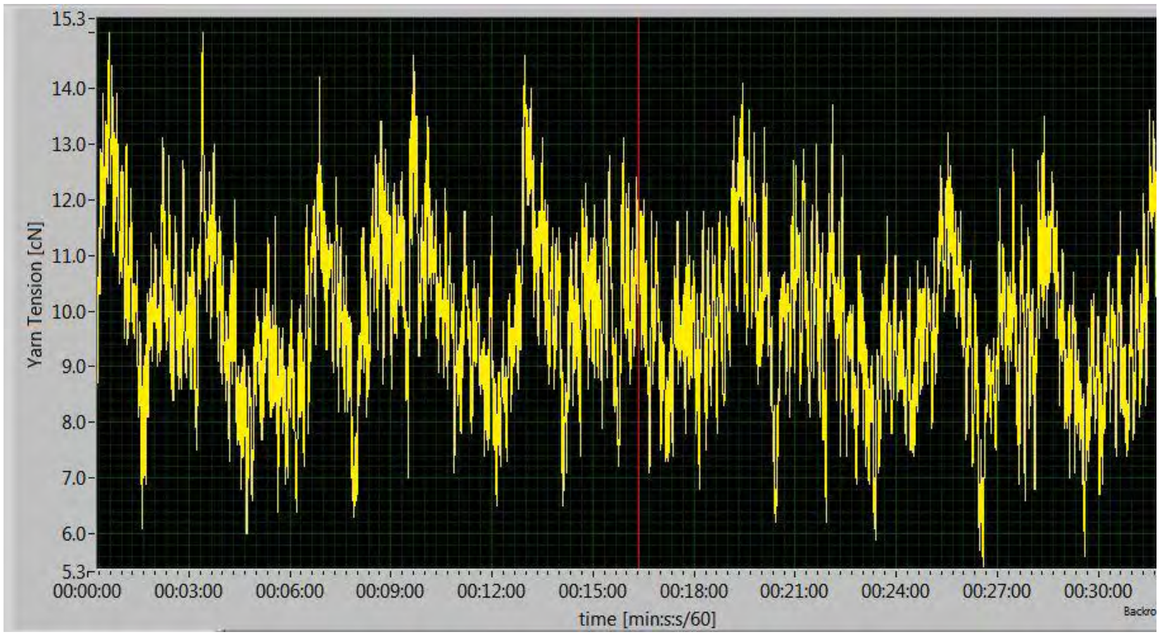


Figure **O21**: YIT waveform obtained for knitting production with 19.92 Tex Cotton at cam setting 0.5

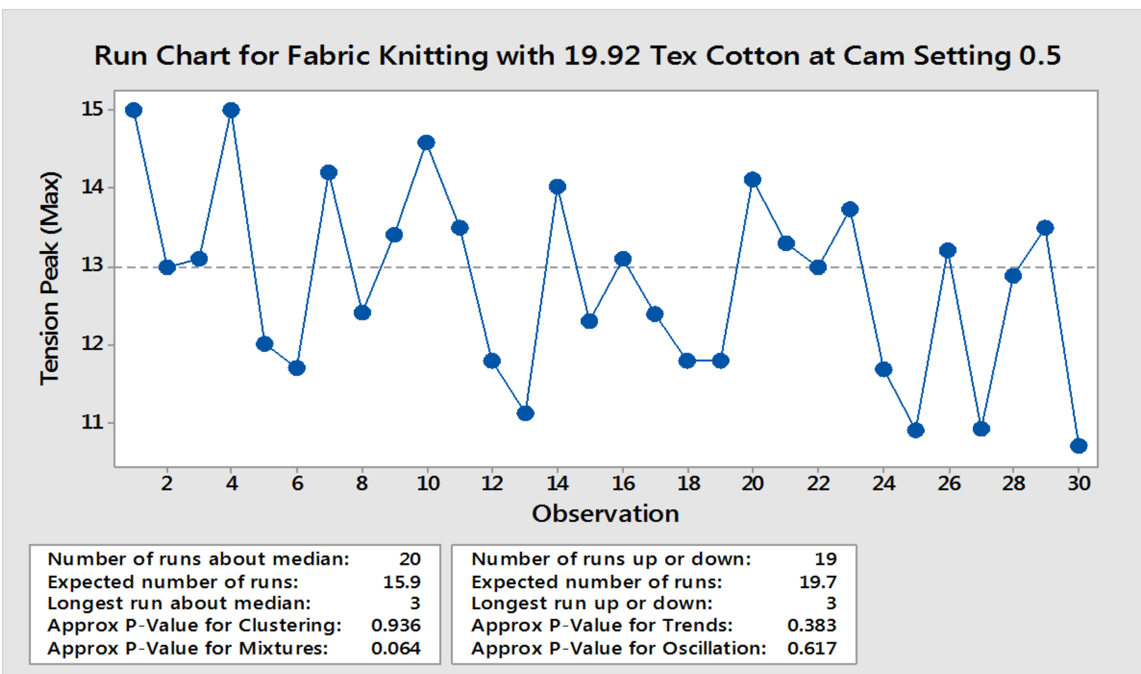


Figure **O22**: Run chart for production run no. 11 (30 second)

Production Run No. 12

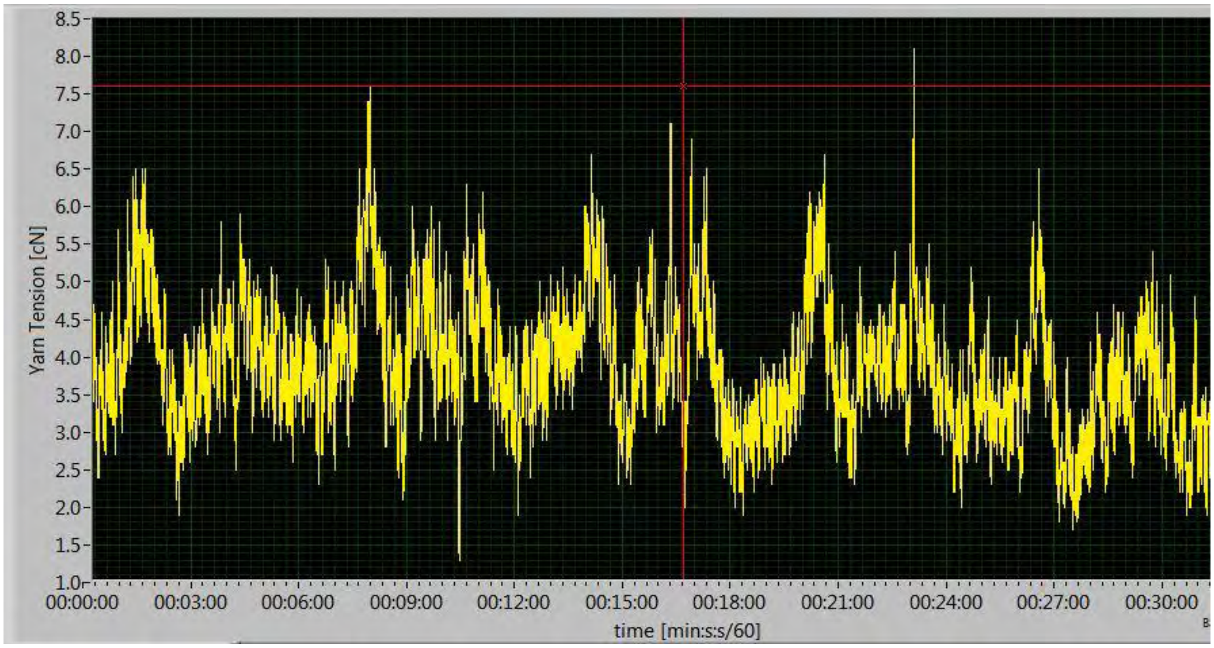


Figure **O23**: YIT waveform obtained for knitting production with 19.92 Tex Cotton at cam setting 0.4

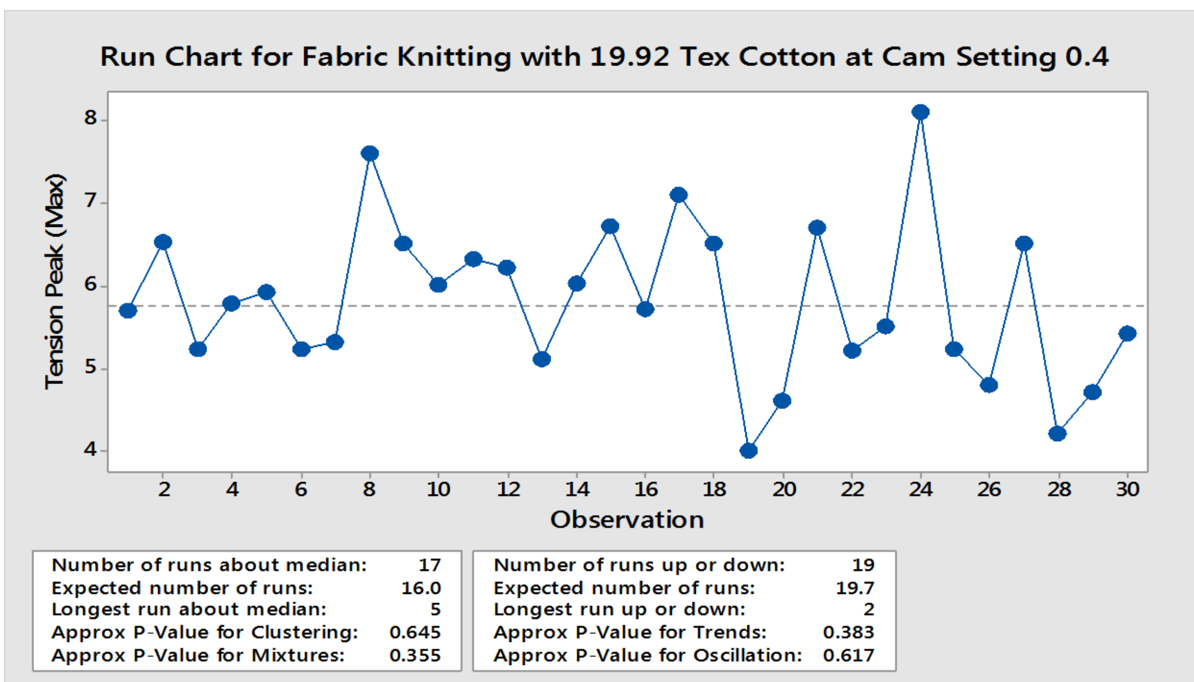


Figure **O24**: Run chart for production run no. 12 (30 second)

Production Run No. 13

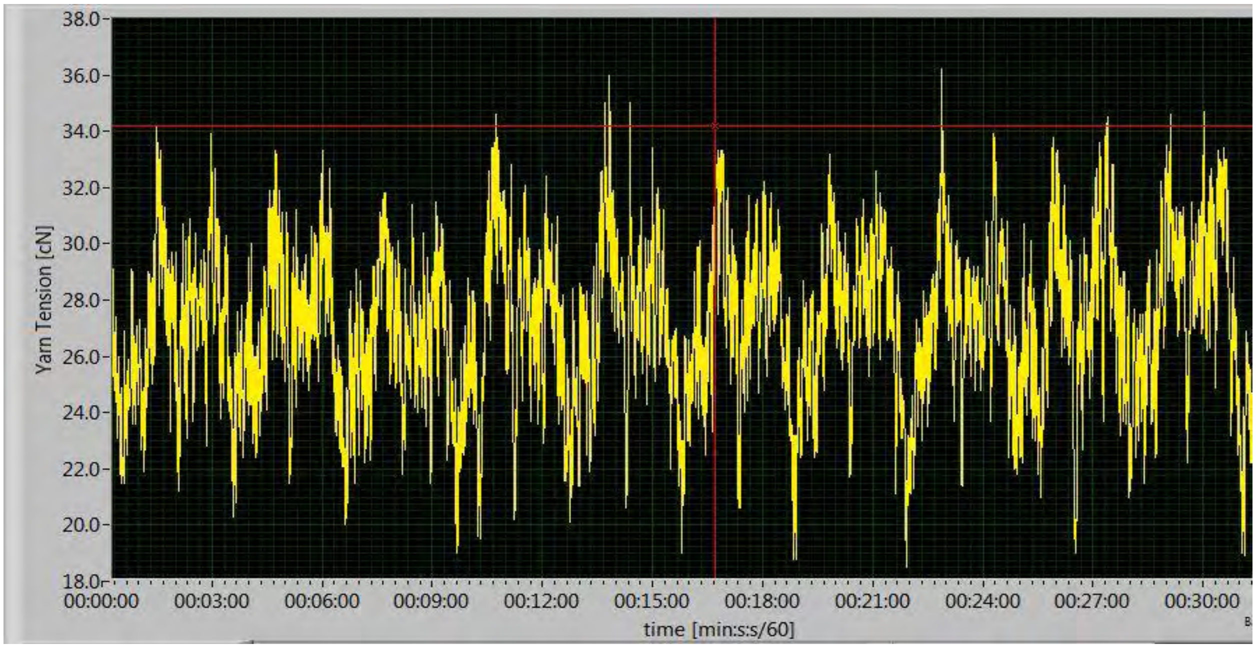


Figure **O25**: YIT waveform obtained for knitting production with 15.22 Tex Cotton at cam setting 0.7

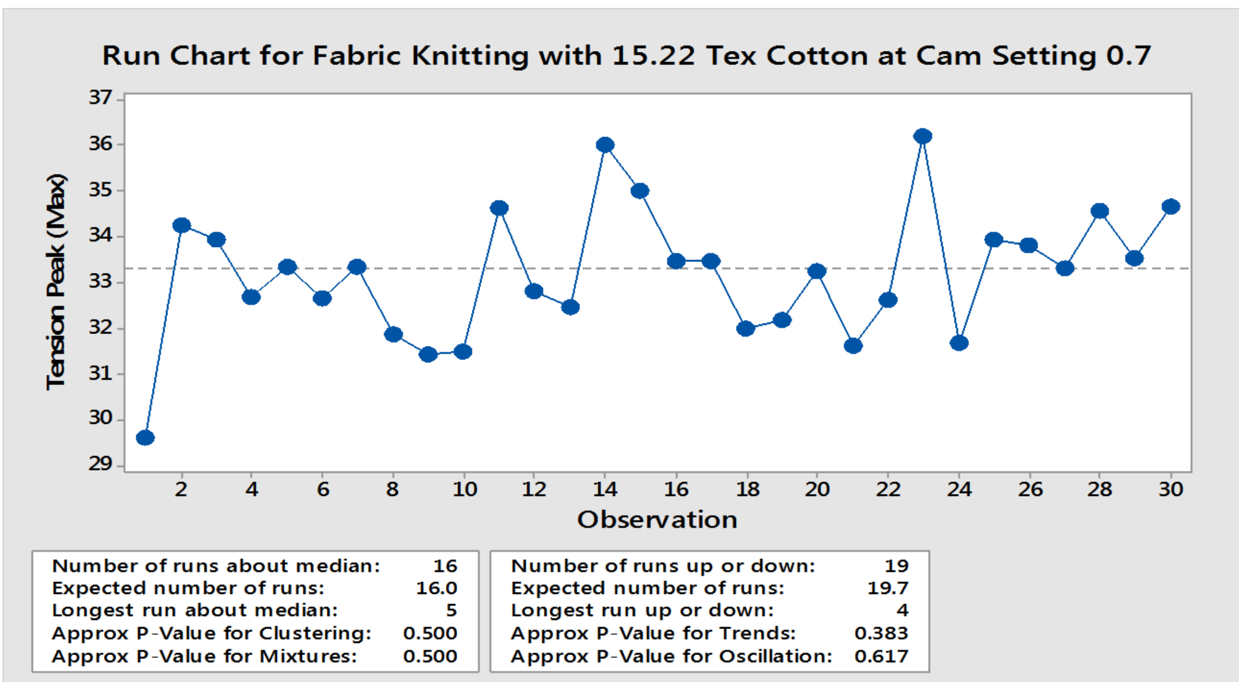


Figure **O26**: Run chart for production run no. 13 (30 second)

Production Run No. 14

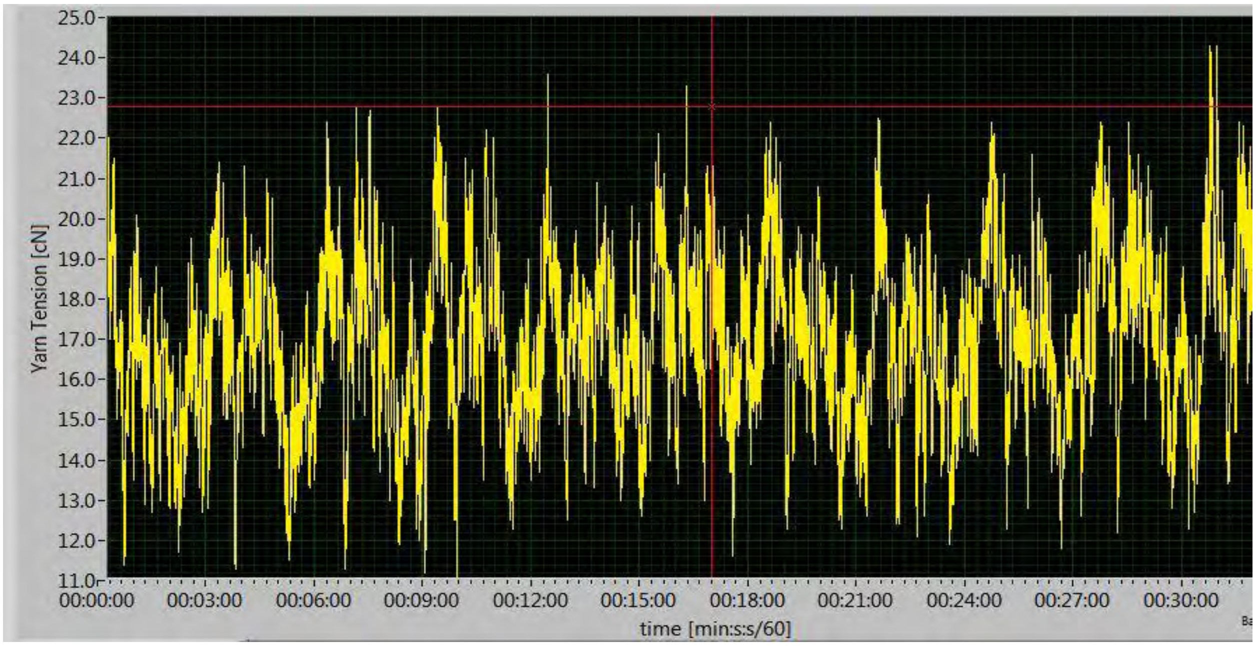


Figure **O27** : YIT waveform obtained for knitting production with 15.22 Tex Cotton at cam setting 0.6

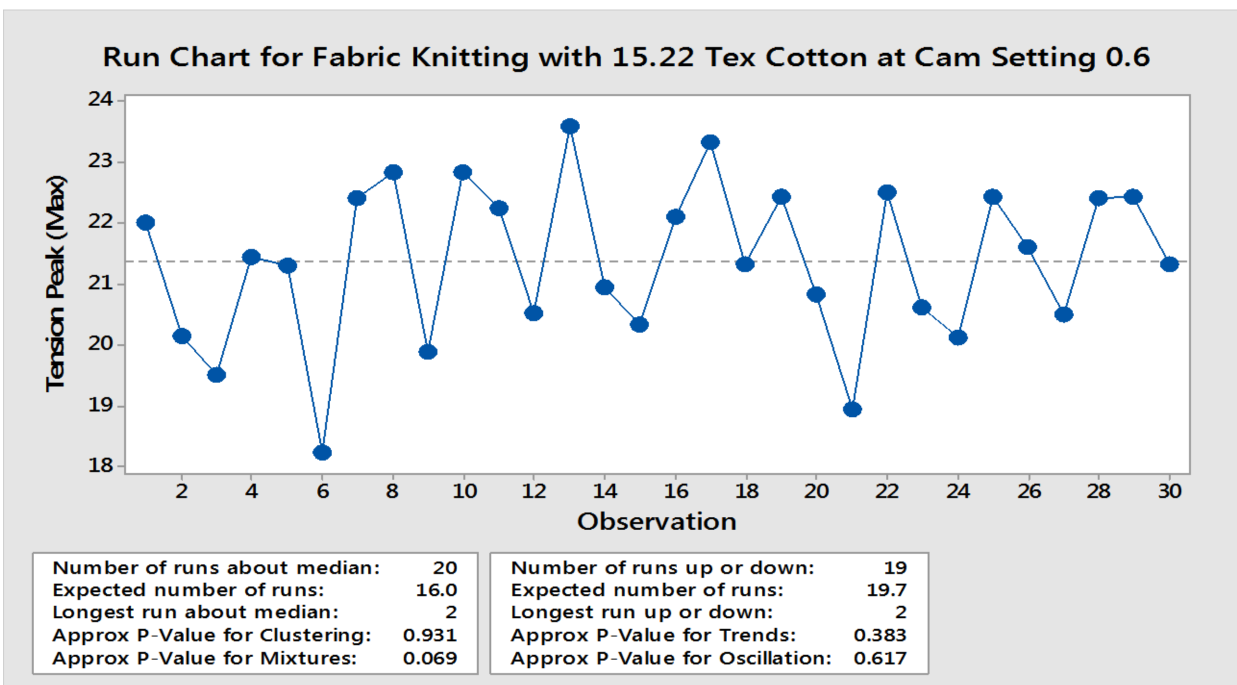


Figure **O28**: Run chart for production run no. 14 (30 second)

Production Run No. 15

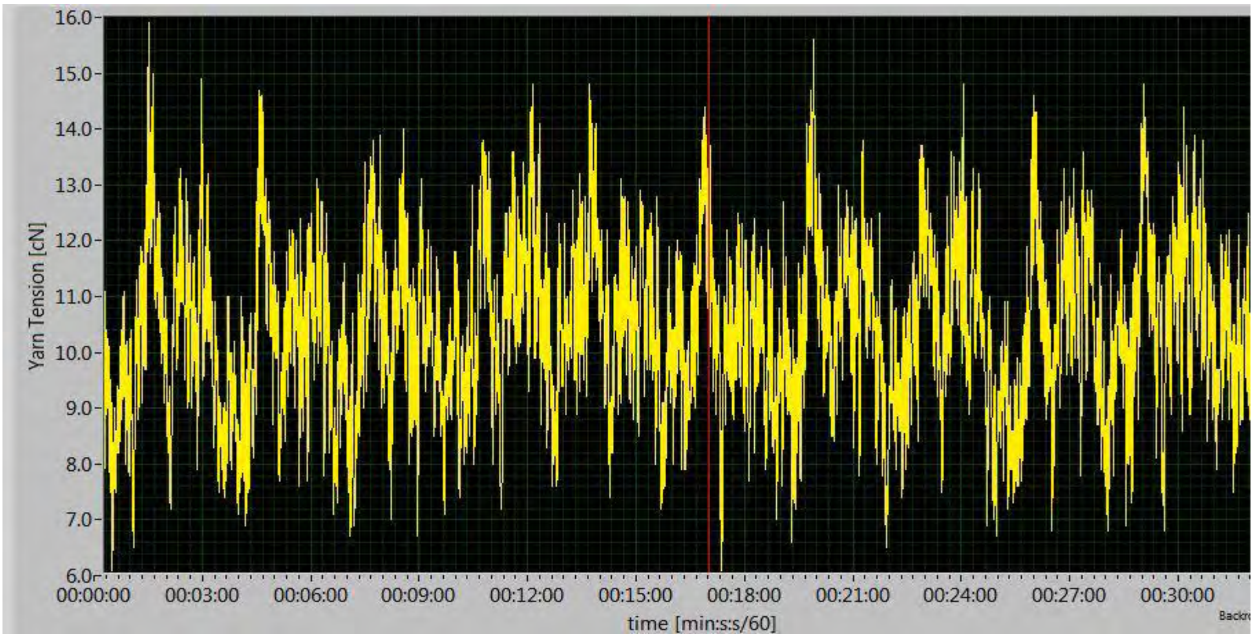


Figure **O29**: YIT waveform obtained for knitting production with 15.22 Tex Cotton at cam setting 0.5

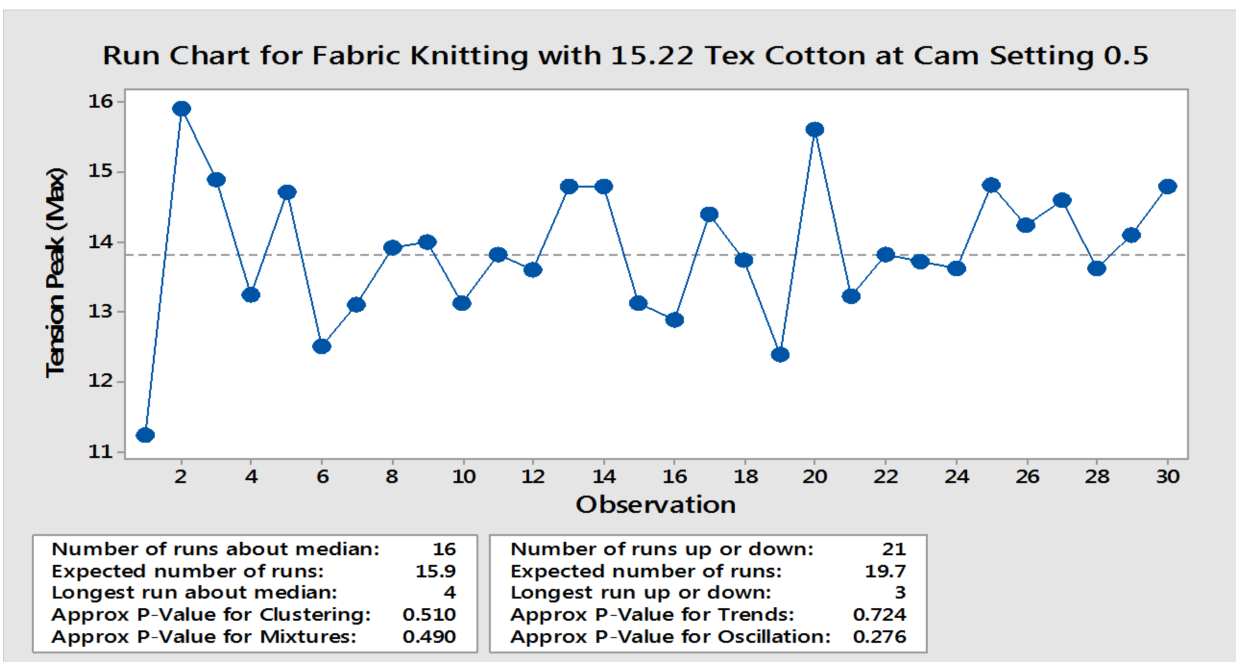


Figure **O30**: Run chart for production run no. 15 (30 second)

Production Run No. 16

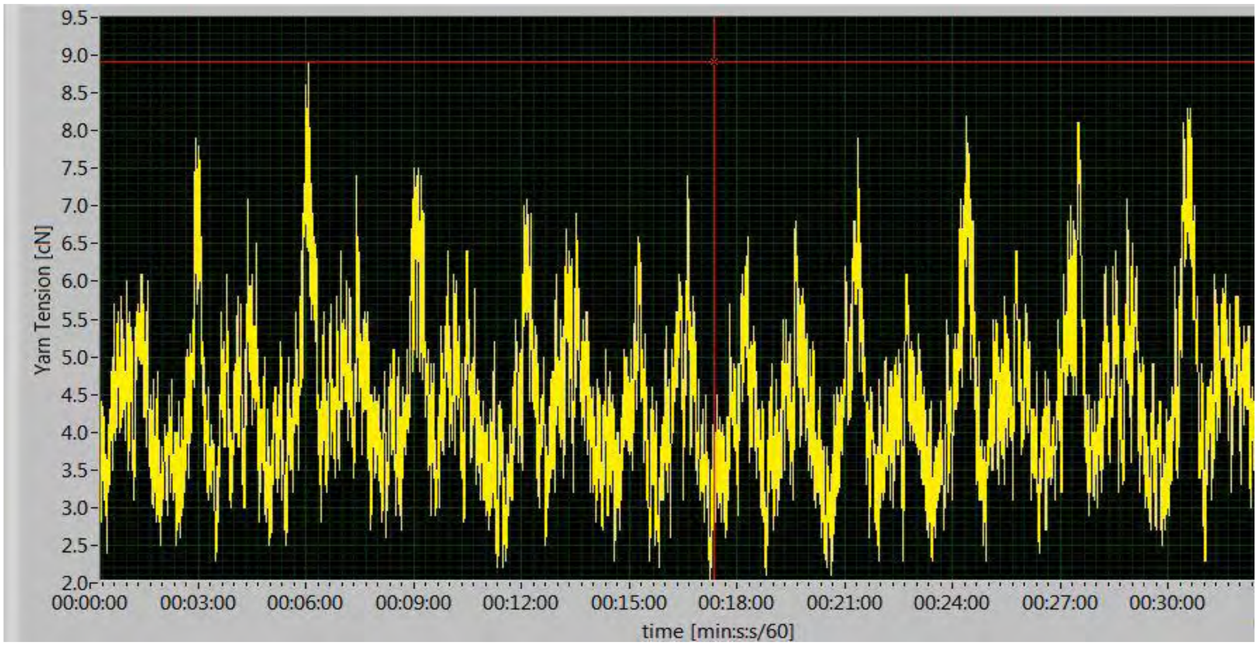


Figure **O31**: YIT waveform obtained for knitting production with 15.22 Tex Cotton at cam setting 0.4

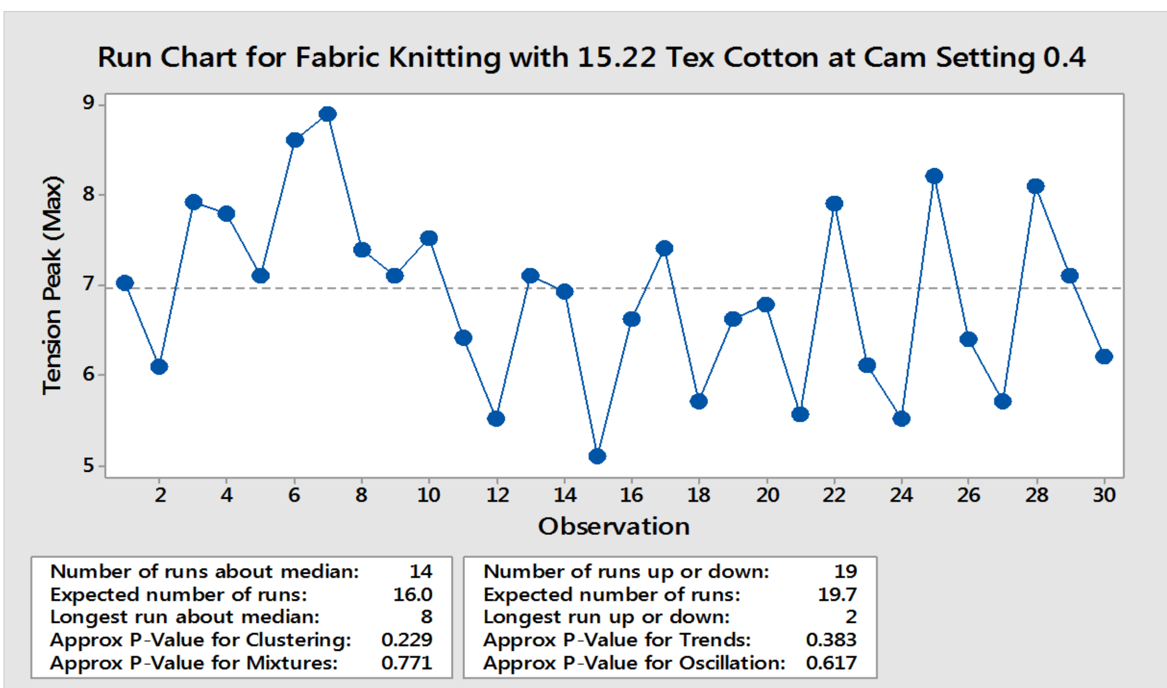


Figure **O32**: Run chart for production run no. 16 (30 second)

APPENDIX P: A typical example of existing setting for dust removal through compressed air (Source: Knitting floor, PPCKFL)

Table **P1**: Air flow rate obtained for the reference position of compressed air ejecting nozzle- end

Machine Brand	Pressure (bar)	Reference Position	Distance (mm)	Air flow rate (m/s)	Average Air flow rate (m/s)
Orizio	2	Needle to comoessed air ejecting nozzle- end	10	22.1	22
				21.7	
				22.2	
				20.9	
				22.8	
				21.9	
				22.1	
				21.8	
				22.3	
				22.2	

APPENDIX Q: An example of price quotation for QAP belt cleaning brush

Authorized Dealer
GROZ-BECKERT®
Sole Agent & Service Partner
MEMMINGER-IRO

F. F. TRADING CORPORATION

DATE: 04.11.2018

PRICE OFFER FOR MEMMINGER IRO SPARE PARTS

CUSTOMER NAME : Ahsanullah University of Science and Technology
141 & 142, Love Road, Tejgaon Industrial Area,
Dhaka 1208

SL No	DESCRIPTION OF GOODS	Unit Price	Stock Status
1	CLEANING BRUSH	1,400.00	After 1 months
2	BRUSH SHELF	15,000.00	After 1 months

Offer Validity :10 Days
Terms of Payment :in Cash/Cheque
Time of Delivery : as soon as possible after work order
Packing : Standerd export carton packing

Shahnawaz
Sr. General Manager

Nasir Uddin Tower (7th Floor) 104/1 Bir Uttam Samsul Alam Road, Kakrail, Dhaka-1216, Bangladesh.
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