İSTANBUL TECHNICAL UNIVERSITY ★INSTITUTE OF SCIENCE AND TECHNOLOGY

ANALYSIS OF NEEDLE PENETRATION FORCES IN LOCKSTITCH SEWING PROCESS

M.Sc. Thesis by
Fatma BAYTAR, B.Sc.

Department : Textile Engineering

Programme: Textile Engineering

JANUARY 2003

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(503001603)

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Supervisor (Chairman):	Assoc. Prof. Dr. Fatma KALAOĞLU
Members of the Examining Committee	Prof. Dr. Bülent ÖZİPEK (İ.T.Ü)
	Assoc. Prof. Dr. Binnaz MERİÇ (U.Ü)

JANUARY 2003

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

KİLİT DİKİŞ İŞLEMİNDE İĞNE BATIŞ
KUVVETLERİNİN ANALİZİ

YÜKSEK LİSANS TEZİ
Müh. Fatma BAYTAR
(503001603)

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FOREWORD

During the long period that I had hard times, they were all with me, therefore;

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December 2002 Fatma BAYTAR

CONTENTS

ABBREVIATIONS

AC : Alternative Current
ADC : Analogue to Digital Converter
ANN : Artificial Neural Network
ASTM : British Standards
BS : Navigation System with Time and Ranging
CSIRO : Commonwealth Scientific Industrial Research Organisation
ESAM : Electronic Signal Acquisition Module
FAST : Fabric Assurance by Simple Testing
FEM : Finite Element Method
FFT : Fast Fourier Transform
HESC : Hand Evaluation and Standardisation Committee
HBM : Hottinger Baldwin Messtechnik
JIT : Just in Time
KES-F : Kawabata Evaluation System for Fabrics
LVDT : Linear Variable Differential Transformer
NCSU : North Carolina State University
NTC : National Textile Center
PTFE : Polytetraflourethylene
QR : Quick Response
rpm : revolutions per minute
spm : stitches per minute
TMR : Thread Motion Ratio
UMIST : University of Manchester Institute of Science and Technology

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E : Elastic modulus
K : Gauge factor
L : Length Change in length
Ne : Metric cotton yarn count
Nm : Metric yarn count
$R_{1,2,3,4}$: Resistances
V_{in} : Input voltage
V_{out} : Output voltage
ε : Strain
$\mu\varepsilon$: Micro strain
σ : Stress
υ : Poisson's ratio
ω : Angular speed

ÖZET

Günümüz konfeksiyon işlemleri, yüksek hıza sahip motorlarla donatılan dikiş makinelerini kullanmaktadır. Yüksek hız sebebiyle ipliklere gelen gerilimler ve iğne batış kuvvetleri çok artmıştır. Sonuç olarak, dikim sırasında hem dikiş iplikleri hem de dikilen malzemedeki iplikler zarar görmektedir. Oluşan bu hasar, denim gibi sık, kalın ve ağır yapılı kumaşlar kullanıldığı takdirde daha da ciddi olmaktadır.

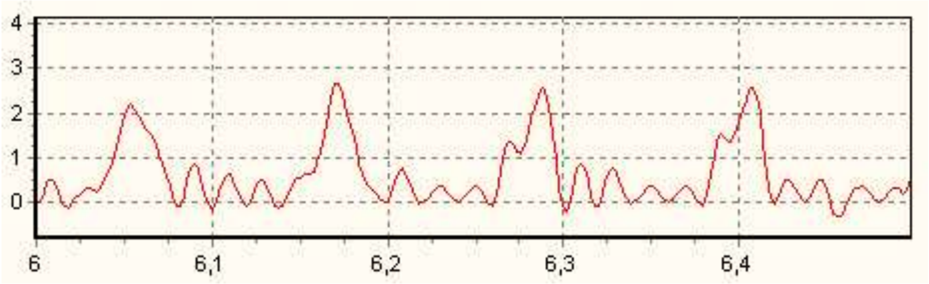
Şiddetli iğne batış kuvvetlerinden kaynaklanan bu sorunun üstesinden gelmek için, öncelikle dikiş sırasında etkiyen kuvvetleri analiz etmek gerekmektedir.

Literatürde iğne batış kuvvetleriyle ilgili çok az bilgi vardır ve olanların çoğu da yetersiz sensör ve veri alma teknolojisi ile gerçekleştirilmiştir. Bu çalışmanın hedefi, kilit dikiş işlemi sırasındaki iğne kuvvetlerini analiz etmek amacıyla bir dikilebilirlik test cihazı kurmaktır. Strain gauge tipi kuvvet sensörleri ve yüksek hızlı veri alma ünitesi kullanılarak gerçek zamanlı olarak iğne batış kuvvetlerinin izlenmesi mümkündür.

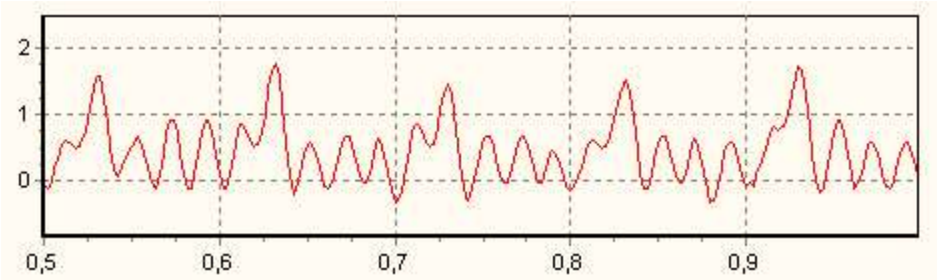
Dikilebilirlik test cihazını kurmak için, Singer 591 D300A kilit dikiş makinesi ile beraber, ölçüm ünitesi olarak Hottinger Baldwin Messtechnik (HBM) firmasınca üretilen strain gaugeler ve ESAM Traveller amplifikatör kullanılmıştır. Dikiş dinamiği üzerindeki etkilerini görmek için, beş tip ham denim kumaş, üç tip iğne (Singer 16, 18 ve 22 no.lar) ve iki tip dikiş ipliği (40 Tkt ve 20 Tkt etiket numaralı) seçilmiştir. Makine hızı dakikada 1100 devir civarında olacak şekilde ayarlanmıştır. Numuneler, ileriki çalışmalarda da kullanılmaları planlandığından, ASTM-D1908 standardına göre hazırlanmıştır. Şekil 1. kurulan sistemin genel görünüşünü vermektedir.

Şekil 1 Sistemin genel görünüşü

Strain gaugelerden alınan veriler, ESAM yazılımı tarafından değerlendirilmiş ve filtrelenmiştir. Sonuçlar, bu sistemin değişen işlem parametrelerine bağlı olarak özel dalgaboyları verdiğini göstermektedir. En düşük ve en yüksek gramaja sahip kumaşlar ele alındığında, 40 Tkt dikişipliği ve Singer 16 no. iğne kullanıldığı zaman, iki farklı sinyal elde edilmiştir. Şekil 2 ve Şekil 3, bu iki farklı dikiş şartındaki değişimleri sırasıyla göstermektedir.



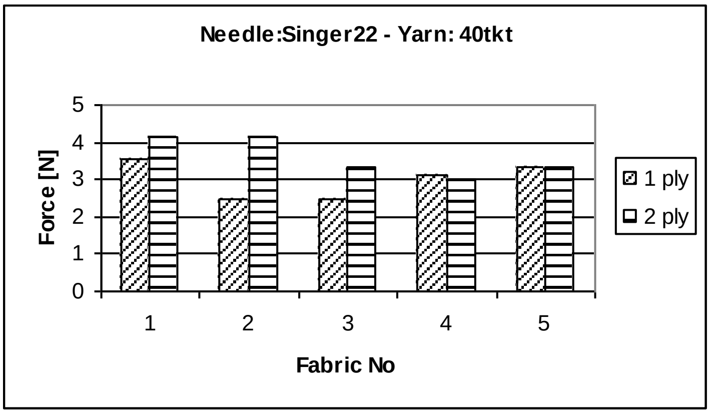
Şekil 2 1112 kodlu numuneden elde edilen dalgaboyları (en yüksek gramajlı kumaş)



Şekil 3 1142 kodlu numuneden elde edilen dalgaboyları (en düşük gramajlı kumaş)

Şekil 2 ve Şekil 3 ten de açıkça görülebileceği gibi, en yüksek gramaja sahip kumaşta en yüksek iğne batış kuvvetleri gözlenmiştir. Ayrıca, şekillerden iğne batış kuvvetlerine ait özel dalga formları ve bunların düzeni de görülebilmektedir.

Histogramlar incelendiğinde, sistemin işlem sırasında kumaş katlarını tanıdığı söylenebilir. Şekil 4, deneyde kullanılan tüm kumaş numuneleri için, Singer 22 iğne numarası ve 40 Tkt dikiş ipliği kullanıldığında, iğne batış kuvvetlerinin tek katlı dikilen kumaşlara oranla çift katlılarda daha yüksek olduğunu göstermektedir.



Şekil 4 Kumaş katlarının iğne batış kuvvetlerine olan etkileri

Sonuçlar açıkça göstermektedir ki, daha da geliştirildiği takdirde, sistem değişik tip iğne numaraları ve malzemeler açısından iğne batış kuvvetlerini belirleyecek bir dikilebilirlik test cihazı olarak kullanılabilir. Böylece, konfeksiyon ve tekstil üreticilerine kalite problemleri ile karşılaşmaksızın işlemlerini ayarlama gücünü verecektir.

SUMMARY

Modern garment manufacturing processes use motorized high-speed sewing machines, which exert very high tensions in the thread and also high needle penetration forces. As a result, both the sewing thread and the yarns in the fabric get abraded/severed during the seaming process. The extent of damage becomes more critical if the fabric being used is of a dense, thick and heavy construction such as denim.

To overcome problems, depending on the penetration forces, at first, the forces acting during sewing must be analysed.
There is a little knowledge about needle penetration forces in literature, most of them were done using inefficient sensor or data acquisition technology. The target of this study, to establish a sewability tester to analyse the needle penetration forces of a lock-stitch machine during sewing process. By using strain gauge and high speed data acquisition systems, it can be possible to monitor needle penetration forces on-line.

To establish a sewability tester, strain gauges produced by Hottinger Baldwin Messtechnik (HBM) and ESAM Traveller amplifier were used as measuring unit, besides the Singer 591 D300A lockstitch sewing machine. Five different constructed grey denim fabrics, three types of needles (Singer 16, 18 and 22) and two types of sewing threads (40 Tkt and 20 Tkt) were chosen to see their effects to the sewing dynamics. The machine speed was kept around 1100 rpm. The samples were prepared according to the ASTM-D1908 standard for the further study. Figure 1 shows the general view of the system.

Figure 1 General view of the system

Data taken form the strain gauges were processed and filtered using the ESAM software. The results showed that this system gives specific waveforms according to the changing sewing parameters. For example, for two fabrics, having the maximum and the minimum weights, two different signals were obtained, for a 40 Tkt sewing thread and Singer 16 needle type. Figure 2 and Figure 3 shows this difference between the two sewing conditions respectively.

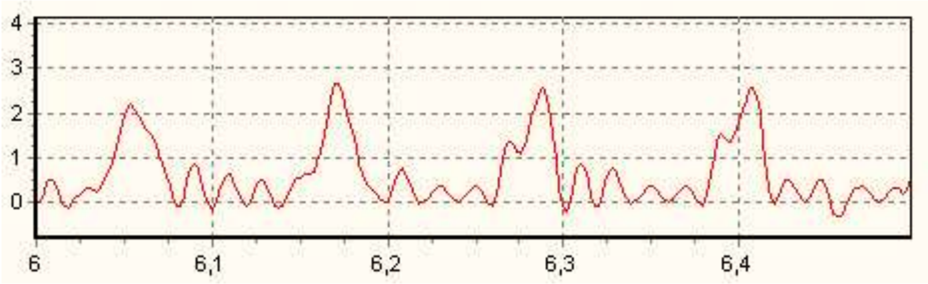


Figure 2 Waveforms obtained for the sample coded 1112 (fabric having the maximum weight)

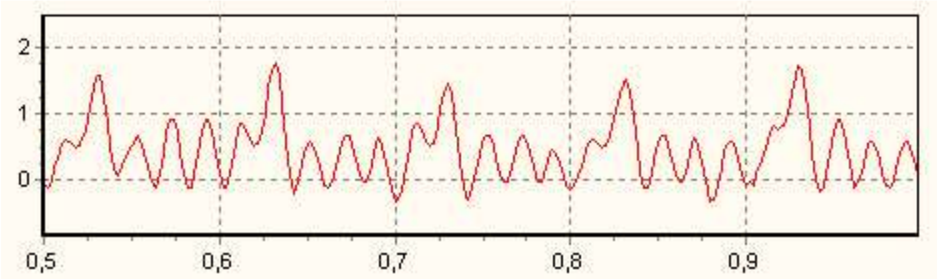


Figure 3 Waveforms obtained for the sample coded 1142 (fabric having the minimum weight)

As can be seen clearly from the Figure 2 and the Figure 3, maximum penetration forces are higher for the heavier fabric. Also the specific waveforms of the needle bar forces and their order can be seen from the figures.

If histograms are examined, it can be said that, this system can recognize the ply differences during sewing. Figure 4 shows that for Singer 22 and for 40 Tkt sewing thread, needle penetration forces were higher for 2 plied fabrics than 1 plies of the all five fabrics used during the experiment.

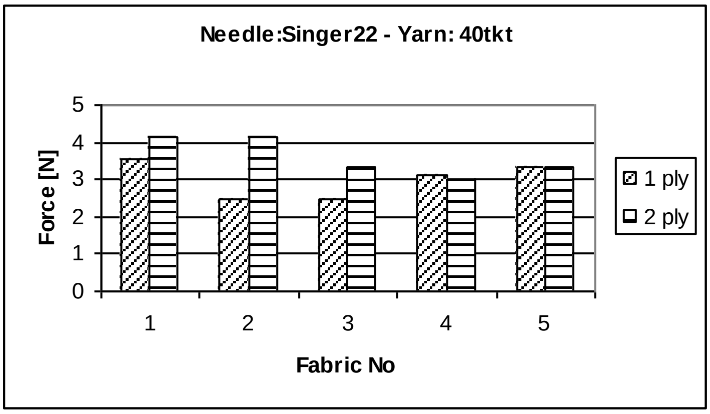


Figure 4 Effects of fabric plies on the needle penetration forces.

Results apparently show that this system, if developed further, can be used as a sewability tester to determine needle penetration forces of different types of needles or materials, empowering apparel and textile manufacturers to tune their processes, avoiding quality problems.

1. INTRODUCTION

The wearing of clothing became a necessity very many years ago, for reasons of modesty, comfort and protection. This necessity has survived over the years but the reasons become more complicated and involve social and psychological factors [1].

The most acceptable means of joining textile materials for apparel use is by sewing, and although other techniques have been invented such as ultrasonic welding, fusing and gluing, they have found limited use due to their low strength, low extensibility and relatively high cost [1].

In the apparel industry, sewing is one of the main processes, in which there has been a constant increase of the degree of automation. The process itself however is not totally controlled. Mathematical models are normally unavailable or of little practical use, and quantitative information about the operating parameters of the machines are in great part unknown and/or not used in practice. The existing knowledge is mainly empirical, acquired over the years by apparel, sewing machine and accessories manufacturers. Choice of needles, threads, and machine settings is based on general guidelines, experience and trial and error. The increasing variety of fabrics to be sewn, combined with the significant reduction of order size, boost the need to reduce lead times and to avoid quality problems, which normally introduce serious production delays [2].

Apparel manufacturing is traditionally very labour intensive due to the extensive style and fabric variation of the products. Most of the sewing machine manufacturers and some of the larger apparel companies have developed semi-automated sewing stations to perform operations, which are constant across a large style range. These normally require an operator to load the machine, which then automatically sews and stacks the components. Although such stations improve production efficiency, they remove the almost unconscious operator inspection of the operation. The result is that only major seam faults are observed, for example, thread breaks. Other faults, mis-stitches or non-included seams for example, may not be detected until the garment is completed or perhaps not until after laundering. At this point, the manufacturer's cost is at a maximum. In order to reduce the number of defective garments it is necessary to develop complete seam monitoring systems that meet the apparel manufacturer's requirements of flexibility, cost and reliability [3,4].

Fibres are a valuable natural resource and the mass production of clothing consumes much energy. It is therefore important that we produce only quality garments to eliminate waste and conserve resources. The engineered production of high quality fabrics and garments is an essential factor in the consistent production of high quality garments. In future, we must produce only good garments and not produce poor ones, because fibres are valuable natural resources, and mass production spends a lot of energy. For these requirements, the engineered production of high quality fabrics and garments is essentially important [5].

High quality garments are essential for competing in today's highly competitive, global market. Seam construction is a critical process in assembling most apparel products. Traditionally, seam inspection has been the responsibility of a quality control inspector and the operator to inspect the seams for defects. This sort of quality control is capable of detecting only visual seam defects during the construction of the garment. Less noticeable or hidden flaws that may not be detected until the garment is complete. While some of the defective garments so produced may be repaired or sold as seconds, others must be discarded at the manufacturer's loss. While the prospect of semi- and fully automatic sewing stations offers the possibility of increased production efficiency, traditional quality control measures must be replaced with on-line automated seam monitoring systems [6].

Automated sewing machines will increase their use gradually in the apparel industry to improve the labour-intensive style of apparel manufacturing. The intelligent sewing machines which can be controlled by fabric properties will become more popular in the near future. The automation of individual machines in the production line is much more important than the completely continuous automated line at this stage. First, the completion of the component machine is necessary and then a total system can be designed [7].

2. STITCH FORMATION AND SEWING MACHINE

2.1 Stitch Formation

For the purpose of standardization of stitch and seam formations, two standards were developed about the same time: The United States Federal Stitch and Seam Specifications (Federal Standard 751a) and The British Standard BS 3870: Schedule of Stitches, Seams and Stitchings.

Federal Standard 751a makes the following distinctions by defining these terms:

- A stitch is one unit of conformation of thread resulting from repeatedly passing a strand or strands and/or loop or loops of thread into or through a material at uniformly spaced intervals to form a series of stitches.

- A seam is a joint consisting of a sequence of stitches uniting two or more pieces of materials and is used for assembling parts in the production of sewn items.

- A stitching consists of a sequence of stitches for finishing an edge or for ornamental purposes or both in preparing parts for assembling [8].

Much of the application of technology to clothing manufacture is concerned with the achievement of satisfactorily sewn seams.

The achievement, at an economical level, of the various requirements of appearance and performance of sewn seams, both initially and during use, is the result of the selection of the correct combination of five factors during manufacturing. Namely;

- The stitch type which is a particular configuration of thread in the fabric,

- The seam type which is a particular configuration of fabric(s),

- The needle which inserts the thread into the fabric,

- The sewing type feeding mechanism which moves the fabric past the needle and enables a succession of stitches to be formed;
- The thread, which forms the stitch which either holds the fabric together, neatens or decorates it [9].

2.1.1 Stitches

2.1.1.1 Stitch Properties

Properties of stitches that relate to aesthetics and performance are size, tension and consistency. Stitch size has three dimensions: length, width and depth. Each may affect the aesthetic appearance, durability and cost of a garment.

- Stitch length is specified as the number of stitches per inch (spi). It is determined by the amount of fabric that is advanced under the needle between penetrations. High spi means short stitches, which are usually more durable than long ones because of subjecting to abrasion.
- Stitch width refers to the horizontal span (bight) covered in the formation of one stitch or single line of stitching.
- Stitch depth is the distance between the upper and lower surface of the stitch.

Thread tension involves the balance of force on the threads that form the stitch and the degree of compression on the fabric created by the threads that as a stitch is formed. Tension ensures the uniform supply of thread and determines how well stitches conform the standard formation. Tension is controlled by adjusting a screw that holds the pressure disks.

Stitch consistency is the uniformity with which each stitch is formed in a row of stitches. There must be a compatibility of fabric, stitch and seam type, needle, thread and machine settings [9].

2.1.1.2 Stitch Classes

Every category of sewing machine produces a specific type of stitch formation depending on the number of needles, loopers and threads, which combine to construct the stitch. Each of these configurations is known as a stitch type and they are classified according to their main characteristics [10].

British Standard 3780: Part 1: 1991: Classification and Terminology of Stitch Types is the standard reference to the wide range of stitch types. It defines a stitch as " one unit of conformation resulting from one or more strands or loops of thread intralooping, interlooping or passing into or through material [9, 11].

Intralooping is the passing of a loop of thread through another loop formed by the same thread, interlooping is passing of a loop of thread through another loop formed by a different thread, and interlacing, a term also used in relation to certain stitches, is the passing of a thread over or another thread or loop of another thread.

A series of recurring stitches of one configuration is defined as a stitch type. BS 3870 divides the many types which are available into six classes [9].

- Class 100: chainstitches
- Class 200: stitches originating as hand stitches
- Class 300 lockstitches
- Class 400: multi-thread stitches
- Class 500: overedge stitches
- Class 600: flat seam or covering stitches [9, 10]

The principal type of sewing machine remains the lockstitch, which is most widely used and is likely to remain the most common and versatile machine for the near future, particularly for sewing woven fabrics [12]. The commonest stitch type in use in the industry is the lockstitch. It is also the one with which people are initially most familiar since it is almost universally used in domestic machines. Because this study was done on lockstitch sewing machine, it is found to be necessary to only mention about lockstitch properties [9].

The commonest stitch type in use in industry is lockstitch [11]. The stitch types in this class are formed two or more groups of threads, and have general characteristic the interlacing of the two or more groups. Loops of the one group are passed through the material and are the secured by the thread or threads of the second group. One group is normally referred as the needle threads and the other group as bobbin threads. The interlacing of thread in stitches of this class makes them very secure and difficult to unravel. The appearance of the stitch is shown in Figure 2.1

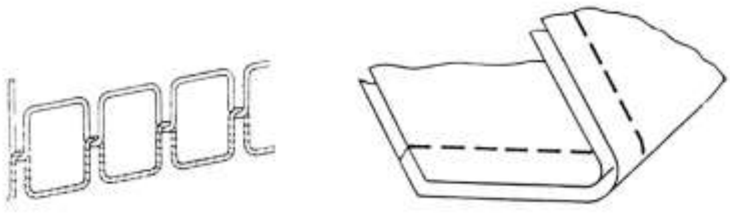


Figure 2.1 The appearance of the stitch

Lockstitch has enough strength for most purposes, provided that suitable thread is used, and enough stretch, when correctly balanced, for conventional and comfort stretch fabrics stretching up to 30 per cent or even more. It has the same appearance on both sides, and advantage denied to virtually all other stitch types and of significance in the assembly process of garments. The stitch is secure because of the breaking of one stitch in wear will not cause the whole row to unravel and additionally the end of a line of stitching can be secured by reversing or 'backtacking'. Alternatively, if the backtack lever is deliberately restricted, a group of small or condensed stitches is formed which secures the end of the stitching without the machine actually sewing in reverse. The thread in lockstitch generally beds well into the fabric, which improves abrasion resistance [9].

2.1.2 Seams

The primary function of a seam is to provide a uniform stress transfer from one piece of fabric to the other, thus preserving the over-all integrity of the fabric assembly [11].

Seams must have flexibility and strength. Garment design, end use, fabric type and weight, operator skills and equipment are analysed to determine which seam types are the most appropriate for a particular style [8].

2.1.2.1 Seam Dimensions

Seams have three dimensions: length, width and depth. They affect garment quality, performance and costs.

- Seam Length: It is the total distance covered by a continuous series of stitches, such as side seam or shoulder seam, and determined by garment design and size.

- Seam Width: Its considerations are divided into three: seam allowance is measured from the cut edge of fabric to the main line of stitches. This is the amount of fabric that extends beyond the actual seamline. Seam heading is the distance from the folded edge of the top ply to the first line of stitches. The width of the stitches is relative to the seam varies with stitch type, lateral movement of the needle bar and spreader, or the number of needles used. Seam width is the distance between the outermost lines of stitches as determined by the space between the needles on the needle bar.

- Seam Depth: It is the thickness or compressibility (flatness) of a seam which affected by fabric weight, fabrication and selection of a seam type [8].

2.1.2.2 Seam Classes

A seam is a joint where a sequence of stitches unites two or more pieces of material. Seams, like stitches, are classified according to main and sub-classes [10]. The choice of seam type is determined by aesthetic standards, strength, durability, comfort in wear, convenience in assembly in relation to the machinery available and cost. Table 2.1 shows seam classes' descriptions.

Table 2.1 Seam Classes

British Standard	Federal standard	Description
Class 1	SS	Superimposed
Class2	LS	Lapped
Class3	BS	Bound
Class4	FS	Flat

The British Standard divides stitched seams into eight classes according to the minimum number of parts that make up the seam, two of them were added in 1983 edition of British Standards without descriptive names. These two additional classes are included in the U.S. Standards as lapped seams [9, 11].

- Class 1 (Superimposed Seam) (SS): The most commonest construction seam on garments is Superimposed Seam (Class 1) The simplest seam type within the class is formed by superimposing the edge of one piece of material on another. A variety of stitch types can be used in this type of seam, both for joining the fabrics and for neatening the edges or for achieving both simultaneously as can be seen in Figure 2.2 [9]

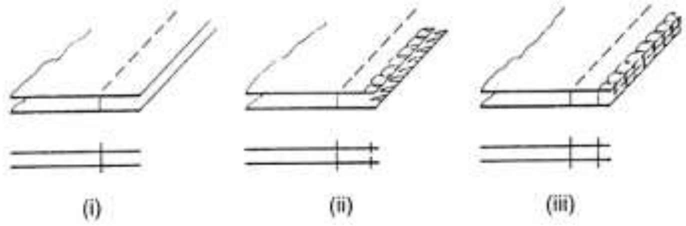


Figure 2.2 Superimposed seams

- Class 2 (Lapped Seam) (LS): It is defined as two or more pieces of fabric joined by overlapping at the needle. This is the largest seam class, including 101 different seam types. These seams may be sewn with a lockstitch or chainstitch.

- Class 3 (Bound Seam) (BS): This class requires a separate piece of fabric that encompasses the edge of one or more pieces of the garment. They may be sewn with a lockstitch, chain stitch or cover stitch.

- Class 4 (Flat Seam) (FS): The formation of this seam occurs with the butting together of two pieces of fabric, but not overlapping them. They extend across the seam, holding both pieces together and covering the seam on one or both sides. [8]

- Class 5 (Decorative Stitching): The main use of the seam is for decorative sewing on the garments.

- Class 6 (Edge Neatening): Seam types in this class include those where fabric edges are neatened by means of stitches.

- Class 7: Seams in this class relate to the addition of separate items to the edge of a garment part. They are similar to the lapped seam except that the added component has a definite edge on both sides.

- Class 8: In this class, only one piece of material need be involved in constructing the seam[9].

2.1.3 Feed Systems

The material handling components of a machine are often referred to as the feeding system. For a precise line of stitches to be formed, fabric must be moved through the stitch forming area of the machine with accuracy and precision. The feeding system controls fabric movement. It usually consists of three parts: the presser foot, the throat plate, the feed dogs (the feed mechanism). They are specific to the machine type, number of the needles used, type of the adjustments used and the types of operations [8]. Figure 2.3 shows the feed system components.

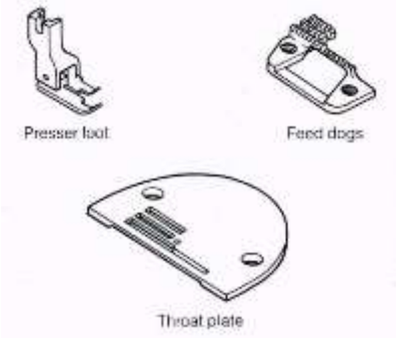


Figure 2.3 Feed system components: presser foot, feed dogs and throat plate

2.1.3.1 Presser Foot

The presser foot, which is attached to the presser bar, is the upper part of the feeding combination that holds the fabric in place for the feeding action and stitch formation. It controls the amount of pressure placed on the fabric as it fed through the machine [8]. Figure 2.4 shows the presser foot and feed dog [13]

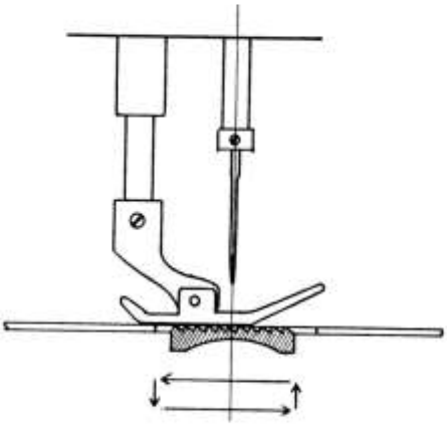


Figure 2.4 Presser foot and feed dog

2.1.3.2 Throat Plate

Throat plates are removable metal plates attached to an adapter plate or throat plate support, directly under the needle. Throat plates support the fabric as the needle penetrates to form the stitch [8].

This provides a smooth surface for the material to pass over, and has one or more slots to accommodate the movement of the feed dogs. The throat plate also has a needle hole(s) and sometimes a slot for sewing needle actions such as that of a zigzag machine [10].

2.1.3.3 Feed Mechanisms

Feed mechanisms control the direction of fabric movement and the amount of fabric movement for each stitch. These move the material forward a pre-determined distance to allow successive penetrations of the needle. The stitch regulator fitted to machines controls the distance the work travels between each penetration, and this distance called stitch length [10]. Most machines have bottom-drop oscillation feeds called feed dogs, major part of most lower-feed systems, that rotate in an elliptical pattern below openings in the throat plate. Feed dogs (feed teeth) rise above the throat plate and carry the fabric toward and away from the needle and drop down and away from the fabric as the needle descends into the fabric to form a stitch. Variables are tooth height, shape, angle, width, number of rows, number of teeth in each row, and the placement of the rows. Top feeds can be used with feed dogs or operate independently of bottom feeds [8].

There are various feed systems in common use are: drop feed, compound feed, unison feed, drop and variable top feed, differential bottom and variable top feed [10].

2.1.4 Needles

These were probably among the first tools devised by man that still remaining in use today [10]. The functions of the sewing machine needle in general are:

- To produce a hole in the material for the thread to pass through and to do so without causing any damage to the material;

- To carry the needle thread through the material and therefor m a loop which can be picked up by the hook on the bobbin case in a lockstitch machine or other mechanism in other machines;

- To pass the needle thread through the loop formed by the looper mechanism on machines other than lockstitch [9, 14]. The commonest needle shape, with its various sections labelled, is shown in Figure 2.5

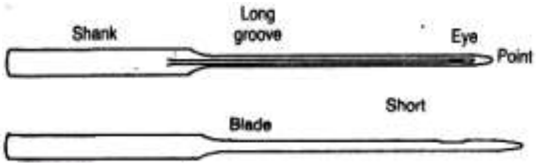


Figure 2.5 Parts of a sewing machine needle

Needle size indicates the diameter of the needle blade shortly above the scarf or the short groove [15]. There are about 30 needle size systems in current use and the equivalents between systems are usually shown in the manufacturer's handbook, which comes with the sewing machine [10, 16]. Needles are available in a wide range of sizes and the choice of size is determined by the fabric and thread combination, which is to be sewn. Correct size is essential to good sewing performance but as fabrics tend to become finer and, in many cases, more densely constructed, the demand is for needles and threads which can be used satisfactorily in smaller sizes. Different needle manufacturers use their own nomenclature to describe needle sizes but the simplest sizing system is the metric one. The metric size or Nm of a needle is related to the diameter at a point at the middle of the blade above the scarf or short groove but below any reinforced part. This measurement, in millimetres, multiplied by 100, gives the metric number. Thus a diameter of 0.9 mm is an Nm 90; a diameter of 1,1 mm is an Nm 110. Figure 2.6 shows metric needle sizing.

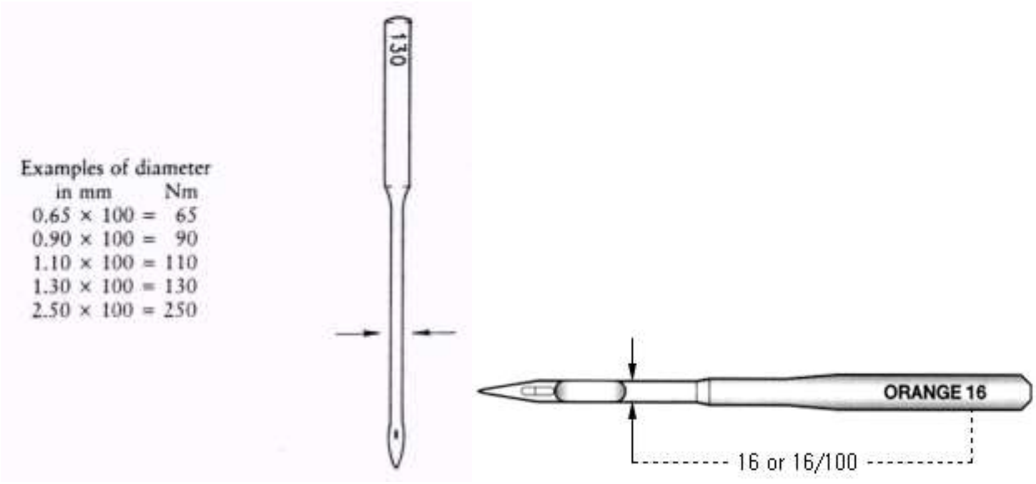


Figure 2.6 Metric needle sizing

Typical metric needle sizes are shown in the Table 1.2 along with the equivalent sizes in the Singer system and typical thread sizes, given in the ticket number system for synthetic threads [9].

Table 2.2 Needle and thread sizes

Thread sizes in synthetic ticket numbers	Needle sizes in metric system	Needle sizes in Singer system
8	180	24

16	140	22
30	120	19
50	110	18
75	90	14
120	80	12
180	70	10
320	60	8

The shank is the upper part of the needle, which locates within the needle bar. It may be cylindrical or have a flat side, according to how it is secured into the machine. It is the support of the needle as a whole and is usually larger in diameter than the rest of the needle for reasons of strength.
The shoulder is the section intermediate between the shank and the blade, the latter forming the longest part of the needle down to the eye.

The blade is subject to the greatest amount of friction from the material through which the needle passes. In needles designed for use in high-speed sewing machines the shoulder is often extended into the upper part of the blade to give a thicker cross-section which just enters the material when the needle is at its lowest point on each stitch. This supplementary shank or reinforced blade strengthens the needle and also enlarge the hole in the material when the needle is at its lowest point, thus reducing friction between it and the material during withdrawal after each stitch.

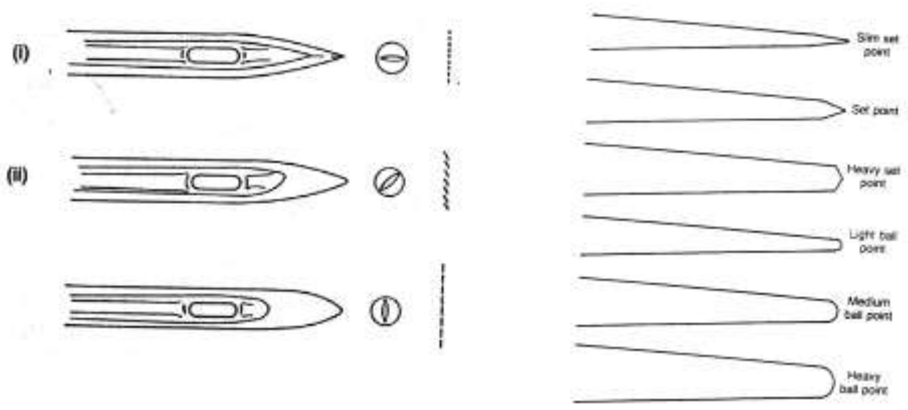
The long groove in the blade provides a protective channel in which the thread is drawn down through the material during stitch formation. Sewing thread can suffer considerably from abrasion during sewing as a result of friction against the fabric and a correctly shaped long groove, of a depth matched to the thread diameter, offers considerable protection to the thread.

The short groove is on the side of the needle, which is towards the hook or looper and is a groove, which extends a little above and below the eye. It assists in the formation of the loop in the needle thread.

The eye of the needle is the hole extending through the blade from the long groove on one side to the short groove on the other. The shape of the inside of the eye at the top is critical both in reducing thread damage as the needle penetrates the material and in producing a good loop formation. On some needles, known as bulged eye needles, the eye area has a larger cross-section than the rest of the blade. This serves a similar purpose to the reinforced shoulder mentioned above in that, as the needle enters the material, it creates a larger hole than is needed by the main part of the blade, thus reducing needle to fabric friction.

The scarf or clearance cut is a recess across the whole face of the needle just above the eye. Its purpose is to enable a closer setting of the hook or looper to the needle. This ensures that the loop of needle thread will be more readily entered by the point of the hook or looper.

The point of the needle is shaped to provide the best penetration of each type of material according to its nature and the appearance that has to be produced. It is also the part of the needle, which must be correctly selected in order to prevent damage to the material of the seam being sewn [9]. The most important aspect of needle design is the point, because it has to penetrate the fabric without cutting or causing other damage. As a rule, fine round point needles are used for delicate fabrics while sturder round points are preferable for coarser cloths [10]. A suitable sewing needle is very important for quality assembly of garments' parts. Good knowledge of kinds and properties of processed textile materials as well as of types of sewing needles is needed in order to select the appropriate sewing needle for a certain material [14]. The basic division of needle points is into cutting points and cloth points. Figure 2.7 shows the needle points. This division is necessary because of the fundamentally different constructions of the two types of material which must be sewn, namely leathers and plastics which are essentially sheet materials with no gaps within the structure, and textile fabrics which, whether woven, knitted or made from bonded textile fibres in a non-woven form, have spaces within the structure through which a needle can penetrate. In a sheet material, the needle point must cut a sufficient hole that the needle blade and thread can pass through it without excessive friction, but there must be sufficient strength of material left between the holes that they do not run together, especially when under stress, and cause the garment to split. In a textile material cutting of the fibres is precisely what must be avoided since, depending on the fabric construction, yarns may run back from the hole that is created, causing poor appearance and a weak seam [9].



(a) (b)

Figure 2.7 Needle Points (a) Cutting points, (i) Wedge point, (ii) Narrow reverse twist point, (iii) Cross point (b) Cloth points: set point, heavy set point, light ball point, medium ball point, heavy ball point.

Different shapes of needle points are used in sewing. First of all the shape of a needle point depends on processed material. The needle with a normal needle point (notation R or without notation) can be used for sewing of the majority of textile materials. The needle point is slightly rounded and during the penetration through the material pushes away the threads without damaging the material. Needles with rounded or ball points (notation SES for light ball point and SUK for medium ball point) are used for knitwear processing. The needle point pushes the thread loops away effectively since no thread damages are allowed because of possibility of loop bursting. Elastic materials with built-in elastic threads require special heavy ball points (notations SKL and SKF) [14].

The tip is the extreme end of the point, which combines with the point in defining the penetration performance [9].

2.1.5 Threads

Sewing is done with a needle and sewing thread either manually or by machines. Sewing thread is one of the most important elements required to produce neat, firm and durable seam, which gives the garment the necessary aesthetics and the stamp of a quality product [11]. They are used in garments, upholstery, high-temperature applications and geotextiles to join different components by forming a seam [17].

Sewing thread may be defined as smooth, evenly spun, hard-twisted ply yarn, treated by a special finishing process to make it resistant to stresses in its passage through the eye of a needle and through material involved in seaming and stitching operations. It joins different components of fabric by forming a seam that primarily provides uniform stress transfer from one piece of fabric to another, thus preserving the over-all integrity of the fabric assembly [11, 17].

A wide variety of threads is available that differ in fibre type, construction, size, colour, and finish. The choice of thread depends on the performance of the available sewing threads and the material being sewn [11].

For the sewing process to be trouble free, the thread must be of uniform diameter, free from knots, and must have minimum tendency to snarl. All conventional sewing threads begin their production cycle as singles yarns, generally having S-direction twist, and re next twisted together in the Z direction. Threads are generally 2-, 3- or 4-ply (folded) or a cord (cabled) [11, 18]

Characteristics of sewing threads are as follows:

- Sewability: Ability to produce a seam with minimum thread breakage during sewing operation.
- Seam security: Security of seams during long use of fabrics, garments.
- Color matchability: Must be accept a wide range of colours to match with a wide range of fabrics shade [19].

2.1.5.1 Thread Sizes

When choosing a thread for a particular application, the thread type (cotton, spun polyester fire, core-spun etc.) and size or ticket number must be specified. The size and strength of a sewing thread must be appropriate to the weight, thickness and closeness of the fabric to be sewn. It should be suitable for the needle to be used. In general, thicker thread is used for heavier fabric. The clothing industry tends to use the finest thread that provides adequate seam strength in a given application [11]. The size of a sewing thread is given by its 'ticket number' (Tkt no.), which is intended to help in choosing the correct thread for a particular purpose. In BS 4134, sewing threads made wholly or partly manufactured fibres (for synthetic and corespun threads) have ticket numbers approximately equal to three times the metric count (Nm) of the thread (that is to say, in the three-fold thread the metric count of the singles component). Sewing threads made of wholly cotton have ticket numbers approximately equal to three times the cotton count (Ne) of the thread. Some sewing threads carry a decitex numbering and this conforms to the standardisation of the tex yarn numbering system with the textile industry. The denier system is used for monofilament sewing threads Table 2.3 shows how ticket numbers should be related to ranges of the total nominal decitex [18].

Table 2.3 Relation between Ticket numbers and decitex

Sewing threads containing manufactured fibre		Wholly cotton sewing threads	
Decitex (dtex)	Ticket number (Tkt)	Decitex (dtex)	Ticket number (Tkt)
158	180	274-324	60
178-200	160	324-398	50
354-388	80	398-468	40
575-635	50	540-665	30
710-805	40	665-810	24
1430-1580	20		

2.1.5.2 Types of Sewing Thread

As with other textile materials, sewing threads are composed of a fibre type, a construction and a finish, each of which may influence both the appearance and the performance of the thread. The simplest division of sewing threads is, in terms of materials, into those made from natural fibres, those from man-made fibres and those made from a mixture, and, in terms of construction into those spun from staple or short fibre lengths, those made from continuous filaments and those which are a combination of the two [9].

The majority of sewing threads used by the clothing industry are mostly made from cotton and polyester fibre. Sewing threads made from natural fibres such as linen, silk, and certain man-made fibres, for example polyamide fibres, acrylic fibres, polypropylene fibre, PTFE fibre, Kevlar aramid fibre, glass fibre and viscose are also used but their applications are restricted owing to their inherent limitations. Also, for some specific applications, like embroidery, high-temperature and geotextile applications, sewing threads are engineered to meet certain requirements [11].

- Cotton Threads: They are made from good quality long fine cotton fibres.

Cotton threads in general provide a good sewing medium, but strength and abrasion resistance are inferior to synthetic fibres threads of equal thickness. Cotton threads withstand high temperatures better than synthetic fibres threads and are therefore less affected by needle heating in sewing and by high temperature pressing. Cotton threads are of three types: soft, glace (polished), and mercerised.

- Linen Threads: Threads spun from flax are stronger than those of cotton but if they are to be exposed to bacterial action in wet conditions, they should be rot proofed. Today, they are mainly superseded by modern synthetic fibre threads.

- Silk Threads: Silk is available both as continuous filament that is extruded by the silk worm and as broken filaments spun into a yarn. It has high extensibility, good lustrous appearance and performance, but its high cost restricts its use to some special areas.

- Synthetic Fibre Sewing Threads: Synthetic fibre threads generally have low shrinkage in dry cleaning and under normal washing conditions. This property is essential to avoid puckering in minimum-care garments. They are stronger and have a greater resistance to abrasion than other threads. Further, synthetic fibre thread of high extensibility can be engineered for knitted or stretch fabric. They are not significantly affected by rot, mildew or bacteria. They have high tenacities, especially in continuous-filament form, and also high resistance to abrasion [11]. They are divided mainly into three sub-classes:

a) Core-Spun Threads: Corespun threads consist of a high-tenacity continuous filament polyester core covered by either a sheath of a long staple cotton fibres, to provide natural appearance and to reduce the heat generated by constant fast movements of thread through the needle, (Poly/ Cotton), or a polyester fibre covering, because it is longer-lasting, stronger and non-flammable, (Poly/Poly). The thread is formed by twisting several of these corespun yarns together to provide cohesion of the fibre covering [11, 18].

b) 100% Staple-Fiber Thread: The most popular thread for clothing manufacture is a spun staple-fibre thread of 100% polyester-fibre yarns. The reason for producing these fibres opposed to continuous-filament synthetic-fibre sewing threads is to increase the bulk or fullness of the thread. The comparative hairiness of the thread helps to reduce the thread friction and improve sewability [11].

c) Continuous- Filament Thread: This class is sub-divided into six classes

i. Monofilament: Each thread consists of only one filament. Nylon 6.6 is usually used because of its higher melting point, which is important when needle heating occurs. The thread is stiffer than most sewing threads, but it is claimed advantage is that, since it is translucent, the colour of the fabric that is being stitched shows through and consequently a wide range of different-coloured sewing threads is not needed. Monofilaments tend to shrink and cause seam pucker. They are harsh on the machine, causing accelerated wear on machine parts, and rather inflexible because of its cross section never varies as it would with multifilaments. These threads are of limited use [11, 18].

ii. Multifilament: More conventional constructions of continuous-filament thread are in multifilament form, in singles or plied or corded. In single ply-threads, each thread consists of numerous individual filaments and incorporates a bonding agent to prevent filament separation. The threads are suitably twisted and then treated with a light-bonding finish. In plied threads, each thread consists of two or more yarns, each containing numerous individual continuous filaments the thread may be bonded.

iii. Bonded Continuous Filament Thread: They are continuous-filament threads with low twist to which a suitable bonding agent has been applied. Bonding of sewing threads consists in the application of a uniform coating, commonly nylon, after which the thread is lubricated. The bonding agent protects the thread from possible heat damage in sewing, prevents cut ends from fraying and also prevents run-back of the twist [11].

iv. False-Twist Textured Polyester and Nylon Threads: By virtue of their crimp rigidty, textured threads are very soft and extensible. They are ideal for covering very extensible seams in knitwear, underwear, swimwear, foundation wear and tights with and added advantage of their softness to the skin [18]. Texturing reduces the high strength in continuous filament threads [11].

v. Air-Textured Continuous Filament Thread: Because air-bulking process gives a discontinuous surface to the thread, danger of thread fusion at high sewing speeds is reduced. These yarns provide better lock in the fabric.

vi. Air-Jet Intermingled Polyester Fibre Thread: This thread is composed of a continuous filament core surrounded by filaments that have been entangled by an air jet [11].

2.2 The Thread Path

The needle-thread is taken from a supply package and then passes through a pre-tensioner and between two profiled metal discs held together under spring pressure to provide the major frictional resistance on the thread. The spring pressure on this master tensioner is adjusted by turning the threaded nut through the looped extension of the check-spring, which is a coiled spring working in a torque mode.

The check spring adds further resistance to the thread movement, and it also acts to remain a small reservoir of thread in a loop held by the spring. From the check spring, the needle thread passes through a guide and then through the eye of the take-up lever. This lever provides fundamental control of the movement of the thread through the sewing machine, and its drive geometry is such that, during each stitch cycle, it rises twice as fast as it falls. Form the take-up lever; the thread passes through another guide and through the eye of the needle.

2.3 The Stitch-Formation Sequence

The lockstitch creation cycle commences with the sewing the needle descending into the fabric plies, which are stationary on the throat plate of the sewing machine. The take-up lever falls during this action and releases thread, which the needle draws down through the needle hole in the throat plate. After reaching the limit of its downward excursion, the needle begins to rise; yet, the take-up lever continues to fall. Once the needle has risen by approximately 3 mm (this is machine-dependent), the friction of the needle-thread against the fabric, coupled with the absence of thread-feed tension, causes a loop to form in the scarf to the rear of the needle. This loop is penetrated by the rotary hook at the top of its cycle. The downward motion of the hook, combined with the geometrical profile of the jib on the rotary hook, causes the loop to twist through 90^0 and to extend around the bobbin, the bobbin-case, and the base. The take-up lever, in continuing to fall, supplies thread for this purpose, and the check spring is also tensioned by this thread motion. The needle-thread is taken down to the jib on the rotary hook through the needle hole in the throat plate. As the thread passes round the maximum hook and base diameter, to interlace with the bobbin thread, the jib casts off the stitch. The tension in the check spring is released and assists the removal of the yarn from the rotary hook by drawing thread into its reservoir. At this time, too, the take-up lever commences its ascent and draws excess thread up through the throat plate and through the fabric, thus pulling the interlocked stitch into the fabric plies. As the needle assumes its highest position, the serrated dogs of the fabric feed mechanism rise through slots in the throat plate and clamp the fabric against the underside of the presser foot. The fabric is then advanced through the sewing machine by one stitch length under the action of the feed dogs.

With the fabric feed in motion, thread is required to form the upper and lower lengths of the next stitch. During the fabric progression, the take-up lever approaches the top of its vertical travel, and this upward excursion also creates a demand for thread.

The needle thread, which is required to form the increasingly large loop around the rising take-up lever and to form the stitch length, is initially taken from the check-spring reservoir, and the check-spring is tensioned as this thread is drawn away as part of the initial satisfaction of this demand. The damping action of the check-spring usefully reduces the peak thread tension during yarn feed. When the check-spring reservoir is exhausted, the check-spring reaches the stop at the end of its travel. Thread is taken from the supply package by drawing it through the tension discs on the tension barrel.

As the take-up lever begins its descent, the stitch interlock is set into a balanced state within the fabric plies, aided by the recovery of the check spring, which returns to its start position, extracting thread to replenish its reservoir, which action also prevents the descending needle from piercing the needle thread. The process then repeats for the creation of the following stitch [20]. The process is shown only for needle and bobbin case in Figure 2.8 [9].

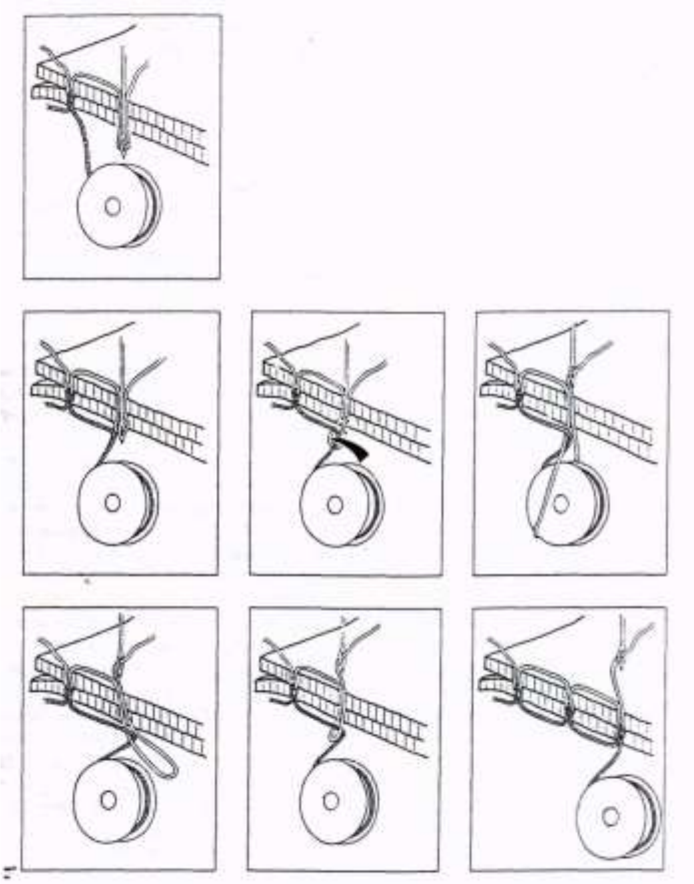


Figure 2.8 The mechanism of stitch formation

3. SEAM APPEARANCE AND PERFORMANCE

The pressure from industry for higher productivity has been matched in recent years by considerable increases in sewing speeds. Apart from increases in speed, new types of textile materials and new finer sewing threads have also been developed, which have required finer sewing needles and improved control of the sewing process. These developments have not been without their associated problems during the course of clothing manufacturing, e.g. achieving puckerless seams at higher sewing speeds required finding the appropriate combination of needle, thread and sewing parameters. In each case the solution of such problems required an understanding of commercial sewing related to seam characteristics and properties such as seam strength, extension, damage, and appearance [12].

Seam appearance and performance affects both the aesthetics and performance of a garment and it is very important to its saleability and longetivity. Seam appearance and performance is dependent on the interrelationships of fabrics, threads and needle; stitch and seam selection; performance of sewing and pressing equipment; handling of materials and appropriate operation and maintenance of the equipment.

Seams are evaluated by the manufacturer during product development and prototype testing. Consumers evaluate seam appearance and performance before purchase based on their standards and past experiences and after wear and care procedures based on its original state [8].

3.1 Seam Appearance

Seam appearance is evaluated on drapeability, consistency of stitch and seam formation and flatness.

3.1.1 Drapeability

It is affected by the flexibility of materials and seam construction. Seams need the same amount of drapeability as the rest of the garment. Use of heavy thread, complex seam structures and other factors that contribute to bulkiness can contribute to the rigidty of a seam [8].

3.1.2 Consistency of Stitch And Seam Formation

It is critical to garment appearance. Varying stitch density (spi), irregularities in stitch and seam formation, and loose thread ends all affect the appearance of the garment. Irregularity in the line of stitching affects the shape of the garment and can cause poor fit and unsightly appearance [8].

3.1.3 Seam Flatness

High level of relaxation shrinkage and large hygral expansion can cause seam pucker [21].

Pucker is a wrinkled appearance along a seam in an otherwise smooth fabric. It generally appears as if there is too much fabric and not enough thread in the seam, as if the thread is drawing the seam in. For this reason, the sewing thread is often blamed for causing the problem but there are several factors, which contribute to pucker [9].

A flat seam is free of fabric creases, waviness and pucker. Some factors affecting seam flatness may be controlled by pressing, top stitching and cover stitching. Seams that are not flat are puckered. Seam pucker is a quality problem that affects appearance but does not the fabric damage. Seam pucker is rippling of a seam that occurs just after sewing or after laundry, causing unacceptable appearance. It has always been a major problem in garment assembly. Change in fabrics, styling and technology creates new potential for pucker [8].

It could be said that there is pucker present in all sewn seams because it is impossible to introduce stitches into a fabric without it suffering some distortion, but in practice, there are many fabrics of loose construction from soft yarns, which show no visible pucker at all. By contrast, many of the modern smooth, fine synthetic fabrics are almost impossible to construct without pucker [9].

Puckering problem cannot be solved by the settings of the sewing machine only and it depends on the fabric mechanical properties. Seam puckering occurs for three reasons as follows: inappropriate mechanical property of fabric, the relaxation shrinkage of fabric, the poor setting of sewing machine [5].

Seam pucker occurring when sewing knitted fabrics is caused by: displacement between fabric layers, sewing thread tension, sewing thread contraction, differential shrinkage, diameter of sewing thread and needle, type of stitch, pressure of presser foot.

Seam pucker occurring when sewing woven fabrics is caused by a number of various factors. These factors can be listed under the following headings: Fabric; its structure, mechanical properties and dimensional stability, Sewing thread; its tension, extensibility and relaxation, diameter and shrinkage, Stitch type, length and seam type, Incompatibility of fabric and threads, Sewing machine, its feed, needle, needle/throat plate assembly and sewing speed [22].

Four main probable causes of seam pucker are discussed here [8]. The complexity of the problem means that combinations of the above types of pucker are usually found. The lighter and finer the fabric, the more difficult it is to find the cause of the problem [23, 24].

3.1.3.1 Feed Pucker

It happens due to the drag of the presser foot on the top ply, as two plies of fabric are sewn together. If the fabric on the bottom is fed more rapidly than the top ply, the bottom fabric puckers. Feed pucker can be detected when a garment is puckered on only one side of the stitched seam. Figure 3.1 shows the feed pucker asymmetrical to the seam [23].

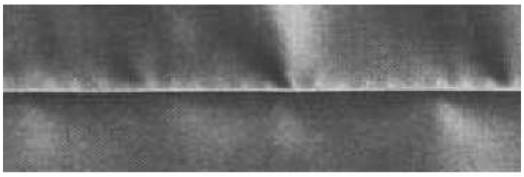


Figure 3.1 Pucker asymmetrical to the seam

Differential fabric stretch of the two plies being sewn may also cause only one side of a seam to pucker [8, 24].

3.1.3.2 Tension Pucker

It may be caused by tight thread tension, which causes the thread to elongate as stitches are formed. Tight tension settings on upper or lower threads during stitching or bobbin winding, or damaged thread guides may be causes. Bobbin winders may be set too tight in order to get more thread on a bobbin and reduce the number of changes necessary [8] Winding the bobbin thread must be done very carefully, because if the thread is wound too tightly there is a risk of stretching it along its entire length, this means it will then be stitched into the seam in this condition. If this happens, there will always be puckering of the seam when the thread later returns to its original unstretched condition. Too loosely wound bobbins are the reason for untidy looking stitch formation and thread breaking problems [23]. Figure 3.2 shows pucker symmetrical to the seam.

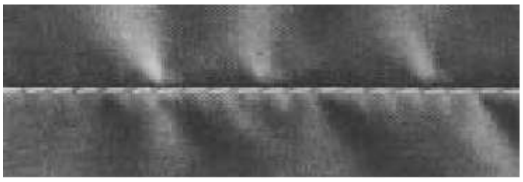


Figure 3.2 Pucker symmetrical to the seam

During sewing, the sewing threads are under some tension. When the thread tension is relieved, the threads start to contract, resulting in a decrease in stitch length. If the decrease in stitch length is greater than the contraction of fabric within the stitch, the seam will pucker. The amount of thread elongation and contraction depends on sewing thread composition and tension. Threads of low elastic modulus (generally synthetic threads) are easier to elongate. The amount of elongation, and also the contraction, due to the applied tension to these threads is greater than for threads of high elastic modulus (cotton) [24]. Tension pucker is primarily a problem with synthetic thread. As the thread relaxes it can cause the fabric to draw together and pucker. Poor quality and wrong size or type of thread is other probable causes [8]. The surface friction of the sewing thread is important in terms of seam appearance, because a higher thread tension develops when sewing with threads of a higher surface friction, and therefore the contraction of the threads, after sewing, is greater and probability of seam pucker is increased. The higher friction between the fabric and the thread during the formation of a seam, the higher the thread tension, and the greater the tendency for seam pucker [25].

3.1.3.3 Displacement Pucker or Jamming

It is caused because of the displacement of fabric yarns from their original position as the needle and thread pass through the fabric. Fabric yarns are pushed together between needle penetrations, which causes puckering that cannot be removed. The tendency for jamming increases with more stitches per inch, higher count fabrics, finer fabrics and thicker sewing thread [8]. It is generally believed that a high fabric set leaves little or no room in the fabric to accommodate the needle or sewing thread, some of the fabric yarns have to be moved aside along the seamline. This leads to some fabric elongation and compressing along the seamline resulting in a puckered seam [24].

In every stitch the unavoidable tension in the threads subjects the fabric in the stitch to bending and compression. If the fabric is compressible the threads can recover without causing pucker. If the fabric is jammed the stiffness of the fabric and thread control the occurrence of pucker [24, 25]. Irregularity of sewing threads can have an effect on seam pucker because, the thick places in a sewing thread can cause structural jammed seam pucker, in the same way as a coarse thread [25].

The risk of displacement pucker arises particularly at high sewing speeds. This problem is very typical because of today's finely woven micro fibre fabrics. The structure of plain woven fabrics means that these are more likely to be affected by displacement pucker than satin woven or twill woven fabrics. Figure 3.3 shows schematic view of fabric displacement by the sewing threads.

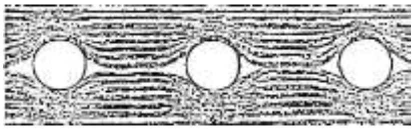


Figure 3.3 Schematic view of fabric displacement by the sewing threads

To prevent from that kind of pucker, it is sometimes required to run the seamline at a slight angle to the warp direction. In the design of the finished garment and in the cutting room, attention should already be given to ensuring that all edges running in the warp direction are aligned at an angle of 5 to 10° C to the seamline. If the seam line is at an angle to the warp direction, the displacement of the fabric threads will be divided among several warp and weft threads [23].

3.1.3.4 Moisture Pucker

It is not a product of the sewing process, but one of concern to the lasting appearance of a garment. Its cause is differential shrinkage of the shell fabric (dfference in dimensional changes of the seam forming fabrics, which takes place when the fabrics are not compatible in terms of their dimensional stability thread or other attached materials such as interlinings [8, 24]. In such cases the seam may appear perfectly flat and unpuckered as it leaves the machine. However, on subsequent laundering or steaming, pucker may occur due to the dimensional instability of the seam components.

When the shrinkage of sewing thread, due to steaming, laundering, wetting, dry-cleaning, etc. is greater than that of the fabric, the new seam length is smaller than the fabric length, which has to be accommodated in the seam length. This kind of pucker can be identified through comparison of the seams before and after wetting, laundering, etc. unshrinkable threads would help to reduce this problem [24].

The effect that severe seam pucker can have in a garment may be aesthetic, i.e. the garment loses its aesthetic appeal to the customer, or/ and functional, i.e. it can downgrade the garment in terms of drape and/or comfort [26].

3.2 Seam Performance

Good seams are essential factors in garment quality. The characteristics of a properly constructed seam are its strength, elasticity, durability, stability and appearance. The factors that govern these properties are seam and stitch type, thread strength and elasticity, stitches per unit length of seam, thread tension, and the seam efficiency of the material (fabric) [11, 27].

The sewing performance depends on the selection of the right thread for the right needle at the right machine suiting to the thickness, structure and finish of the fabric to be sewn [28].

Performance of seams means the achievement of strength, elasticity, durability, security and comfort, and the maintenance of any specialised as strong as the fabric, in directions both parallel to and at right angles to the seam. They must also stretch and recover with the fabric. Seams must also be durable to the kind of abrasion expected in wearing and washing as well as secure against fraying apart or the unravelling of stitches. A seam in a close-fitting or underwear garment must not present an uncomfortable ridge or roughness to the skin [9].

3.2.1 Elasticity

Elasticity involves two factors: elongation and recovery. Seam elasticity is the degree of a seam recovers to its original length immediately after elongation. Seams vary in elongation potential.

Elongation is the amount that a seam can be stretched without breaking. If a seam will not elongate as much as the fabric, the stitches and thread will usually break. Seam elongation is related to thread properties, thread tension, seam type, stitch type, spi and fabric properties. More stitches per inch can produce more stretch, but too many may stress the yarns and cause fabric damage.

Recovery is the return of the seam to its original length when the stress is removed. Seam recovery can be inhibited by the selection of inappropriate stitch and seam type, too many stitches per inch and thread that is too large [8].

3.2.2 Strength

Seam strength is important factor in determining the durability of a garment. It is determined by resistance to pulling force and abrasion. Seam tenacity is the force necessary to break the fabric or the weakest stitch of a seam. Seam abrasion resistance is the amount of rubbing action needed to wear away stitches in the seam. Seam strength is related to stitch type, thread strength, thread tension, seam type, seam width and spi [8, 9, 29].

Seam failure in a garment can occur because of either the failure of the sewing thread, leaving the fabric interact, or fabric rupture, leaving the seam intact or both breaking at the same time [22].

When stress is applied to a seam at right angles to its length, the load is carried by the intersecting loops of the sewing threads, and when the latter rupture, the break occurs at the opening of the loop. The strength parameter that applies is therefore the loop strength rather than the straight tensile strength of the sewing thread [8, 22].

Although seam strength is important to durability, the seam does not need to be stronger than the fabric of which it is being constructed [8].

Durability of the seam largely depends on its strength and its relationship to the elasticity of the material. It is measured in terms of seam efficiency where:

Seam Efficiency=(seam tensile strength/ fabric tensile strength) x 100 (3.1)

In general, it ranges between 85 and 90 % which can be optimised through various factors, such as seam type, type and density of stitches, and the selection of sewing threads and needles. Under strain, it always preferred for the sewing thread in the seam to break before the material because the seam can be restitched, whereas an expensive fabric cannot be re-woven [11, 18, 27, 28].

3.2.3 Seam Durability

The length of life of a seam in a garment should be as long as that of the other materials and both should be appropriate to the required end of the garment. An immediate failure of the thread would be regarded as a failure of seam strength or extensibility.

3.2.4 Seam Security

If the last stitch is not properly locked, if a thread is broken (which causes the problems of seam strength and stretch), or is a stitch is slips because the machine is improperly adjusted or it sews over a thicker section of fabric, it will run undone very easily [9].

3.2.5 Seam Flexibility (Seam Comfort)

Seam flexibility affects the drapeability, comfort and abrasion resistance of apparel. Flexible seams allow for more body conformity and movement. Rigid seams can cause body discomfort and irritation [8] Particular problems associated with the use of monofilament polyamide threads [9]. A flexible seam is able to bend, shift and fold without damage to the seam or change to the silhouette of the garment. Without flexibility, abrasion and wear will occur in the same location or to the same set of yarns. Fabric structure and weight and seam type are major factors that affect seam flexibility [8].

3.3 Seam Problems

Seam problems affect appearance and performance. Seam failure can cause costly repairs, consumer dissatisfaction and returns and increased costs. Causes of seam failure include inappropriate choice of stitch or seam type, incompatibility among thread type and size, needle type, size and fabric, improper adjustment of feed mechanisms and machine settings and operator performance [8]. Seam problems are explained below. The problems which arise when materials are sewn vary in their seriousness, with some causing only minor appearance problems, negligible in low price garments, whilst others cause damage to the material which it would not be economic to repair even if it were possible [9].

3.3.1 Distortion

Distortion is the disruption of the fabric surface of the deformation of a garment. Incorrect handling during garment assembly often contributes to distortion. Incorrect machine settings, poor machine maintenance, excessive needle heat and incorrect needle and thread type and size are can be referred as the factors in the creation of distortion. It can be prevented with better training of operators, better machine maintenance and appropriate selection of thread, needles and stitch and seam types [8].

3.3.2 Problems of Stitch Formation

The main problems which arise from the actual stitch formation are: slipped stitches, staggered stitching, unbalanced stitches, variable stitch density, needle, bobbin or looper thread breakage.

- Slipped (skipped/missed) Stitches: Skipped stitches are a common sewing problem affecting quality, seam performance and aesthetics of a garment. It is caused by the failure in stitch formation when the needle thread loop is not picked up by the hook or looper.(the sewing machine' misses out' one or more stitches and then' picks up' the stitch and carries on normally. The result in lockstitch and single needle double chainstitch seams is that when mis-stitches occur stitches in the upper surface of the seam are twice the normal size or even larger. If the needle is too large for the thread, there will be poor control of the loop formation, which may cause slipped stitches. Mis-stitching is more common in knitwear manufacturing where the knitted fabric tends to vibrate slightly with the vertical movement of the needle, affecting the shape and size of the thread loop [30]. In a lockstitch type of machine, during normal straight sewing, the needle and hook tend to insert some Z twist to the sewing thread. A thread with S twist becomes untwisted by the action of the machine and then frays and breaks, improper ballooning of the thread occurs during the up-and-down of the needle, which may lead to missed stitches [11].

Skipped stitches create a lack of uniformity in a line of stitching and are susceptible to snagging. They also become the weak link and have potential for breakage. Skipped stitches are most likely to occur when changes are made in fabric, thread or needles. Mis-stitch, however, can happen quite randomly without any apparent reason in a way which is difficult to predict and hence detect. The faulty seam in most cases is recognised in the quality control stage after which the seam is unpicked and then resewn, this is expensive [30].

- Staggered Stitching: It can be caused by yarns in the fabric deflecting the needle away from a straight line of stitching, giving a poor appearance. In some hard, woven fabrics, really straight stitching will only be achieved at a slight angle of bias [9].

- Unbalanced Stitches: In lockstitching can reduce the potential for stretch in a seam in a knitted fabric and, lead to seam cracking [22]. Bobbin tension should be adjusted until a full bobbin in its case will just slide down the thread when held by the end of the thread. Needle thread tension should be adjusted so that the threads interlock in the middle of the fabric, unless different colour threads are being used.

- Variable Stitch Density: It arises from insufficient foot pressure in a drop feed system, causing uneven feeding of the fabric through the machine. It can occur particularly with materials with sticky or slippery surfaces [9]. At high speed sewing the presser foot `bounces' and loses contact with the fabrics, due to the fact that the feed dog rises above the throat plate and hits the presser foot. This lack of control, just when it is most essential usually results in an irregular stitch [31].

- Needle, Bobbin or Looper Thread Breakage: It is a common problem with many causes such as needle heat, incompability of needle, thread and fabric, and defective machine parts and adjustments. Needles must be rethreaded and seams restitched. If stitches break and are not formed correctly during the sewing operation, it is very difficult and time consuming to go back and repair a line of stitching [8, 22]. Also, thread lubrication has an important effect on the thread breakage. If the finish is not regular, an irregularly balanced seam will result, with relatively high thread breakage [32].

3.3.3 Seam Cracking

When a seam in a knitted fabric is extended along its length, the extension limit of the sewing threads is reached before that of the fabric itself, and the sewing threads that break at one or more points along the seam causing an effect known as seam cracking and this will lead to seam breakdown [9, 33].

3.3.4 Seam Grin

Seam grin is a separation of a sewn seam as a result of transverse stress that allows the stitches and thread to show. It is a condition that is likely to occur with a low stitch count, insufficient tension on threads, or improper stitch and seam selection [8]. Too loose a tension or too large a stitch, or the use of wrong stitch type causes seam grin [22, 34].

3.3.5 Seam Slippage

Seam slippage occurs in woven fabrics when yarns slide together along other yarns or a line of stitching thus allowing seam grin [8]. The amount of slippage mainly depends on the weave, fabric raw material, type of seam, stitch density, and sewing thread tension [18, 27, 35, 36]. It may be affected also by stitch type and size, tension, seam size, thread choice and excessive use of fabric lubricant. Most slippage occurs in seams that run parallel to the warp. Slippage will more likely occur in fabrics that have filament yarns, low count or unbalanced weaves [8]. The tighter the stitch grips the fabric, the less seam slippage there will be. Increasing the width of the seam allowance increases the number of yarns that are between the seam and the cut edge, which creates a resisting force to slippage [8, 22, 34, 37].

3.3.6 Sewing Damage

Sewing damage is two types: heat damage and mechanical damage. During sewing, the fabric resists penetration by the sewing needle. This frictional resistance results in the generation of heat and also produces mechanical strains in the yarn and in the fabric [38].

Sewing damage is a serious problem in garment production, leading to poor seam appearance and performance and, in a severe case, to complete breakdown of the seam.

The problem is especially serious in knitted fabrics because they will ladder if damaged and because the damage is often not apparent when first sewn. It only becomes evident when flexing in wearing and washing causes the damaged or broken yarn to run back and become visible.

The problems which occur in sewing can be divided into those of mechanical damage and those of needle heating damage [9].

3.3.6.1 Needle Damage (Yarn Severance)

Yarn severance is the breakage of fabric yarns that occurs during stitching due to incompability of needle, fabric and sewing speed. Damage to the structure of the fabric occurs when the fabric is penetrated by the needle. Since no allowance is made for the position of the fabric loops during the sewing process, the needle can penetrate at any point in the fabric. It can therefore deform the fabric loops or cause the fabric structure to be opened to such an extent that it will be torn open or damaged. In many cases, this type of damage is caused by a finishing treatment of the fabric, which is too hard. This makes the fabric loops rigid and inflexible and prevents them from being displaced by the tip of the needle [23]. Damage is more likely to occur on tighter, denser fabrics [38].

Sewing damage is generally caused by lack of mobility in the fibres of the yarn, due to high twist; by lack of mobility of the yarns themselves due to close construction of the cloth or to the nature of the finish; or to the use of over-large or blunt needles [18].

The penetration force of the sewing needle is the quantitative measure of the damage which appears in the garment as the result of the sewing process. To get a better look at this process, knowledge of the fabric, the used thread, the sewing needle and the sewing machine mechanisms are important [39].

As combining rows of loops makes knitted fabrics, there is the possibility that the needle can destroy loops. In choosing a proper needle, it is absolutely necessary to find out the correct needle size and point form. Figure 3.4 shows the needle damages to knitted fabrics [15].

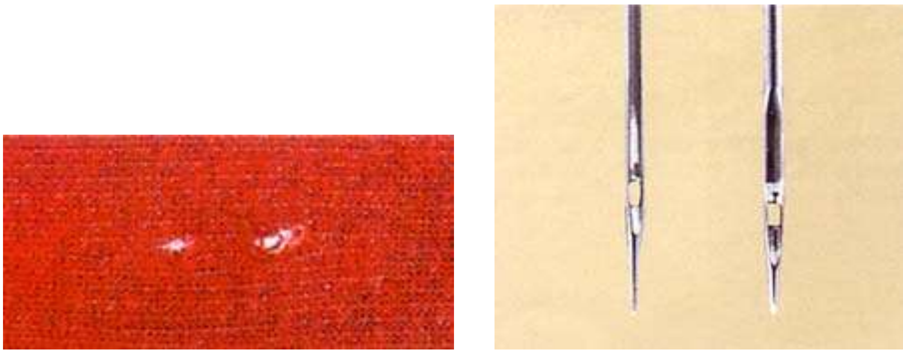


Figure 3.4 Needle damages to knitted fabrics according to the needle sizes

Needle damage is not always visible immediately after sewing, but after the garment has been flexed and stretched in wear, or after machine washing, burst loops would show up as frayed yarn ends or as ladders running back from the seam. Knitted fabric develops ladders, which radiate from the damaged seam and it is the dense, fine-gauge, double jersey structures that are particularly liable to such damage [18, 40].

Yarn severance can be a serious problem with weft knits. Runs may form and travel beyond the point of damage. With woven fabrics there may be broken yarns, weakened seams and poor aesthetic qualities. Excessive yarn severance can mean second quality garments and customer returns.

Causes of yarn severance are damaged needles and incorrect type, point and size relative to the fabric being sewn. Incorrect thread type and size and high sewing speed are also potential causes. Thick seams often require thicker needles and coarser feeds, which can damage yarns. High speeds do not allow time for yarns to move away from the penetrating needle point which may result in ruptured yarns. Lubricants may add during fabric finishing that will facilitate yarn movement during the sewing process [8]. Figure 3.5 shows the examples of damage to the structure of the fabric [23].

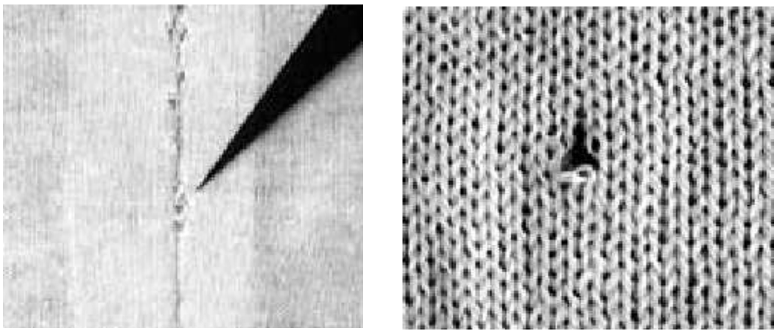


Figure 3.5 Examples of damage to the structure of the fabric

It is well known that if an excessive needle thickness is used, the fabric structure can be deformed beyond its elastic limit and as a result can be subject to an irrecoverable strain. This can result in significant damage to the structure of the fabric. Ball-point needles will prevent damages as well. When sewing knitted fabrics, it is beneficial to use needles with a small ball point shape (SES) for fine fabrics, or a medium ball point shape (SUK) for heavier fabrics. These points will not penetrate into the individual threads or capillaries of the fabric, but instead will simply displace them slightly. For special fabric grades, the use of needles with other tip shapes may also be found to give good sewing results. Even the slightest damage to the tip of the needle will automatically cause damage to the structure of the fabric each time the needle penetrates it. The needle should therefore be checked constantly and changed whenever necessary. Practical experience shows that frequent changing of the needle at regular intervals greatly reduces damage to the structure of the fabric. Figure 3.6 shows the damaged needle point [23].

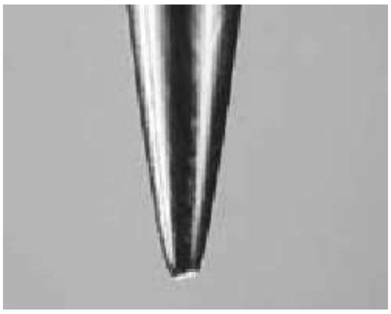


Figure 3.6 Damaged needle point

The size of the needle holes in the needle plate should always be matched to the needle thickness, because if the needle holes are too large the fabric will be pulled through them in the shape of a funnel. This is another way in which damage can be caused to the structure of the fabric. If the above recommendations are followed and the fabric is still damaged, the cause may be an excessively high rotational speed of the machine. Reducing the speed of the machine will always give better sewing results [23].

The problem of material damages as a consequence of unsuitable sewing needle is above all present during sewing of knitwear. Because of specific positions of yarns, built in fabric and knitwear, mainly mechanical and thermal damages occur during the sewing process. The fabric is composed of two rectangular thread systems. When the needle penetrates the fabric, the yarns are being pushed away. Even if the yarn is damaged, the consequences are not heavy since other yarns support it. Damaged spots extend only a little. In knitwear, the yarns are connected with loops. The needle point pushes away the loops during needle penetration. The wrapping angle is here considerably greater than in the previous case. While the penetration force during sewing the fabric is being distributed on four yarns, it is concentrated only on one yarn in the case of sewing the knitwear. Damage of material appears when the needle penetrates into the layer(s) and hits the thread. The thread can be damaged or even broken if the needle is too thick. Damages can be seen in materials produced from natural or man-made fibres as holes that spread across the elastic thread system. They can have different forms and can be clearly visible under the microscope. Bursting of fibres mostly appears in materials made from cotton while thermal damages are characteristic of synthetic fibres. Friction between the sewing needle and textile material that acts at high sewing speeds causes heating of the needle. The needle temperature can exceed the fibre's melting point, which results in material damage. Needle size has a decisive role on the appearance of material damage. An oversized needle can cause bursting of threads or tension around the stitch area, which results in too large holes. For that reason as fine a needle as possible should be used. However, one must pay regard also to considerable vibrations of finer needles at high sewing speeds, which can result in frequent needle fractures. Type and fineness of a sewing thread also influences the size of a sewing needle [14].

3.3.6.2 Needle Heating

Heat is generated during the sewing process as a result of friction between the needle and the fibres in the threads forming the fabric. The extend of heat generation depends on the machine speed, the size, shape and surface finish of the needle, the density, thickness and finish of the fabric, and the type, size, and finish of the sewing thread [11].

Needle heat is the result of friction. It occurs when sewing heavy fabrics at high speed or when stitching several fabric layers with close stitches [8, 18]. Dense fabrics create more resistance and more friction. If temperature exceeds the melting point of thread, the thread is likely to melt when sewing stops. Needle heat causes thread breakage and fabric damage and it may fuse synthetic fabric and thread. Breakage usually appears at the start-up of the stitching. Examination of the thread under a microscope will help determine if melting was the cause of breakage [8, 11].

Needle heating causes sewing thread breaks, cross-threads, skipped stitches, seam damage and physical damage of the needle [27].

The type of needle finish and the needle shape are factors that affect the friction. Needles for sewing cloth are often finished with a nickel or chrome plating or Teflon. The chrome finish helps dissipate heat as well as resist melted particles that may collect needle heat may be reduced by using a smaller needle size, a ball eye, additional fabric and thread lubricants, a different thread type and size, or needle coolers, tube like devices that blow air on the needle to reduce the temperature created by friction [8].

Needle heating generally results from friction when sewing at very high speed; the most severe problems are caused when sewing with synthetic fabrics or threads [15]. The high thermal loading coupled with mechanical loading may lead to yarn breakage [11].

The most serious problem in the process of sewing synthetic materials lies in the low heat resistance of the synthetic fibres. Their softening point is between 180° C and 230° C, and the melting point is between 230° C and 260° C. In high-speed sewing, the temperature of the needle reaches the melting point of the synthetic fibre soon, and then it begins to melt and adheres to the groove or eye of the needle. As a consequence, stitch skipping and thread breakage occur and naturally the sewing operation will stop [15].

4. TESTING FOR TAILORABILITY AND SEWABILITY

The question of testing materials prior to production for what is termed "tailorability", which is the ability and ease with which components can qualitatively and quantitatively be sewed together to form a garment but here, largely pucker, and for sewability, i.e. mechanical damage and needle heating damage [41]. Testing for such properties should be as automatic as testing for other aspects of materials' performance which will affect a garment during making up, wearing and cleaning but it is not often so. There are two instruments which have been available for some years for investigating sewability and two more recent instruments which have been developed to investigate tailorability [9].

4.1 Tailorability Testing

The Kawabata Evaluation Sytem for Fabrics (KES-F) was originally designed to measure a range of mechanical and physical properties of fabrics, which were related to the handle of a fabric. The system consists of four instruments, which between them measure the tensile, shear, compression, bending and surface properties of fabrics. From these mechanical properties (also including weight and thickness values of fabrics), the various primary hand values (HV) of a fabric are calculated using translation equations. The primary hand values are then translated into fabric quality in terms of the total hand value (THV) by another specially developed translation equation. The THVs are described in terms of 5: excellent, 4: good, 3: average, 2: fair, and 1: poor. Primary hand values are rated as 10: strong, 5: medium and 1: weak. These properties can also be used to predict how easily the fabric will make up into a garment, i.e. the 'tailorability' of the fabric. Fabric mechanical problems can also be plotted and connected by a line on a HESC (Hand Evaluation and Standardisation Committee) data chart, a so-called "snake chart" which indicate the allowable limits for each of the mechanical properties before problems arise in cutting, sewing, etc. [5, 9, 22, 42, 43, 44].

The FAST equipment (Fabric Assurance by Simple Testing) was developed by CSIRO in Australia specifically to measure the mechanical properties of woollen and worsted fabrics, which were relevant to tailorability [9]. The system consists of four instruments: FAST-1 compression meter determines fabric thickness at various loads, fabric surface thickness and released surface thickness (the variability and durability of the thickness of the fabric surface layer). FAST-2 bending meter measures fabric bending length which is related to the ability of a material to drape and the fabric bending rigidty related to the quality of stiffness when a fabric is handled. The bending rigidty is particularly crucial in the tailoring of lightweight fabrics as a very flexible fabric (low bending rigidty) may cause seam puckering. FAST-3 extension meter measures extensibility at various loads. During garment making-up, in particular fabric shaping and sewing, the fabric needs to be stretched to certain degree to conform to the intended shape. This ability of a fabric to stretch at low load, or fabric extensibility, is of major concern to tailors. This instrument also determines bias extensibility, shear rigidty (the ability of two dimensional piece of fabric to form a three dimensional garment). FAST-4 dimensional stability tester measures relaxation shrinkage, caused by the recovery of fibres strained during manufacturing, and hygral expansion, caused by the swelling or deswelling of hygroscopic fibres. High level of relaxation shrinkage and large hygral expansion can cause seam pucker [21, 43]. In addition to the aforementioned properties measured by FAST, there is a new property namely Pressing Performance. This measurement helps to predict the seam pressing performance of a fabric prior to cutting [21].

The results are plotted on a chart similar to that used for the KES-F instruments, with upper and lower limits marked for each property. Fabrics whose properties lie within these limits should make up into garments without any problems [9, 43].

Unlike the KES-F System, FAST only measures the resistance of fabric from deformation. However, FAST System is much cheaper, simpler and more robust and perhaps more suited to an industrial environment [44].

4.2 Sewability Testing:

Modern sewing machines can now run at speeds of up to 10000stitches/min, and operating speeds of 600-800 stitches/min are not unusual. Such machinery can accelerate to full speed from rest in fewer than half a dozen stitches and the most modern machines can do so in less than one stitch. With these machines being run at very high speed and in stop-start manner as garments are fed in, problems are common. Damage to the material being sewn or to the threads used is impossible to avoid and is tolerated so long as it does not cause breakdown of the seam [11].

The purpose of quality control is to improve the quality of the seam for better sewability.[7] Sewability testers and test devices have been developed to quantify sewability, and in some cases standards [11].

The Hatra Sew was developed to measure the needle temperatures produced when sewing the fabric, employing the temperature as s measure of the fabric frictional condition. It is used in conjunction with a sewing machine and it measures the temperature reached in the sewing machine needle when sewing a particular fabric, making use of an infrared detection device [9, 11, 45]. An F-index is generated that characterizes the frictional condition of fabric samples sewn under standard conditions. Surface finish has a close correlation with needle temperature [45]. Since the frictional condition of the fabric influences both the level of mechanical damage and the needle temperatures attained, measurements of either one of these parameters serves to monitor both [38].

The L&M Sewability Tester operates independently of a sewing machine. It measures the needle penetration forces in order to determine the frictional condition [46]. Because fabrics, by virtue of their construction, the material of which their fibres or threads are made, or their finish, have different degrees of resistance to penetration by a sewing needle this device tests fabric sewing properties comprising a fabric support and a needle head relatively movable to effort or attempt needle penetration at a plurality of spaced apart points on the fabric and measures the force required to push a needle through a fabric [9, 47]. It enables consecutive readings of force penetration of the fabric by a selected needle to be measured on a small sample of fabric at a rate of 100 penetrations/min. Using a threshold figure high counts are recorded when the threshold is exceeded. Good sewability is indicated by the absence of 'high' counts [48].

There is a fairly good correlation between the L & M and the Hatra sew values. Both tests are based on data from needle-to-yarn and interyarn factional forces [49].

Both these methods are indirect, and their relationship to actual sewing damage must be determined empirically [46]. All of these tests are off-line methods of acquiring information about fabric. The Hatra tester is used while sewing, but the device is meant as a rapid screening test. The L&M tester simulates the fabric/machine interaction, but it is used at only 100 stitches per minute, far from industrial speeds of 4500 stitches or more per minute. None of these devices was intended to allow the sewing machine to adapt [45].

5. SEWABILITY

Today, apparel manufacturing industry faces with the production of smaller lots in a faster time but at the same time increasing the percentage of first-quality product. This is a challenge to automation since frequent changes of fabrics as well as styles cause extensive set-up times for the equipment. Any system that allows for consistent machine settings for a given fabric from lot to lot and workstation to workstation will enhance the apparel assembly process [50].

The apparel industry is trying to respond to foreign competition' s pressure by changing its production philosophy to accommodate the consumer demand for ever increasing style variation and retailer demands for more frequent Just-In-Time (JIT) deliveries of smaller orders. The apparel industry must be able to respond to these demands to remain competitive. Apparel manufacturing in a Quick Response (QR) environment must have the ability to quickly optimise its processes when faced with rapidly changing fabrics with variable material properties. This variability is inherent (statistical) within a given fabric and between different types of fabric [51].

At the centre of the sewing operation is the sewing machine, and in general, an experienced operator is required to set up the sewing machine to properly sew each fabric type. As the manufacturing industry moves toward smaller lots with greater product variability, the sewing operation becomes increasingly inefficient due to frequent trial and error alterations of sewing machine parameters to match fabric properties. As a result, the quantity and quality of goods produced is directly related to the skill of the operator. Automation is seen as a means of deskilling the sewing operation, and providing a means of achieving new methods of manufacturing such as JIT and QR. To fully automate apparel assembly, the sewing machine must be able to sense and compensate changing sewing conditions. If the fabric type or number of plies being sewn changes, the sewing machine should detect this change and alter sewing parameters to optimise seam quality, i.e., the sewing machine should adapt [45].

Clothing manufacturing operations are basically involved with the conversion of initially flat textile materials into a three-dimensional. Garment, through a number of operations, the majority of which are sewing operations in which fabric sewability is a factor of the utmost importance [12].
The last two decades of research on sewability have led to a greater understanding of the complex interactions involved in joining two or more plies of material with thread. Although it is almost 150 years since the invention of the sewing machine, a significant analysis of this joining system did not emerge until sewing speeds increased beyond 3000 stitches per minute. The number of problems related to sewability increased with the higher sewing speeds used to join the newer textile materials. Changes to finer gauge knits and fabrics finished with different dyes and finishes, together with the widespread acceptance of synthetic fibers in both fabrics and sewing threads, created new sewability problems.

Previous researchers have investigated these problems with a wide range of instruments and recommended a number of approaches to minimize the problems. As the apparel industry becomes more and more automated, however, the sewing machine will be subjected to new requirements, since the operator will no longer have direct control of the fabric and machine. In future manufacturing environments, the sewing machine will have to be more flexible to perform equally efficiently across a wider range of fabrics [1].

Analysis of sewing techniques indicated that higher quality apparel assembly required research into the fundamental aspects of sewing control. From this analysis, the two courses of research to be followed were; the determination of methods for characterizing the dynamics of high speed sewing machine and fabric interactions, and the determination of methods of adaptively controlling the sewing system based on the on-line evaluation of the fabric/machine interactions [51].

5.1 Sewability Definitions

Knowledge of the behaviour of fabrics in the manufacturing process is most important in garment design and production preparation, as this allows for a predetermination of the parameters of the process. These parameters are commonly called 'sewability factors' [12].

Sewability has become a generic term in textile science and technology, meaning the ability of the material to be joined effectively and to conform within a given specification of quality and performance acceptable for its end use [52].

Sewability was defined in 1989 by Curiskis as 'the efficiency of joining two or more layers of fabric material with thread via machine sewing'. Uchiyama defined sewability as the 'ease with which a given fabric can be transformed into the final three-dimensional garment'. Adding to this definition words such as 'without causing sewing problems' or 'damage to the product' can explain this term more explicitly. It is also useful to point out that fabric sewability has qualitative as well as quantitative aspects, which should not be excluded in the evaluation of sewability [12]. Behera et. al. defined sewability as the ability and ease with which fabric components can be qualitatively and quantitatively seamed together, to convert a garment. The characteristics of a high-quality seam are strength, elasticity, durability, stability and appearance. These qualities can be measured by seam parameters such as seam efficiency, pucker, slippage, damage and appearance [53].
Good sewability implies better ease of formation of shell structures from two-dimensional fabrics, resulting in distortion-free, unpuckered garments. Improved sewability requires optimum integration of such variables as stitch length, thread tension, thread and fabric characteristics, and sewing machine set up [11].

For good sewability, it is necessary to minimize the forces recorded in penetration and withdrawal of the needle and for manufacturers to optimise needle penetration by combining proper fabric finish and construction and sewing parameters [1].
Investigations into many new problems in sewing, arising from the use of new synthetic fabrics, evolved from the application of basic engineering principles, e.g. measurements of the needle penetration forces and measurement of the heat generated by the needle and its effect on fabric damage in the process of sewing. This type of work led to many innovations in sewing, such as new shapes and coatings of needles, lubrication of threads, the finishing of fabrics and recommendations on the revised setting of sewing machine parameters [12].

In order to solve the problem about sewability, signals must be generated which are indicative of faults in quality. If this can be done successfully, there is a chance that the sewing process can be automated. The quality of the seam is mainly influenced by the amount of thread consumed, the needle penetration force and the fabric feed [54].

5.2 Sewability Measurement Methods

Early work on sewability was related principally to the following areas: the search for a simple method/formula of assessing sewability through, for example, needle heat or seam efficiency, based on a knowledge of a limited number of parameters, mainly for qualitative assessment, evaluation of separate components of the sewing process, for example, needle penetration force or sewing thread tension, for quantitative purposes. These measurements were based on the application of commonly available instruments used in the engineering field, which were usually able to collect only a small amount of data and needed time consuming calculations.

Early contributions towards an understanding of sewing technology came from a paper published by Davies in 1933, which contains results of an investigation into stitches and seams in the course direction in plain, knitted fabrics. Six types of seam were measured with respect to strength, extensibility and thread usage, and the results provided a basis for analysis and subsequent improvement of quality and for a costing of thread usage. This constituted one of the first published examples of sewability, treated as a 'problem in sewing'.

In the paper published in 1939 by the Shirley Institute (one of a series of reports on quality of fabrics, garments and sewing, started in 1936), the causes of seam failure in woven fabrics produced by transverse loading, were for the first time, defined and categorised into breakage of the sewing thread, breakage of the fabric, and slippage of the cloth yarns lying close to and parallel with the seam. The work of the Shirley Institute was the first example of such systematic research in the world and it continued during and after World War II.

The first work, which although rudimentary, was done in 1951 by Scott who analysed the needle penetration traces generated by a force transducer placed in a machine for sewing sacks additionally the thermal damage caused by the needle was observed but not quantified. The first instrumented machine mentioned in the literature was a bagging machine, which had a force transducer mounted on the needle bar. Needle penetration traces were obtained and the damage to the fabric was evaluated. However, no further details about it could be found in any available library collection.

The second work carried out at Quarter Master General in Philadelphia, was related to the method of quantifying seam efficiency.

Further research on the sewing conditions resulted in an expansion of the range of investigations of the causes of damage by a needle to the fabric, e.g., due to heat generation [12]. In 1952, Frederick studied the effects of needle damage on seam strength in cotton fabrics. He defined the sewability of a fabric as the degree of its resistance to needle damage [12, 37]. His report implied that all seams failed through fabric breakage caused by needle cuts to the yarn. His work demonstrated the need for a better method of calculating seam effectiveness. In the old method the number of damaged yarns had been counted and their value was taken as characterising sewing efficiency. Frederick's work resulted in an improved seam efficiency formula, the ratio of seam tensile strength to fabric tensile strength, expressed as a percentage. This allowed more accurate comparisons of seam efficiency at the stage of garment design. Nevertheless, this was still inadequate as the sole measure of fabric sewability, since other investigations had discovered many more factors of importance, such as sewing environment and human factors, which influenced sewing operations [12].

Four factors, which affects mostly on the sewability are as follows: the effect of thermal damage on sewability, the effect of needle penetration forces on sewability, the effect of sewing thread on sewability, the effect of fabric feeding on sewability. Researches are divided into four parts according to this classification.

5.2.1 The Effect of Needle Penetration Forces on Sewability

In 1972, Nowak did very informative work and carried out one of the most important single pieces of research thus far, when he analysed the characteristics of the needle penetration process in quasistatic and dynamic form in real, not simulated, conditions, in contrast to previous researchers. His results showed that needle penetration forces are of the same character under quasistatic and dynamic conditions, but the magnitudes are four times higher in dynamic conditions. From these experiments, it was obvious that quasistatic conditions were not suitable for the evaluation of needle penetration forces, and could only be used for qualitative assessment [12].

In 1978, Leeming and Munden studied the factors affecting needle penetration forces in knitted fabrics and designed the 'L&M Sewability Tester', which has also been used for woven fabrics [47].

In 1979, Nestler and Arnold contributed to knowledge on sewability by investigating the relationship of needle penetration forces and thermal damage in a lock-stitch sewing machine [12].

The structure of fabric and its resistance to needle piercing was widely discussed by, Dorkin and Chamberlain, Galuszynski and Gersak and Knez [12, 36]. Galuszynski examined the effects of fabric structure on the fabric resistance to needle piercing. He used a lockstitch sewing machine. Wool- woven fabrics were sewn with and without thread and with three different needle numbers at a speed of 1740 rpm. The results obtained showed a good correlation between the needle penetration force and fabric tightness and mass [55].
In 1995, Stylios and Xu investigated the influence on the needle penetration force caused by the shape of the cross section and the profile curve at the needle point. They analysed the forces acting between the constituent fabric yarns and the needle surface by means of the mechanical principles of elasticity. They found that the factors influencing the penetration force of the sewing machine needle mainly include the mechanical properties of the textile materials, the variation ratio of needle radius, the contacting arc length, the frictional coefficient of the needle surface and the machine speed. High penetration force is one of the key reasons causing the sewing damage. But the magnitude of the maximum penetration force can be changed if the needle point profile is changed [56].

In 1996, Lomov computed the maximum needle penetration forces with a mathematical model. He also did an experiment to compare the measured data with the predicted ones. He used five 100% cotton woven fabrics, having different structures, and one type of chromium-coated needle. He measured the maximum penetration force on Instron equipment. This measurement gave static penetration forces of the needle. Results showed that, there is a direct dependence of penetration force on fabric structural parameters [57].

The needle penetration force can be calculated in different ways: as a function of a normal force and friction coefficient, where the normal force is expressed with the resistance force of a yarn or as a function of normal force and needle profile and speed. The movement of a sewing needle depends on a characteristic movement of a whole mechanism, which moves needle bar or needle. Values of needle velocity in the penetration area could be obtained with the help of simulation of needle bar mechanism movement. In 1998, Lojen simulated the needle bar mechanism using the program package ADAMS. The results showed that, the construction of a needle bar mechanism has an important influence on velocity and acceleration values. Higher main shaft velocity results in higher velocity of a sewing needle in the penetration area. In addition, the penetration force is higher in that case. Achieved information on velocities could be used for calculation of the penetration force of a needle [58].

Fabrics by virtue of their construction, the material of which their fibres or threads are made, or their finish, have different degrees of resistance to penetration by a sewing needle [47].

Needle penetration force results from the resistance of the fabric in terms of friction force on its lateral surface during the alternating movement of the sewing cycle. Other factors such as needle thread tension and the inertia forces caused by needle bar accelerations contribute to the variation of this force [59, 60].

Generally, there are four major sources of fabric resistance to the penetrating needle:

(1) Membrane stress resulting from the fabric bending in the direction of the needle motion;

(2) Friction between the needle and the fabric

(3) Threads resistance to a displacement in the vicinity of the needle, resulting from threads resistance to bending and friction between warp and weft threads;

(4) Threads tension owing to their elongation after the displacement [57].

Figure 5.1 shows the forces, acting on the penetrating needle.

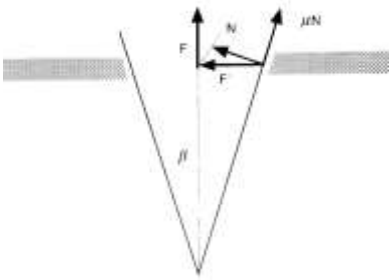


Figure 5.1 Forces acting on the needle

Figure 5.2 shows a typical simulation result from the Finite Element Analysis (FEM) of sewing needle penetration displaying the needle cutting actions. From the figure it is seen that when the needle reaches the fabric, the fabric first bends and then yields, forming a hole [61].

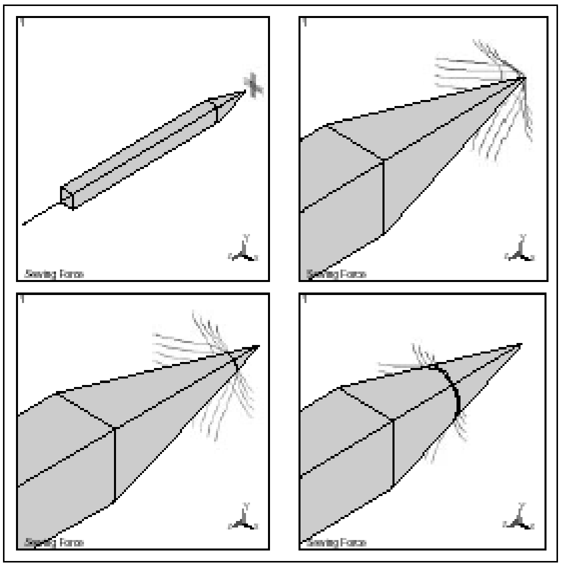


Figure 5.2 The simulation of sewing needle penetration using FEM

The penetration force represents the vectorial sum of all the reaction forces, which occur when the needle penetrates the fabric as a result of time-dependent impact, displacement, and frictional forces. The impact force is determined mainly by the shape of the needle point, the flexibility/and support of the fabric, as well as the shape of the stitch hole and impact speed. The displacement force or resistance of the fabric depends largely on the fabric's structure and rheological characteristics as well as on the needle/speed. The rheological characteristics of the fabric include the fibre surface/characteristics and the crosswise forces which occur in the fibre assembly, i.e. the fibre/fibre friction; the compactness of the knitting yarns; the displacement and compression effect of the cone angle; the cross-section of the needle point; the size and shape of the stitch hole and the number of layers of fabric. The frictional forces between the needle and the fabric on the other hand are a function of the compression forces in the fabric and of the lubricant present on the fibre material, i.e. the fibre/metal coefficient of friction. The displacement and compression forces depend, in turn, on the construction and density of the fabric [62].

In 1999 Ujevic described the main characteristics of cotton knitted fabric finishing and softening. The application of a new device for testing loop damages is discussed, together with the measuring system for testing the sewing needle penetration force. The reduction of the incidence of loop damage, in relation to the sewing needle penetration force is investigated on the single jersey cotton knitted fabric [63].

5.2.2 The Effect of Sewing Thread on Sewability

Although the characteristics of current sewing threads are adequate, their technical properties still require improvement to match more demanding process requirement more closely. The physical and mechanical properties by which the quality of thread should be judged include breaking strength, elongation at break, variation of physical and mechanical properties, and twist thread liveliness). During sewing, a thread is subjected to a multitude of frequent changes of tensile forces, which are destructive and reduce thread strength in lockstitch machines by 30% and more. This reduction in seam strength requires stronger threads, which are consequently more expensive. A weakened thread is also prone to break, which consequently leads to stoppages of the sewing machine.

Past research into sewing threads has been concentrated in two main directions: defining the proper parameters correlated with thread breakage and quantification of forces to which thread is subjected, their causes and their distribution during stitch formation [12]. A good sewing thread should give an acceptable seam appearance, i.e. proper stitch geometry and tight, uniform and unpuckered seam [64].

In 1952 Kolesnikow, Pankowa and Alexeev published their research on sewing thread tension variations during the sewing process, which they linked to the number of resistance points from thread guides which cause an increase in thread tension. The results of their work, although in a rudimentary form, were among the first published, and stimulated intensive research in academia and also by the thread and needle manufacturing sectors over the following decades.
The experiments which focused on measuring thread tension and defining its magnitude during the sewing process are performed by following researchers: Tomanec and Sramek, working on the lock-stitch machine discovered that a relationship exists between the stress in the thread and the load on the plate tensioner of the sewing machine. Nowak and Wezlak measured the distribution of dynamic stresses of the sewing threads on two lock-stitch sewing machines and found that maximum values were at speeds of 500-1000 rpm and 800-1800 rpm. Also the tension decreased with the increase of the sewing speed, which was later confirmed by Deery. They concluded however, that the maximum value of the dynamic tension was lower than the strength of the threads used. In some circumstances particularly in the unfavourable speed range with maximum thread tensions, a high static tension and the existence of weak places in the thread itself could cause thread breakages. This investigation was limited to two sewing machines, and there is a need for further investigation using newer types of

machines [12].

The studies of dynamic tension in sewing threads have generally been intended for improving seam quality. Controlling the tightening tension of sewing thread during high-speed sewing could be useful for improved sewability [11].

In 1991 Gersak and Knez measured thread strength reduction and dynamic strain using PC-based instrumentation and found that these were functions of the following factors: the number of passages thread makes over thread guides, thread factional properties, thread fineness, and the pressure force that the disc tensioner exerts upon the sewing thread. They also analysed the loading of the thread and confirmed the strength reduction range measured by the previous researchers [12].

5.2.3 The Effect of Thermal Damage on Sewability

Early research on sewability was characterised by investigations of damage to fabric caused by the needle. After Scott, there were several attempts to assess thermal damage. Soldhelm discovered that wax content in a cotton fabric reduced the needle temperature, as did other lubricants. Frederick and Zabieboylo mounted silver soldered constantan wire in the back groove of the needle at different positions. By using a special pyrometer the needle temperature was measured during sewing and the conclusion was reached that the interior of the needle was hottest and that the heat generated was a function of fibre frictional properties and cloth tightness [12].

Dorkin and Chamberlain studied the effects of increases in machine speed in relation to a set of various factors (the needle, the fabric and thread characteristics, the number of plies). They also measured needle heating using thermocouples, by the insertion of a small diameter ferrous wire inside the needle eye and by soldering this into the needle groove at different points up to the needle shoulder [36].

Khan et.al, studied the behaviour of needle penetration forces in simulated conditions, using an Instron tensile testing instrument, with the aim of identifying needle-fabric interactions leading to heat generation. The penetration and withdrawal forces and energy expended were measured as functions of needle velocity. The needle velocities were; however, 3-4 times lower than in actual sewing conditions. The results obtained for three major variables (the number of layers, the needle diameter and needle finish) confirmed that they affect the magnitude of needle penetration forces and that the relation of the needle piercing force to needle diameter is linear. This was confirmed also with respect to the number of the fabric layers. However, in their study, the forces were measured under linear velocities instead of sinusoidal in the real sewing process. Also, the magnitude of the velocity is significantly lower than the actual sewing velocities. Howard confirmed the effect of increasing needle diameter in generating more heat. However, because the heat detector could not respond to rapid changes in needle temperature, the profile of needle temperature distribution was inaccurate.

As a result of intensive investigations into problems of needle/thread/fabric interactions, many technical improvements were developed including a special needle design, needle coatings, fabric and thread finishes, fabric lubricants and needle coding methods. For example, Schmetz developed a special needle called 'the blued, bulged eye needle'. The eye of this needle was enlarged, which reduced the contact time with the fabric during the passage of the needle through the fabric layers. All the above mentioned research results contributed greatly to the body of knowledge on sewability of knitted and woven fabric [12].

5.3 Integrated Computer-Based Sewability Measuring Systems (On-Line Measurement)

The early work contributed to the body of knowledge on sewability and showed the complexity of the problems facing the industry, particularly in the process of the development of sewability prediction methodology. This however required more advanced techniques and instrumentation, such as fabric objective measurement technology and instrumentation of the sewing machine with very sensitive sensors integrated in PC-based equipment [12].

Continuous monitoring of the seaming process on the sewing machine as an important prerequisite for the automation of sewing stations is carried out all too infrequently. It is absolutely vital that the, faults be detected while the seam is actually being sewn, so that sewing machines do not produce rejects, even without being supervised by an operative, thereby reducing the costs involved in rectifying faults later on [54].

Advanced sewing machines should be able to set up automatically, detect sewing faults, and self-adjust to required settings. In order to achieve this objective, a sewing machine has been instrumented with sensors, so that wave forms of needle penetration and withdrawal forces, presser-foot compression force, and sewing thread tensions can be captured and analysed.

Statistic process control is fundamental to achieving a state of excellence in quality and "zero defects." On-line process control can adequately manage quality in a modern advanced manufacturing system by finding and eliminating the causes of defects. In the past few years, even though considerable progress has been made in areas such as real-time sewing room production management, the on-line control of sewing parameters has not yet been fully included in the overall package [59, 60]. Computers have made quick and accurate measuring possible, as well as storing quite number of measured data into the computer memory banks, together with the subsequent mathematical processing and analysis of the data obtained. Figure 5.3 shows the principles of measuring [65].

Today, it has become possible to observe and record dynamic changes with a precision in time as fine as 10^{-9} seconds. Such measurements can provide invaluable insights into high-speed sewing (speeds above 3000 rpm for a lock-stitch machine) and should help in apparel processing.

In the light of recent developments in instrumentation, which enable rapid measurements to be made, the dynamic components of the sewing process participating in stitch formation can now be measured with higher accuracy. The importance of these measurements of the sewing process is that quantification is related to real-time, not to simulated conditions. The present measurements are 'nearly real". The resolution reaches 10^{-9} sec., and compulsory pauses in blocks of data acquisition are small, so that it is acceptable to call the acquisition of data 'continuous', as if it was acquired in real time. With the capability of modern instrumentation, many more factors, besides that of the needle penetration force, can be measured simultaneously, leading to a more accurate and precise sewing process analysis. With increased sampling capabilities many unforeseen factors that arise can be quantified and provide fresh input for (fabric, thread, machine) designers [12].

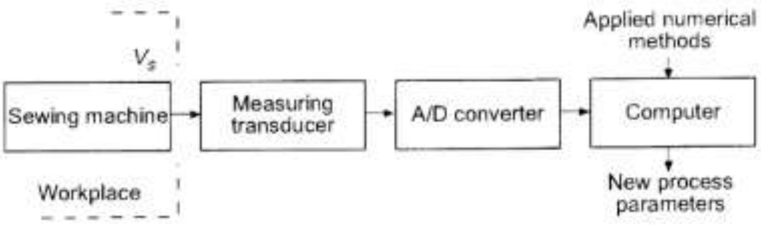


Figure 5.3 Principles of measuring

In 1976, Hurt and Tyler measured the needle penetration force by using a strain gauge in the throat plate of a lockstitch machine. At speeds of up to 2000 rpm, it was found that the damage occurred at the needle eye, and it was claimed that the penetration forces was greater at lower speeds, perhaps owing to increased fabric deformation. It was also pointed out that penetration forces are vector forces and differ with the fabric construction [66].

In the 1980s, dynamic needle force and thread tensions profiles were captured in real time by using computer/ sensor technology.

The first important computer-based measurements were carried out by the Denkendorf Institute of Technology and reported in 1985. The throat plate of a lock-stitch machine was strain-gauged around the needle hole with the cut off part of the presser-foot preventing interference with the aluminium gauge. The analogue input signals were amplified and converted to digital form and analysed by an Apple IIe microcomputer. The sampling rate was 30 KHz. The programme was written in BASIC and displayed 255 data points in 50 cycles, with 5 data points per cycle only, as force magnitude in stick and/or bar forms versus time. Tests were carried out at a speed of 1000 rpm with and without needle thread to investigate different fabric finishes. This system is worth mentioning as the first known attempt to integrate an instrumented sewing machine with a computer. However, the system exhibited some shortcomings; firstly, instability of the strain gauge, located transversely to the axis of the fabric feed direction; secondly, the 1000 rpm speed level was insufficient to expose the full needle piercing forces; and thirdy, there was no capability to measure withdrawal forces [12]. Besides, the sewability testers which has been conducted using a strain gauge attached to the underside of the throat plate generally yield comparative needle penetration forces. A clarity of forces is difficult to obtain because the throat plate is subjected to additional forces from the presser foot. Some workers have tried to minimize presser foot influences by using an alternate feeding mechanism. When this approach is used, the practical value is limited because of the alteration of the sewing system under study. Additionally, previously published studies and sewability testers appear to be limited in terms of adequate resolution of forces at high sewing speeds, losing clarity at 2000 stitches per minute [1].

Since one of the important problems in sewability is fabric damage, another very interesting research project by Stylios is worth outlining. In 1986, he studied dynamic sewing forces on the sewing machine without modifying its action (unlike the one developed in Denkendorf in the Institute for Textile Research). An industrial overlock machine most commonly used for knitted fabrics was selected (Rimoldi-Orion 627) and strain gauged at the throat plate (part of the plate was converted to a cantilever, through cuts in the plate itself) and on the sewing needle (applied successfully for the first time) to investigate the forces acting upon them [67]. The top and underside part of the cantilever contained two piezo-resistive semi-conductor strain gauges. The throat-plate cantilever's natural frequency response was 35 Hz. In the light of current research trends, the frequency response of the transducer was too low, which led to smoothing of the signal and to the risk of some of the higher frequencies of the signal being missed, particularly in an analysis of the interactions of the other kinematic components of the machine. Each sewing cycle was marked electronically using a shaft encoder. The instrumented sewing machine was interfaced with an IBM personal computer. The data acquisition programme was written in Language C. The number of data points was 228 per cycle at 3220 rpm. The author claimed that the system was fully portable and could be used for testing other machines. However, a doubt exists over the reliability of the gauged needle in repetitive measurements for commercial applications. Additionally the needle penetration signal was correlated with a video camera for the purpose of monitoring knitted fabric damage. The correlation of the pictures (the needle interaction with the fabric, at the stitch formation zone) with the needle penetration forces was accomplished and this example showed the possibility of monitoring knitted fabric damage in real-time. It was shown that damage is a frictional problem between yarns and the material of the sewing needle and needle plate. The clamping of yarns in fabric depends upon fabric frictional properties and this explained the importance of fabric lubrication in reducing sewing damage [12, 67].

Kamata et. al.(1987), studied on clarifying the generation mechanism of tightening tension(wave) on a very low-speed sewing by a computer simulation. They used with an industrial single-needle lockstitch sewing machine, Janome DB-J704 [68].

In 1988, Matthews and Little developed a measuring system to capture and analyse forces directly encountered by the needle bar and presser bar from a high speed, single needle lockstitch sewing machine in North Carolina State University. The forces recorded from the needle bar reflect those encountered by needle penetration and withdrawal. The forces recorded from the presser bar are those transferred by the feed dog as it advances the fabric each sewing cycle. A measuring system known as the NCSU sewing dynamometer is capable of detecting changing sewing parameters, including variations in the material being sewn, increasing plies of fabric, frictional forces on the sewing needle, and the dynamics of the feeding system. Force transducers were mounted directly into the shaft of the needle bar and the presser bar, as can be seen from Figure 5.4 [45].

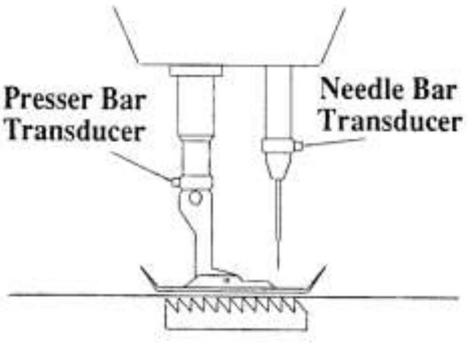


Figure 5.4 Sewing machine transducers

The data were recorded directly to a two-channel recording oscilloscope. To standardize the recording and facilitate the processing of waveforms, data recording was triggered by a signal from the needle positioner. An X-Y plotter was used to plot the digital information in analogue form. They chose three materials to illustrate dynamic forces: paper, rubber and denim fabrics (finished fabrics). Materials were tested in one, two, three and four plies at sewing speeds of 4300 stitches per minute. During their study, researchers subtracted the trace obtained without material under the needle, i.e. inertia force only, from traces obtained by sewing other three materials. The reason for that, according to the authors, was needle bar's traces containing additional tension and compression forces because of acceleration and deceleration of the residual mass of the needle bar and the needle below the transducer. Figure 5.5 shows an enlarged trace of the forces exerted on the needle bar during one sewing cycle.

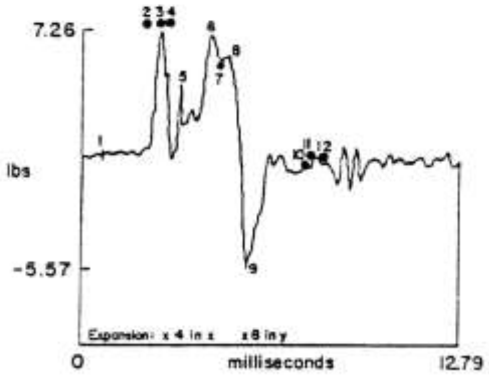


Figure 5.5 Critical points observed during needle penetration and withdrawal. 1-nedle at the top of cycle, 2-point penetration, 3-eye penetration, 4-scarf penetration, 5-frictional forces on the shank, 6- shoulder of the needle penetrates, 7-lowest position in the cycle, 8-marks the change by inertial by the needle bar, 9-frictional forces during withdrawal, 10-scarf withdrawal, 11-eye withdrawal, 12-point withdrawal

They found that, needle penetration and withdrawal forces increase as the number of plies of material sewn increases and this increase depends on the properties of the fabric. Also, they indicated that for all samples, needle penetration forces were greater than withdrawal forces [49].

In 1991, Catchpole and Sarhadi monitored the tension on the two needle threads and the looper thread of an industrial chainstitch sewing machine using strain gauges and the data recorded using an analogue-to-digital converter and 68020 based microprocessor. The data collected analysed to identify the variations relating to missed stitches. The study aimed specifically at developing a means for identifying mis-stitches as they occur. Depending on the cost, the resulting system could be used as a quality control device for existing machines, as a diagnostic system for machine and thread trouble-shooting or as a monitoring system for such future automated systems. The sewing machines used in this study were a pair of Rimoldi B63 chainstitch machines with two needles, producing a double line of stitches with a common looper thread. For these reasons a new gauge set based on piezoelectric ceramic-gauges was being built having a much higher natural frequency. The target for the simple mis-stitch detector was a system, which can be attached permanently to each of the sewing machines, in a medium sized garment factory, and it must therefore be low-cost and simple to mass-produce. According to the authors, to use the results in industry, a real-time system must be developed to handle the processing for a machine running at least 6000 rpm [69].

In 1991, Little et.al. studied on the influence of fabric properties on sewing performance, especially the feeding of plies of textile materials through a sewing machine. Pfaff 463 drop feed lockstitch sewing machine was equipped with high dynamic response transducers on the presser bar and needle bar. A Kistler piezoelectric load washer was inserted in the presser bar just above the presser foot mounting and a proximity sensor was mounted directly above the extended presser bar on top of the sewing head to get the feeding force waveforms and the displacement of the presser bar. The data acquisition system is shown schematically in Figure 5.6. The machine speeds used for trials were 163, 338, 619, 1017, 2600, 3886 and 4600 rpm. Presser bar displacement and force waveforms were analysed both in the time and frequency domains to evaluate how material properties could be used to control or adjust machine settings in an automated apparel environment. Feeding forces were correlated with fabric properties. Presser foot bounce was shown to depend on speed, sewing combination and the properties of the material being stitched. Presser bar displacement and force waveforms were analysed to evaluate how material properties could be used to control or adjust machine settings in an automated environment [50].

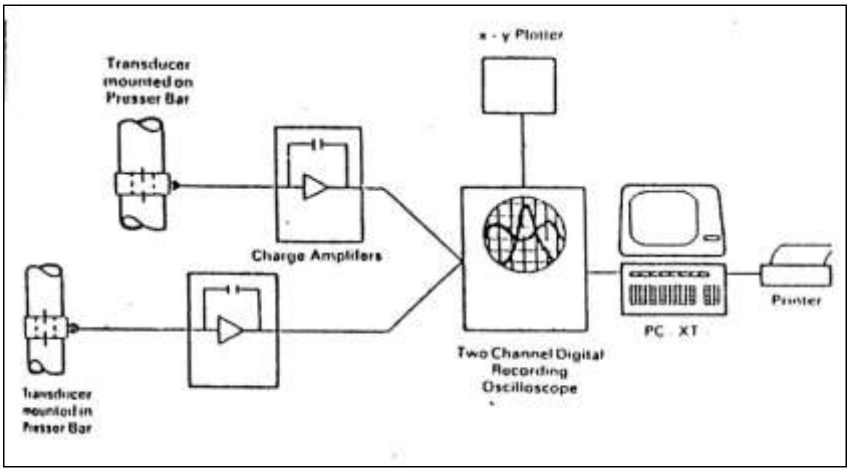


Figure 5.6 Component configuration of the NCSU sewing dynamometer

In 1993 Bühler and Hennrich constructed a test rig, based on a double lockstitch machine, Pfaff class 483, with which the effects of thread tension, needle penetration force and the horizontal and vertical presser foot forces on sewing, could be studied. A new development was the presser foot sensor for converting the momentary pushing and pressing forces into electrical signals. Improvements were also made to the ITV needle plate sensor for measuring the needle penetration force and the thread, tension sensor from Pfaff for measuring the tension of the upper thread, enabling missed stitches to also be detected. The diagram of the needle penetration force recorder is seen in Figure 5.7. They carried out the tests on knitted fabrics. The following aspects were considered with a view to monitoring sewing machines by means of sensors, taking into account industrial requirements and state-of-the-art technology: thread feed, stitch formation, fabric feed.
The aim was to find ways of automatically controlling the machine functions using the measurement signals in order to achieve optimum sewing during fully automatic operations. Another objective was to monitor stitch formation as regards the nature and position of thread looping and laying, so that faults, in the seam could be avoided. The results of the measurements were analysed and displayed using an MS DOS compatible computer. A monitor and a printer were used for data output [54]. Figure 5.8 shows the arrangement of the sewing test equipment.

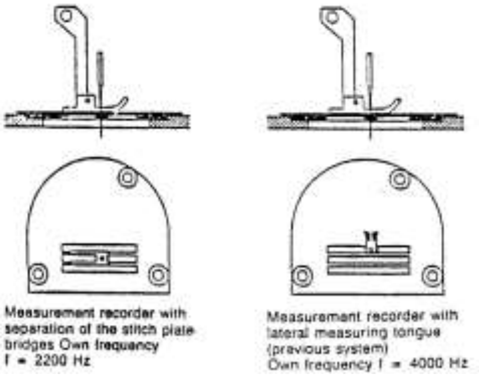


Figure 5.7 Diagram of the needle penetration force recorder

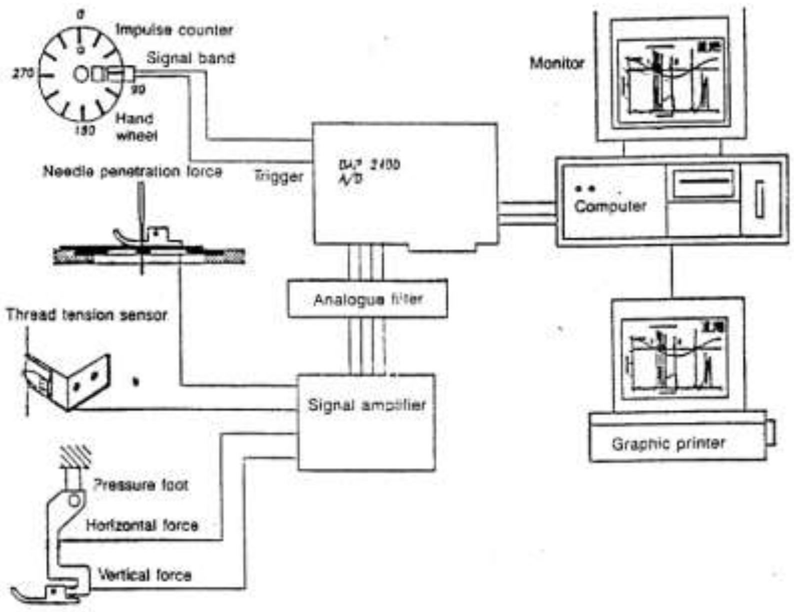


Figure 5.8 Arrangement of the sewing test equipment

In 1993 Ferreira et.al investigated the simultaneous measurement of both the needle thread tension and bobbin thread tension in terms of tension variations in a stitch cycle and how different factors affect their behaviour [70]. And they defined the thread tension settings, based on the measurement of peak tensions, according to changes in sewing parameters, to ensure the production of balanced seams [71]. They showed that the balance of the seam was a function not only of both the needle and bobbin thread tension values, as was traditionally believed, but also of the stage at which the appropriate relationship between both the needle and the bobbin thread tensions occurs [66].

The tension on the needle thread during a stitch cycle was measured on the thread line between the take-up lever and the needle by sensing the deflection of a cantilever beam using bonded foil strain gauges. In order to measure the tension of the bobbin thread, a cantilever beam was made to support the strain gauges and convert the variation in tension into a deflection of the device in the area where the strain gauges were fixed. The cantilever beam using bonded foil strain gauges was fixed in front of the bobbin case where there was a small gap bridged by the bobbin thread. Singer Centurion lockstitch sewing machine (Singer 121D300BA) was used in the experimental program. The data collected in the experiments were processed using the multiple regression technique [70].

In 1994 Clapp et. al studied in a project funded by National Textile Centre (NTC) on investigating new technology which could be used to automatically monitor sewn seams, including skipped-stitches, incorrect tensions, seam allowance variations and the number of plies sewn. Their objective was to attach to a sewing machine a ''black box'' which would automatically adjust the sewing machine settings in real-time to optimise performance. Researchers studied on developing an economically feasible online stitch quality monitoring system. This technique utilized commercially available, low-cost piezoelectric transducers that respond to the vibration caused by the thread motion. The sensor output was collected by a PC-based LINUX data acquisition system and used to study and model the formation of single skipped stitches. Periodic occurrences were identified and attributed to proper stitch formation; whereas, the absence of periodicity in such events can signal the presence of single stitch defects and diagnose their causes. In an effort to model the needle thread motion for a 401 chainstitch sewn at 1800 rpm, they found that the critical portion of each stitch cycle occurs as the needle thread was pulled down through the fabric to be joined with the looper thread, which can be seen in Figure 5.9 This feature was clearly absent in Figure 5.10, which illustrates the occurrence of a single skipped stitch over four stitch cycles. This defect was visually confirmed on the sample [4].

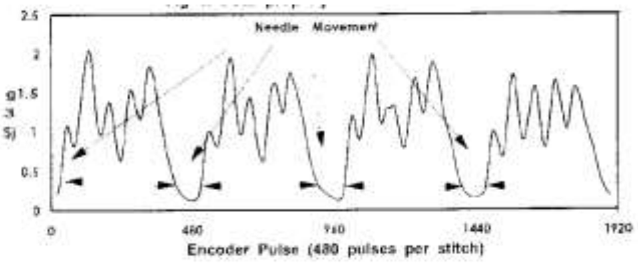


Figure 5.9 Four properly formed chainstitches

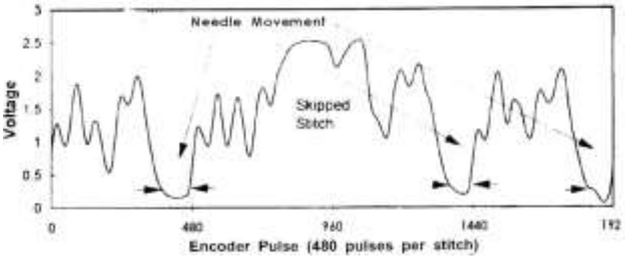


Figure 5.10 A skipped stitch over four stitch

In 1995 Porat et. al. developed an optical system, other than dynamically monitoring the thread tension, to detect mis-stitch(skip stitch) as it occurs on chainstitch machines. A single needle chainstitch sewing machine (401 stitch type) was selected for the study. And they studied with knitted fabrics. In the system decribed, a fiber optic probe used as a flexible light guide to transmit the light to the looper and collect the reflected light from the looper surface. The amount of reflected light indcated the presence or absence of needle thread loop on the looper (in practice the great majority of misstitches were caused by the looper failing to enter the loop of the needle thread trailing from the needle eye as the needle rises). The analogue signal produced by a photodetector and amplification circuitry was read through an interface board containing an 8 bits A/D converter. Data on the machine position was derived from pulses generated by an optical switch connected to a slotted disc located on the sewing machine drive shaft. These pulses provided an accurate window in which the thread presence was checked. The amplitude and shape of the signal of the pattern was different for misstitch and properly formed stitches, as seen from the Figure 5.11. The lens housing was inserted through a hole drilled under the throat plate so that the light beam could be projected perpendicular to the target resulting in maximum reflection. The fed dog was slightly modified to allow clear light path. Experiments were done at 2100 rpm and 6500 rpm and system proved its reliability[30].

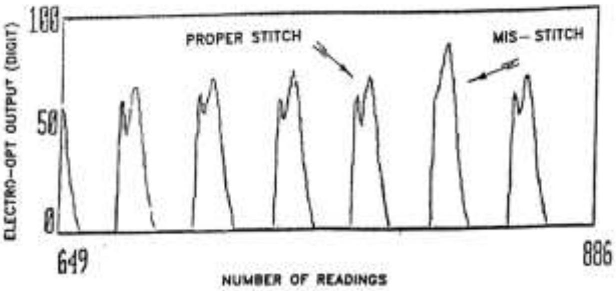


Figure 5.11 Light reflection pattern within a window recorded at 2100 spm

In 1995 Amirbayat et.al. investigated the combined effects of machine variables and compressional parameters of knitted fabrics on seam shrinkage and thread consumption during chain-stitch, type 401, sewing. They also discussed the factors, which affect the dynamic peak, average thread tension and the movement of the pressure bar. For this purpose, a Rimoldi single-needle machine was used. During sewing, the dynamic thread tensions were monitored by a strain-gauged cantilever arm and the vertical displacements of the presser bar were measured by using a Hall-effect position sensor. But they didn't analyse the subject deeply. They just monitored about this subject as an appendix [72].

In 1995, Chmieowiec studied on to simultaneously measure needle thread tension, needle penetration forces, presser foot displacement and presser foot pressure in real time. The system was developed in Hong Kong Polytechnic University and presented as a PhD thesis in Leeds University. In 1995. He instrumented a single needle Pfaff 563 machine with transducers. Sewing speed was up to maximum of 5500 rpm. He gave the name ' RSTM (which stands for Richards Sewability Testing Method) to this tester. He also developed a seam pucker measurement system using digital image processing [12].

In 1996, Dorrity and Olson in Georgia Institute of Technology, studied on thread motion ratio (TMR) to monitor sewing machines. TMR was defined as time of thread motion over total single sewing cycle time. According to their work, time of motion of thread is related to stitch length at constant speed and stitch length generally is a good indicator of stitch quality. To measure thread consumption with time of motion, a piezo-electric transducer was used. They used 301, 406 and 504 stitch types. Experiments were done on denim fabrics [73].

In 1996, Alagha et.al, in UMIST, studied on the effect of sewing variables and fabric parameters on the shrinkage of chainstitch seams sewn by two different thread feeding systems: conventional and positive feed methods. They studied with knitted fabrics through their experiments on a single needle double chainstitch Rimoldi machine (401 stitch type). During the seam construction, the dynamic thread tension was monitored by using a strain-gauged cantilever arm and a bridge circuit. The mean of the highest peak tension was calculated for each sample. The presser foot height from the throat plate was also dynamically measured. Considering the effect of machine speeds on peak needle thread tension and effective fabric thickness under the presser food, they tried to justify the use of the thread feed variation as a means of a fabric shrinkage control [74].

In 1996, Zeto et.al. described a computer-based sewability testing system installed on industrial lockstitch and overlock stitch sewing machines. This tester was the same but the modified version of Chmielowiec's system in Hong Kong Polytechnic University. The system used commercial hardware and developed software to acquire and analyse the collected signals of needle thread tension, presser foot displacement, presser foot pressure, and needle penetration/withdrawal forces. In this work, they investigated sewing process dynamics and sewing penetration forces using a computer-based system installed on industrial lockstitch (Pfaff 563) and overlock stitch (Mauser special L52-54) sewing machines. The effects of sewing speed, needle size, and the number of plies of a fabric sewn together on variations in measured needle penetration and their role in sewing damage were investigated. The sewing performance from the time-frequency response of needle penetration force was measured. The schematic diagram of the experimental unit is shown in Figure 5.12.

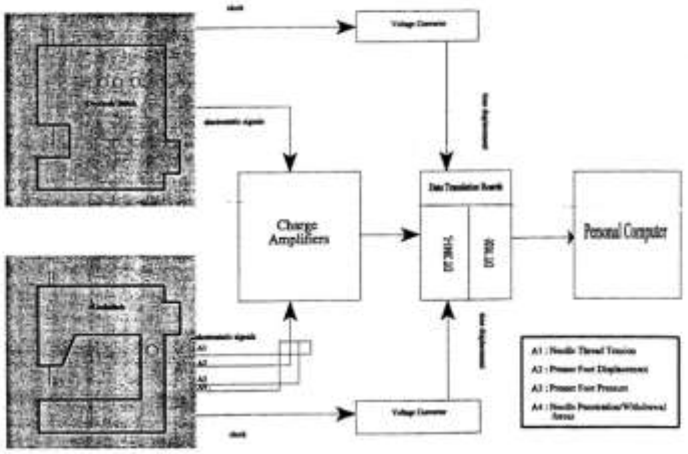


Figure 5.12 A schematic diagram of the experimental sewability unit

The microprocessor-based data acquisition and analysis system captured four analog signals from the transducers (piezo-electric Kistler quartz load washer, type 9001 A) mounted directly onto the shaft of the needle bar of the sewing machine. Analog signals were converted through the data translation board to digital forms at a throughput rate of 750 KHz. Three different needle numbers, three fabrics and 500 to 5000 rpm sewing speed in steps of 500 rpm were the parameters of the experiments. Observations, based on a limited number of experimental variables, indicated that penetration and withdrawal forces were significantly affected by sewing needle size and, to a limited extent, by the number of plies sewn together. They also concluded that both penetration and withdrawal forces rose linearly with machine speeds above 2000 rpm. Furthermore, the magnitude of penetration and withdrawal forces was similar over the entire range of sewing speeds [75].

In 1996 Rocha et al., in University of Minho, aimed to make it possible to understand the dynamics of sewing at the various interfaces (sewing thread/fabric, sewing thread/sewing machine, fabric/sewing machine) and to develop a computer program and adequate hardware to control the sewing operation through an "on-line adaptive control system". In addition, the equipment could also be used to develop sewing specifications, for quick set up, and to test sewability. They instrumented a Singer overlock sewing machine model 882 U by putting miniature piezoelectric transducers (working in compression) on the presser-foot and needle bars, and electric foil strain gauges (working in bending) on the needles and looper thread paths. Figure 5.13 shows the needle bar transducer arrangement. Adjustment of thread tensions and presser foot pressure was done with miniature stepping motors. To treat the signals captured by the transducers before they are sent to the computer for processing, they developed a signal conditioning system. A data Lab PC+ data acquisition board. Their sample frequency was 83.3 KHz.

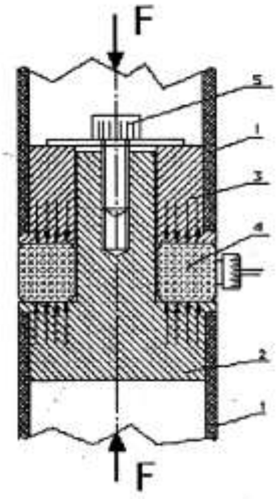


Figure 5.13 Needle bar transducer arrangement: (1) needles bar, (2,3) insertions to transducer positioning, (4) piezoelectric transducer, (5) pre-tension screw

They analysed the performance of the feeding and stitching systems by sewing fabrics, majority of them were knitted fabrics, with different mechanical and structural properties and correlated them with the measured forces. They determined the particular waveforms characteristic of sewing faults. The researchers found that, needle penetration and withdrawal forces are greatly influenced by the characteristics of textile materials being processed (such as thickness, cover and friction) and their finishing states. Figure 5.14 shows the effect of dyestuff on needle penetration and withdrawal forces. By using adaptive control system, they also controlled presser foot compression force and sewing thread tensions [59, 60].

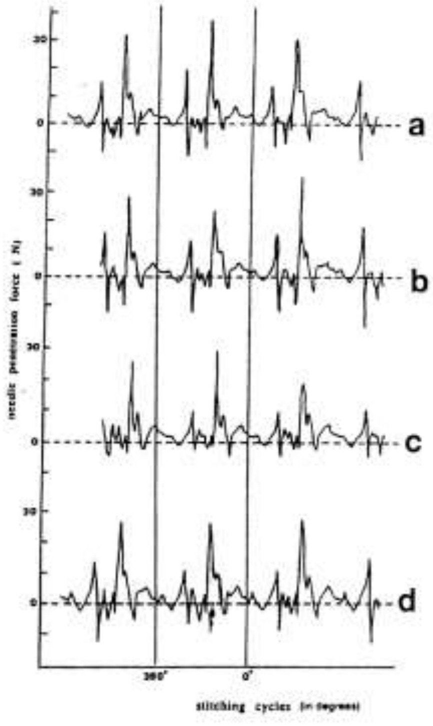
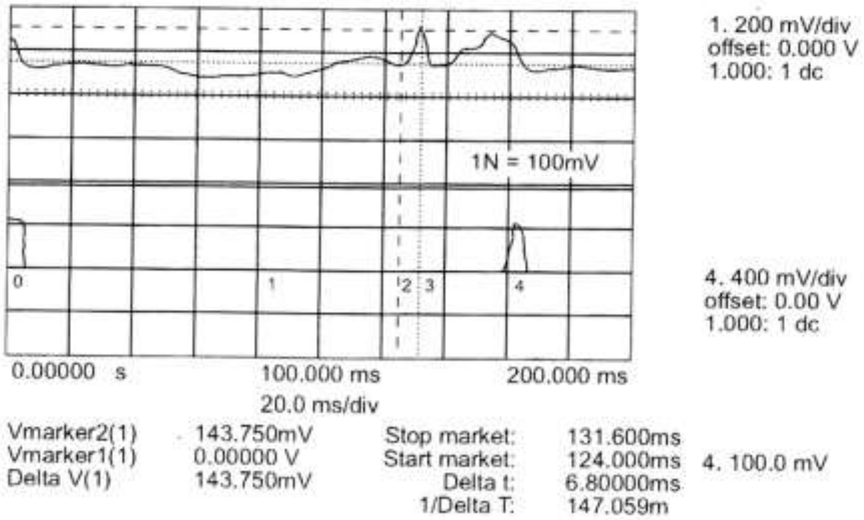


Figure 5.14 Effect of dyestuff on needle penetration and withdrawal forces, (a) dark red, fabric damage, (b) light red, fabric damage, (c) blue, good performance, (d) black, good performance. Jersey fabric of 50% cotton 50% rayon, K=17, 30 Ne, 150 g/m^2 mass, dyed with reactive dyes and finished with 20% softener

Gotlih measured the sewing needle penetration force in 1997, in University of Maribor. A mathematical model for the determination of the sewing needle penetration force was developed and the results were compared with measured values for the chosen fabric, sewing needle and sewing machine. The sewing needle penetration force was measured on the Brother EXEDRA DB2-B737-913 Mark II sewing machine. The measuring device was constructed with strain gauges. The results were shown as a print from the HP 54501A digital oscilloscope with the printer HP 2225. The measuring was done with the sewing machine shaft speed ω= 47.59 rd/s. The print of the measured sewing needle penetration force as the function of time is shown in Figure 5.15 for warp direction seam. The maximum value, for 100 % cotton plain-woven fabric (warp density: 29,5 warp/cm; weft density: 27 weft/cm) was found as 1,44 N [39].



Vmarker2(1) 143.750mV
Vmarker1(1) 0.00000 V
Delta V(1) 143.750mV
Stop market: 131.600ms
Start market: 124.000ms
Delta t: 6.80000ms
1/Delta T: 147.059m

Figure 5.15 The measured sewing needle penetration force for seam in the warp direction

In 1998 Mallet and Du used Finite Element Model (FEM) to study the sewing process. In the model, the fabric was approximated by a number of perpendicular beam elements with elastic and plastic capabilities. On the other hand, the needle was modelled by a simple elastic beam. The variations of the needle geometry and the fabric material properties as well as the sewing conditions were also included in the model. The model could simulate the needle piercing through a material, and calculated the sewing forces as well as the fabric deformation forming a hole. It has been verified experimentally and could be used to study the effects of the key sewing parameters such as the fabric material properties and the needle geometry. The experimental study was done by Gao in the University of Windsor in 1998 and this study was presented as an MSc thesis. To measure the sewing force, a special sensor was designed as shown in Figure 5.16. The sensor was a piezoelectric strain gauge mounted on a packet.

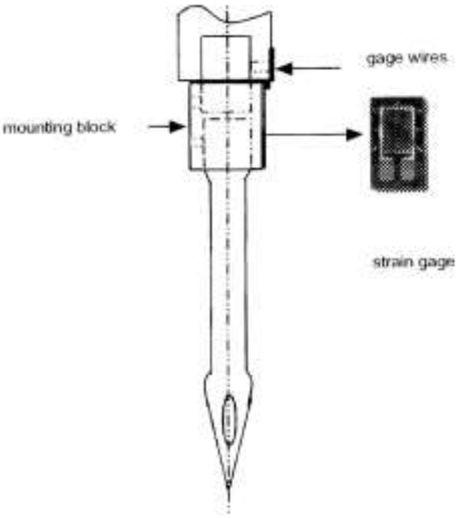


Figure 5.16 Illustration of the sewing force sensor

It was found that the point angle variations did not change the tip piercing force. However, the sharper the needle, the smaller the needle cutting force because the hole was enlarged more slowly. The friction force is proportional to the point angle because the fabric has experienced a less plastic deformation with sharp needles. Figure 5.17 shows a typical sewing force according to the simulation. From the figure, it is seen that the sewing force consists of three components: the needle tip force, the cutting force (generated by the conic portion of the needle), and the friction force. Each component has its own characteristics. For example, the needle force is an impulse of about 5N that disappears after the needle cuts through the material. The cutting force is about 1.5N and has a little tail corresponding to the withdrawal of the needle. The friction force can be further decomposed into two parts. The first part is about 0.7N, corresponding to the needle piercing through the fabric. The second part is smaller, corresponding to the needle withdrawing because the hole has been formed. Figure 5.18 shows a typical sewing force signal collected from the sensor, because of the sensor set up, the signal is reversed when comparing to that in Figure 5.17. The maximum needle penetration force was found around 6 Newton, but details of the sewn material wasn't given by the authors [61].

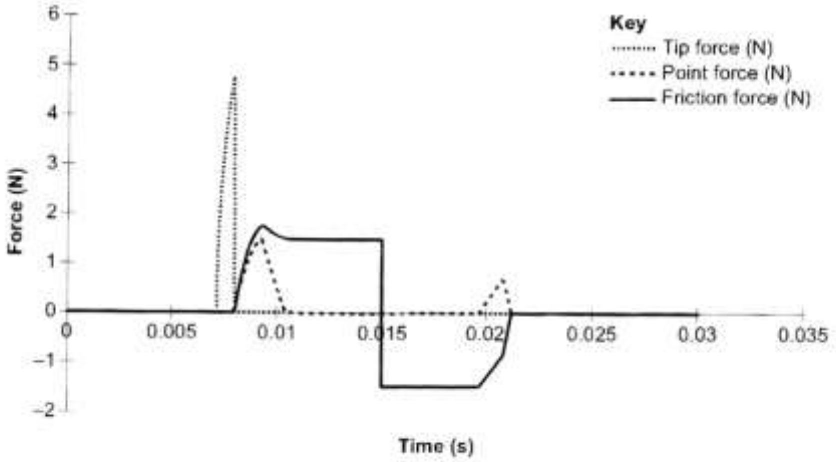


Figure 5.17 A typical sewing force consisting of three components

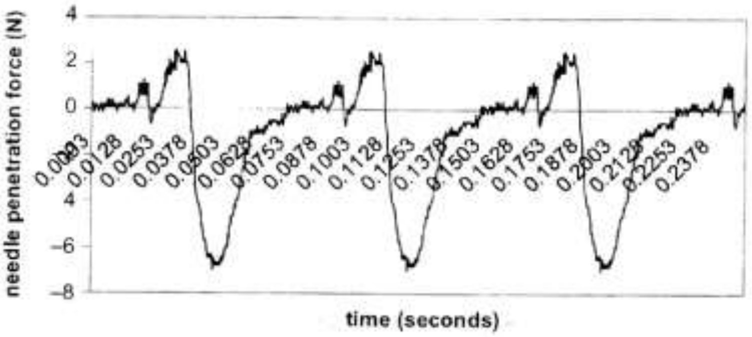


Figure 5.18 A typical sewing force sensor

In 1998 Carvalho et. al., in University of Minho, described the development of sewing test instrument used on the assessment of relationships between sewing machine set-up, material and thread properties, and general sewing conditions with the efficiency and quality of the seams. An industrial three-thread overlock machine was equipped with various sensors and devices, the same machine used in 1996 by Rocha et. al. It was connected to a commercial data acquisition board in a PC. A software program developed in LABVIEW supplied data acquisition. **Thread** tension was measured by custom specified strain gauge based sensors introduced into the thread paths. Thread consumption, closely related to correct stitch geometry and to the thread tension, was measured by digital encoders. To evaluate this effect, a piezoelectric sensor was built into the needle-bar shaft. The sensor not only picked up the forces resulting on the needle-bar from the interaction between the needle and the fabric, but also the undesired components of needle-bar acceleration and thread forces. The signals had to undergo a filtering stage to estimate the values of needle penetration and withdrawal forces. The measurement of these forces made it possible to compare different needle types and widths or different fabric finishing processes. Research was being undertaken in order to establish strategies to detect worn-out or defective needles in real-time, avoiding material damage (bursted yarns or structural distortion in the sewn fabrics). Machine speed was 2050 stitches per minute (spm). Figure 5.19 shows the force on the needle bar generated during two complete stitch cycles with the machine operating unthreaded, with a medium-weight denim fabric (solid) and without fabric (dashed).

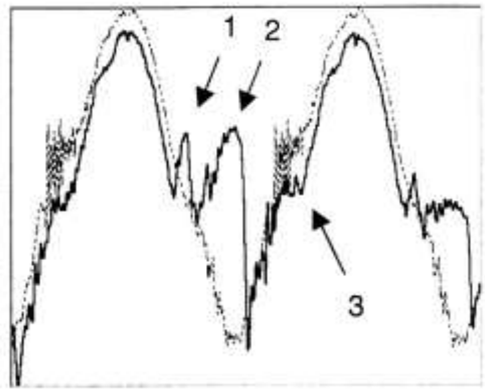


Figure 5.19 Force on needle bar at 2050 spm, with medium-weight denim (solid) and without fabric (dashed)

The effect of needle penetration is clearly visible in peaks 1 and 2. Peak 1 corresponds to a force generated at the first contact of the needle tip with the fabric. Peak 2 is generated when penetration occurs and the eye and blade of the needle passes through the fabric structure. Peak 3 is the effect of needle withdrawal, an inverted peak, generally with a lower magnitude than 1 and 2. Figure 5.20 shows the same stitches of figure after subtraction.

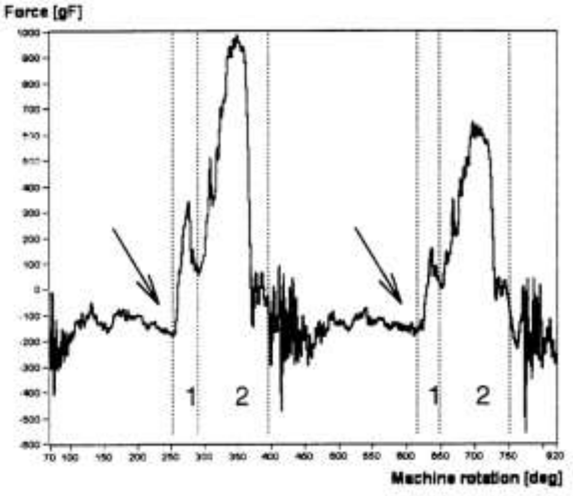


Figure 5.20 Needle penetration signal after subtraction. Phase 1: first contact of needle tip, Phase 2: penetration of eye and blade

They found that all of the calculated values present a great variability. Different needles and different materials were found detectable.

To evaluate the efficiency of the feeding systems, the force on the presser-foot was measured by means of a piezoelectric sensor. Its vertical displacement was sensed by an LVDT. The presser-foot movement, as studied in, had ideally only one elevation, resulting from the vertical movement of the feed dog. At high speeds, though, a second, undesired elevation was produced (by presser foot bouncing) which had to be carefully observed. High peak values of the primary and second presser-foot elevation result in loss of control of the fabric, and consequently irregular seams. It had been found that certain ratios of these peak values were important classifiers for correct stitch formation. Defects like skip stitches (when a stitch does not completely formed), distorted stitches (spontaneous deformation of the stitch geometry), tension variation and incorrect balancing, among other defects, were easily detected [2, 76].

In 1998 Sundaresan et. al, studied on the reduction in fibre strength and the damage inflicted on fibres during high speed sewing on a Singer industrial lockstitch machine, model 191D200AA at a speed of 4000 rpm. The dynamic needle thread tension was measured by using a semi-conductor strain-gauge based tension meter. The tension probe was introduced between the take-up lever and needle just above the needle bar. The instrument was interfaced to a 386 personal computer to enable data acquisition to be achieved for 75 stitches continuously. They found that dynamic loading has a great influence on fibre strength. They also did tensile tests on the fibres extracted from the parent and sewn threads on an Instron Tensile

Tester and compared these values with the average specific peak-tension values calculated from the dynamic tension data [77].

In 1999, Ferreira et.al., studied on the feeding system of an industrial Singer overlock sewing machine. They instrumented a Singer overlock sewing machine, model 882U, which was instrumented in University of Minho. The data acquisition hardware used in this study consists of a LAB-PC+ data acquisition board plugged to a Pentium PC. The software used to ease the acquisition, storage and visualisation of the different signals acquired, using the National Instruments LabVIEW graphical programming language. They studied with knitted fabrics [31, 76]. Figure 5.21 shows the sewing machine equipment.

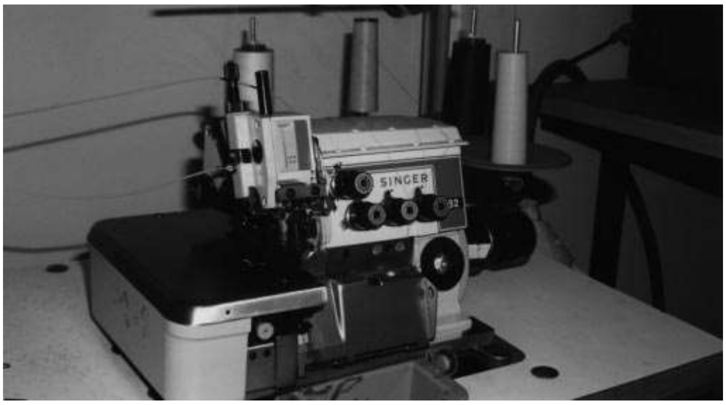


Figure 5.21 The Singer overlock sewing machine, model U882

Free unguided LVDT (with electronics to provide a DC output proportional to the displacement) was used for real-time monitoring the movement of the presser foot bar This device, together with a piezoelectric force transducer placed on the same bar, will permit further understanding of the feeding system dynamics during high speed sewing. Different machine speeds were used:, 186, 2077, 2810 and 465 stitches per minute (spm). Figure 5.22 shows the general view of the transducers arrangement [31].

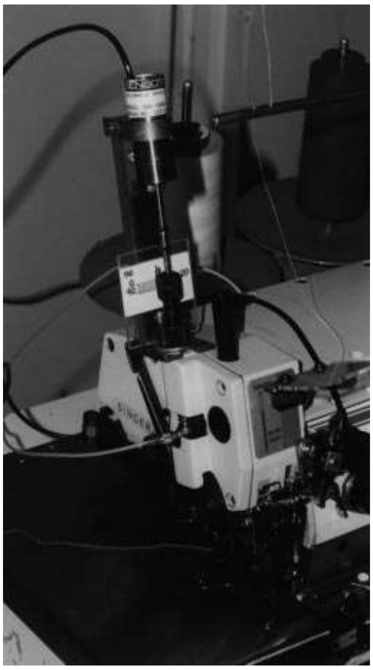


Figure 5.22 General view of the transducers arrangement

In 1999, Carvalho and Ferreira monitored thread tension and thread consumption, pressure foot force and displacement and needle penetration forces on the same three-thread overlock sewing machine in the same university [78].

In 1999, Silva et. al developed a new actuation system attached to the presser foot bar of the same industrial overlock sewing machine, to replace the helical spring. According to the presser bar displacement and compression force waveforms gained from measuring unit, it could be possible to achieve the desired presser foot dynamic behaviour at all sewing speeds [79]. This study provided the basis for the development of a redesigned and optimised fabric feeding system [80].

In 1999, Arai and Akami measured the strain of the tension spring produced by the bobbin thread in a sewing machine, in Tokyo Kasei University. To overcome the difficulty due to the intrinsic mechanism of lockstitch formation, a pair of intermittently working of brush-terminal combinations was attached to the body of the bobbin case to establish the bridge circuit in a measuring system [81]. In the experiments, the latch of the bobbin case had been removed in order to establish two pairs of intermittent brush-terminal contacts on the limited space of a bobbin case. However, this caused an inevitable factor of unstable sewing at speeds higher than 700 rpm. In the second series of this subject, the authors modified the system to attain sewing speeds up to 1900 rpm. They found that, the tightening tension of both needle and bobbin threads were measured simultaneously during stitch formation using their system. During this operation, the output of the gage bridge was recorded by a data-analyser as shown in Figure 5.23 [82].

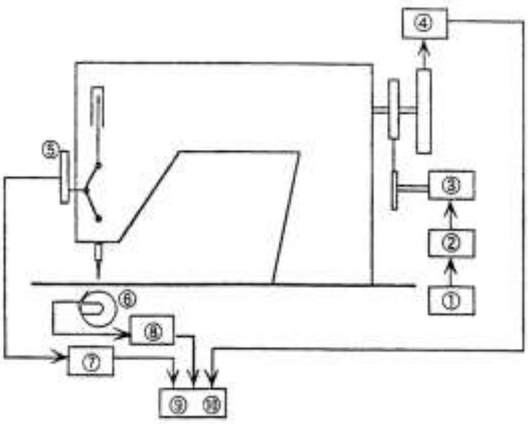


Figure 5.23 Block diagram for simultaneous strain detecting system: 1-standard-voltage supply, 2-controller; 3-AC servo-motor, 4-photo sensor, 5-cantilever. 6-bobbin case with strain gage; 7-8-amplifier; 9-transient recorder; 10-data-analyser, transient recorder and data-analyser are changed when necessary

In 2000, Kennon and Hayes in University, of Manchester Institute of Science and Technology, investigated the stitch formation process of a lockstitch machine (Pfaff, model 463) with the aid of transducers that facilitate real-time monitoring of the sewing cycle. The dynamic needle-thread tension was monitored at the sewing speed of 1406 spm by using a load-cell mounted in the thread path between the eye of the sewing needle and the eye of the take-up lever [20].

5.3.1 Integrated Computer-Based Sewability Measuring Systems Using Machine Learning Techniques

Textile materials are a category of limp materials that we use due to their inherent ease of conforming into three-dimensional surfaces even when under dynamic configuration such as wearing of clothing. Textile fabrics are complicated structures, made of different natural and man made materials, and undergo a variety of processes, which provide them with functional and aesthetic properties to fulfil consumer demands. They are inhomogeneous and difficult to define as engineering structures. Although there has been a lot of research in the last 10 years dealing with establishing their most important properties, their magnitudes and their method of measurement, there is very little on relating and interpreting these properties in the manufacturing context. Although processing machinery for textile fibres, yarns and fabrics has been developed, and we are able to mimic structures such as the surface and texture of butterfly wings or peach skin or to produce artificial silk and leather, very few significant advances have been made in the manufacture of these structures for apparel end uses such as clothing, furnishings, etc.

Despite efforts to find a better and easier means of joining textile fabrics, stitching with a needle and thread has survived for centuries using an ingenious but inherently inadequate for modern manufacturing production mechanical arrangement: the sewing machine. The basic engineering design of the sewing machine has not changed since the 17th century despite enhancements in motorisation, speeds and various add-on devices. Sewing thread tensions and feeding forces are always different for the many stitch types, for every fabric to be stitched, for different designs and at different sewing speeds. The operator's skill increases the complexity of those systems. These circumstances, if to be effectively modelled, need new thinking, new methodology and non-conventional approaches for provision of effective solutions.

The possibility of setting up the sewing machine automatically according to the fabric to be sewn is now, a feasible proposition, and it renders this new generation of "intelligent sewing machines" irreplaceable for quick response technology. In addition, the performance of different needles and feeding and stitching mechanisms can be evaluated, and the interpretation of waveforms may lead to better machine, fabric, and sewing thread design. The on-line approach to adjusting the sewing machine according to fabric properties and behaviour is expected to reduce the effort spent testing materials, therefore improving the overall efficiency of the industry [59, 60].

The definition of an intelligent environment in the textile and apparel context may be one that is able to determine systematically the properties of raw materials (yarn or fabric), predict effectively their ability to be manufactured into a garment (sewability/tailorability), determine fit of certain criteria from the material properties on re-engineering, optimise finally production machinery process settings efficiently, and enable self-learning so that the system can learn from its own experience. For an intelligent environment, therefore, one requires the following systems:

o A fabric measurement system: For measurement of the properties which characterize the mechanical behaviour of fabrics under low stress, equivalent to those under processing and wear. These properties constitute the so-called ''genetic fingerprint'' of a given fabric and are as follows: tensile, shear hysteresis, bending, thickness, compression and surface properties. From these measurements many useful parameters can be calculated which may, consequently, define the performance of the fabric and its interaction with the machinery during the production process. Different fabric types have a number of these properties and their parameters are more predominant than others.

o Sewability/tailorability prediction system: This system is based on modelling the interaction of fabric with the machinery during processing and/or its made-up seam quality, and is used to predict its difficulty during production and/or the maximum quality that can be achieved during sewing without incurring problems associated with uneven seams, deformed seams, damaged stitches, etc. This system can also provide advice on the amount that the magnitudes and properties need to be altered in order to correct the processability of the fabric usually through finishing or re-finishing treatments.

o Intelligent sewing machines: The optimum mechanical adjustments of sewing thread control and feeding foot pressure are made by motors dynamically, depending on the properties of the fabric being stitched and independently of any operational speed of the machine which can be altered by the operator at will. Fabric properties and other parameters are input as barcodes, and they can be transmitted to any number of sewing machines, anywhere. Advice on optimum sewing needle size may also be provided by the system where necessary.

o Self-learning systems: Different types of sewing machines have different seam quality assessment criteria, this is measured online and the signal is sent back to the sewing machine control model to alter or reinforce its control criteria through the interaction between properties and sewing mechanics. These systems are added to the sewing machine or they can be made as an integral part of it. The basic principles of the above-mentioned systems are measurement of material properties, machinery processing conditions, performance or quality attributes of the garment, and their relationship to the understanding the prevailing interacting mechanisms with the incorporation, wherever possible, of people's experience. This is done by designing and constructing the appropriate hardware and software for the effective working of those systems. Care was taken not to be rigid to the traditional methodology and scientific disciplines used, so that a realistic, effective and robust result can be achieved. To that effect, disciplines were crossed over, resulting in hybrid developments which have a mixture conventional and non-conventional methodologies which resulted in the newly evolved area called ''intelligent textile and garment manufacture'', its systems, ''intelligent textile and garment manufacturing systems'', and the new environment, ''intelligent textile and apparel environment''. Although these terms are of academic interest, in the manufacturing sense they denote the new generation of automation, flexibility and integration between fabric/machine/man, which may be one of the most significant areas for this industry at the turn of the century. Figure 5.24 shows a schematic diagram of the ''intelligent textile and garment manufacturing environment'', with emphasis on the individual systems and their integration. The figure simply shows the intelligent textile and garment manufacture environment [83].

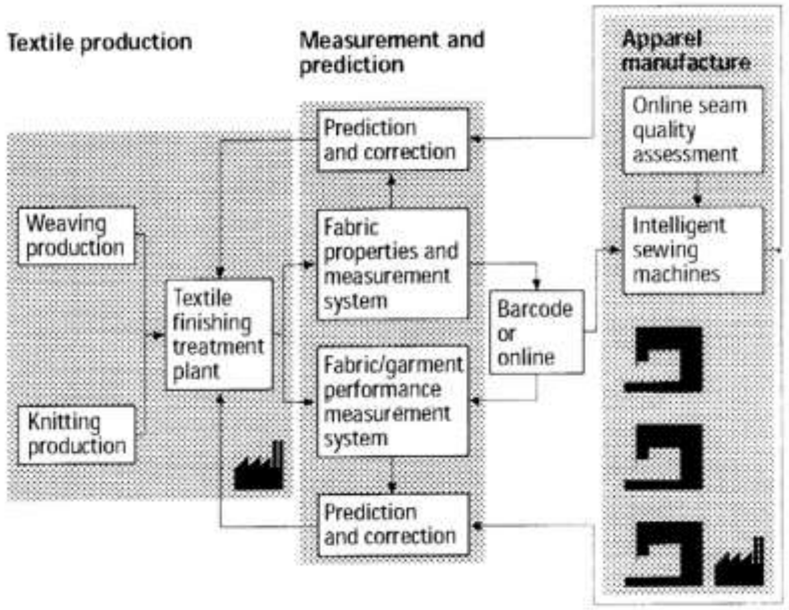


Figure 5.24 The intelligent textile and garment manufacturing environment

The textile and garment industries lend themselves to be perhaps the most challenging recipients of intelligent manufacturing since it has been recognised as the major means for further technological development in these fields. The textile and garment industries, due to their product range, and being traditionally labour intensive, have a plethora of decisions made from skill and subjective assessment in numerous situations. They have developed a culture of human dependence where experience is the predominant factor for survival, growth and profit [52].

Neural networks are used to predict the performance of fabrics in clothing manufacturing. An artificial neural network is one of the new intelligence technologies for data analysis. It imitates the behaviour of biological neural networks to "learn" a subject from the data provided to it. The ANN has been successfully used in areas where a large number of factors contribute to the eventual outcome, but precise relationships between these various factors and their outcomes cannot be defined, for example, medical diagnoses and credit evaluation in banking. Attempts have recently been made to apply the ANN technique to textiles [6].

Needle bar forces occurring during high speed sewing can be used to identify fabrics on-line. The neural network acquires its data from a sewing machine equipped with force transducers. These transducers measure the forces occurring at the needle during the sewing process. The neural network is trained to identify fabrics based on their force' 'fingerprint'. By implementing the neural network on a microprocessor, a practical way exists to identify not only the fabric type but also the number of plies sewn. Utilizing this type of classifier, the automated apparel assembly station can adapt itself to changing sewing conditions and provide quality checks such as making sure all plies were sewn [51].

The synergism of a neural, neuro-fuzzy approach has been found most successful for modelling the control of sewing machinery for complex interactions with limp materials. It is now possible to optimise sewing machinery settings automatically, statically and dynamically, under any material to be stitched [84].

In 1996 Stylios et.al. modified two of the most widely used industrial sewing machines; (a lockstitch and an Pegasus industrial overlock sewing machine) so that their optimum mechanics could be optimised dynamically during the operation for every new fabric used. Figures 5.25 and 5.26 shows these machines respectively. The following data could be captured at different sewing speeds: sewing machine speed (measured by shaft encoder); thread tension (diaphragm-type strain gauge); tension disk pressure (strain gauge); presser foot pressure (strain gauge); feed dog pressure (strain gauge); feed dog differential (linear variable differential transformer) was used during experiments.

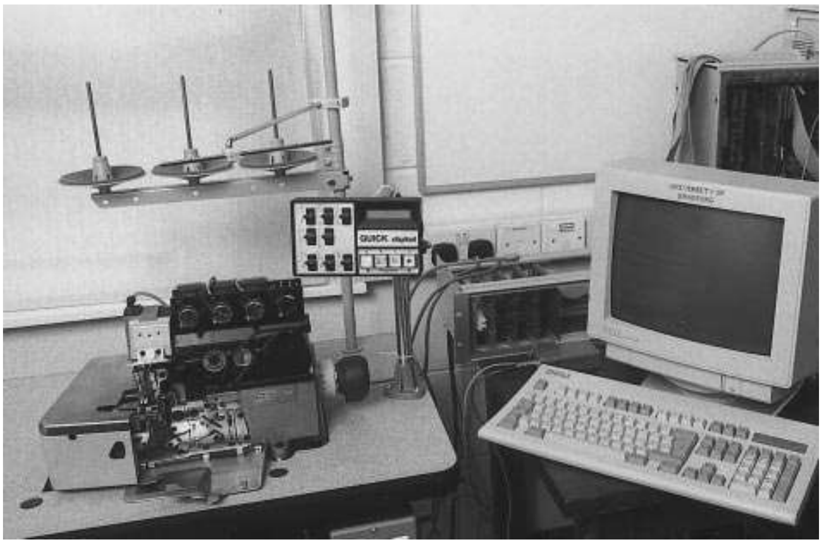


Figure 5.25 The intelligent overlock sewing machine Pegasus

Figure 5.26 The intelligent lockstitch sewing machine integrated with fabric measurement systems

In this system, the basic principle is to make sure that the thread tension and feeding pressure during stitching are optimum at different sewing speeds for any material used. The process thus far is manual, very time consuming and inconsistent. The mechanic feels the fabric before stitching by handling it. Depending on skill and experience he/she then regulates (increases or reduces) the tension and foot pressure of every sewing machine in the line, usually with a screwdriver. Actuating motors have replaced the process of hand/driver for both machines, a fuzzy-neural model has optimised the conditions and dynamically drives the motors, and the fabric property measurement station is used to determine the properties, which are fed to the control model. The machine had three stepping motors for controlling the thread tensions, a compressed air actuator for controlling the feeding foot pressure and two stepping motors for control of the feeding differential and stitch length. The appropriate controls, were programmed by the researcher. This was further analysed in a simplified model schema of the fuzzy-neural network. The sewability prediction is based on a single neuron (like a multilinear regression equation) network approach, with appropriate fabric properties as input and sewability prediction as an output. This output, together with the sewing machine speed, becomes the input of the fuzzy control, which is based on the rules determined from the sewing/fabric/man interactions. The output of the control engine was optimum sewing conditions at various speeds (independent) such as feeding foot pressure and thread tension. ANN was used to tune the membership functions of the control engine and, for the self-learning of the system, an online learning algorithm was used. This is initiated with a failure signal, which enables tuning of the membership functions until it satisfies the optimum criteria. It should be pointed out that, in this design, any fabric can be used and the sewing operator is allowed to increase/decrease/stop the sewing machine at will, in other words, the design respects operator performance (non-dictatorial). The system for online detection of failure signal was a laser line coupled with a camera focusing on the sewing line (wrinkle detection) in the case of the lockstitch sewing machine. The failure signal of the overlock sewing machine was based on a quartz transducer mounted on the feeding plate of the sewing machine to measure penetration forces which correlate with sewing damage [83].

In 1996 Barrett et al. described a sewing system that classifies both the fabric type and number of plies encountered during apparel assembly, so that on-line adaptation of the sewing parameters to improve stitch formation and seam quality can occur. The study was done in North Carolina State University. Needle penetration forces and presser foot forces were captured and decomposed using the wavelet transform. Salient features extracted using the wavelet transform of the needle penetration forces form the input to an artificial neural network, which classifies the fabric type and number of plies being sewn. A functionally linked wavelet neural network was trained on a moderate number of stitches for five fabrics, and could correctly classify both fabric type and number of plies being sewn with 97.6% accuracy. This network was intended for use to classify fabrics on-line and control sewing parameters in real time. The object of this research was to investigate the on-line identification of a fabric within a finite set of fabrics. Implementing these methods of fabric identification within the context of system intelligence would allow the on-line adaptation of sewing machine parameters to optimise seam quality. The Pfaff 483 sewing machine used to conduct this research was equipped with force transducers in both the presser bar and the needle bar. During sample collection, the sewing machine operated at 1435 spm. They studied with five fabrics. A computer was equipped to sample the sewing force signals synchronized with pulses from an encoder mounted on the sewing machine axle. The researchers used 256 encoder pulses, so regardless of sewing machine speed, the same number of samples was collected for every stitch cycle. During experiments, they did not use thread in order to reduce variability due to fabric/thread interaction. Fifty stitches of data were collected for each combination of fabric type (five types), ply number (1 to 4 plies) and orientation (warp or weft). Their results showed that, real-time sewing force measurements provide adequate information to identify both the fabric type and number of plies being sewn [45].

6. MEASUREMENT METHODS

6.1 Signals

In the technological field, the manipulation of signals aiming at the extraction and evaluation of information is an important task. Generally speaking, the dynamic representation of the signals is a powerful tool when a system is designed. Real measured signals are analogue quantities. The digital manipulation of a signal, which is becoming more and more common, presupposes the transformation of the signal into a sampled and digital form. Special devices called Analogue-to-Digital Converters (ADC) are therefore commonly used. The ADCs are converters of a voltage level into the corresponding numerical value within a predefined range. Sometimes, it happens that the output of the source (sensor or generator output etc.) provides an electrical current signal. In that case, amplifiers change the variance range to the requested level or if it is necessary, they linearize the signal. Likewise, if the signal is not in the desired form, special devices, known as transducers, transform it into the requested form. The signals are sampled and their values are used by the automation or control system in order to enable reactions and to make decisions on the controlled operation. The evaluation is a sequence of mathematical operations.

The frequency information of a signal is usually quite valuable. In order to get this information, a transition from the time to the frequency domain is needed. It is well known (Fourier Series) that periodical continuous signals can be analysed in a series of sinusoidal signals or by using other terms in an infinite number of discrete frequency spectrum components. The Fourier Transform is a powerful method permitting the transition without change the signal's information content. The Fast Fourier Transform (FFT) is widely used in many applications.

6.2 Sensors

Automation systems extract information from the process under control. The system will manipulate that information in order to either pass it to other systems or to define its reaction. The basic presupposition of the design and application of the automation systems is the availability of information. In the world of automation, information from the process is the raw material for further actions.

The majority of automation systems are electrical. This means that the signals, as carriers of information, have to be in an electrical form. On another level, it is necessary for the information to be available in the form of an electrical signal. The devices serving this need are called sensors. Their name has a Latin origin, which means the organ of sense. They "feel" the measured object and transmit a signal related to the variations of the measured quantity Sometimes the term transducer is in use. The transducer is a device, which receives energy from a system and transmits it to another. From this point of view, sensors are a subset of the transducers, because they don't only refer to low energy signals. The sensor is the part of the transducer, which is closer to the quantity to be measured.

A lot of common sensors are used in most of the application fields of industrial automation systems. There are various types of measured quantities. What is usually measured is: position (displacement), velocity, acceleration, force, pressure, flow, level, temperature, humidty, proximity, etc.

a) Displacement sensors: Well known methods of displacement measurement use: potentiometer, light reading of transparent elements (disks and rulers) etc.

b) Velocity sensors: Velocity is not always measured directly. The velocity is often calculated from the information taken from the displacement and the respective time. A tachogenerator is usually used as a velocity sensor Its axis is coupled to a rotating shaft and there is a certain voltage generated per rpm.

c) Acceleration sensors: Acceleration is measured by the application of a seismic mass to a force tensor. Another method is to connect a spring in series to a mass and displacement sensor. The acceleration of the mass causes elongation of the spring. The displacement recorded is proportional to the force, and the acceleration is easy to calculate if the mass is known.

d) Force sensors: Force is an important quantity to be measured Load cells are commonly used. These are linear variable differential transformers with movable cores. The displacement of the core unbalances the transducer and a signal is generated proportional to the displacement. If the force acts against the core of the transformer via a spring, the displacement and thus the signal generated is proportional to the force. The deformation of the materials under the influence of the force can be measured. A strain gage translates these deformations into resistance variations. The resistance change of the strain gage can normally be measured. Piezoelectric sensors are also commonly used. When a force acts on a special crystal or on a ceramic material it causes the generation of electrical voltage across the crystal.

e) Pressure sensors: For the pressure measurement, there are special tubes used in order to convert pressure variations into displacement changes These are usually metal tubes which are closed at one end. They are formed in circular or spiral form. When gas or fluid pressure is applied to the tube, it tends to straighten. The closed end moves and if a displacement sensor is connected to this, the displacement recorded gives an indication of the pressure. Another popular sensor is when a strain gauge is bonded on a diaphragm. The deformation of the diaphragm under the applied pressure allows its resistance to be increased. The resistance change is referred to the differential pressure of the two sides of the diaphragm There are piezoelectric pressure sensors as well as integrated monolithic pressure sensors.

f) Flow sensors: Flow is measured indirectly, by using a rotating turbine. The flowing fluid rotates the turbine and the faster the flow the greater the turbine rotation. A device for pulse generation is used in order to give an estimation of the rotation speed of the turbine. Another method for the measuring of flow is the ventouri differential flow meters.

g) Level sensors: Depending on the kind of the fluid in the tank, there are various methods used for the level measurement. A simple method used is the measurement of the displacement of one end of a cord with a float hung to the other end. A pressure sensor can be used to measure the pressure at the bottom of the tank. This indication is proportional to the level of the contained fluid.

h) Temperature sensors: The main sensors are the thermocouples. They generate a low voltage and are not linear. They are simple and inexpensive.

i) Humidity sensors: A usual way for the humidity to be measured is to use two temperature sensors. The first one has a dry bulb and the second a wet one. The evaporation causes the temperature of the wet bulb to become lower than that measured by the dry one. By using a special look-up table, the temperature difference between the dry and wet bulb indicates the relative humidity.

j) Proximity sensors: Proximity sensors are useful sensors in industrial applications If the objects are non ferrous, then ultrasonic transmitters and receivers are used. The reflection of the ultrasound indicates the proximity of an object. If the objects are ferrous, the sensing can be based on magnetic principles. There are also reluctance proximity sensors. They consist of a permanent magnet and a core with a coil around it. The presence of a ferrous material nearby causes distortion of the magnetic field and consequently a coil output.

There are many for sensors in the textile industry. The selection of some representative examples of sensor applications in the textile industry has been made so that it will cover a wide area [85].

6.3 Strain Gauge Measurement

6.3.1 Definition of strain

Strain is the amount of deformation of a body due to an applied force. More specifically, strain (ε) is defined as the fractional change in length, as shown in Figure 6.1 below

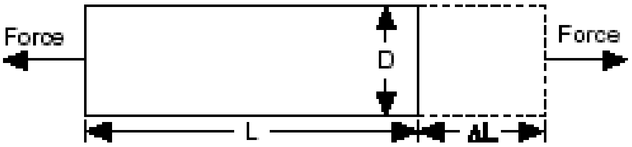


Figure 6.1 Definition of strain

Strain can be positive (tensile) or negative (compressive). Although dimensionless, strain is sometimes expressed in units such as in./in. or mm/mm. In practice, the magnitude of measured strain is very small. Therefore, strain is often expressed as microstrain (με), which is ε x10^{-6} [86].

External force applied to an elastic material generates stress, which subsequently generates deformation of the material. At this time, the length L of the material extends to L+ΔL if applied force is a tensile force. The ratio of ΔL to L, that is ΔL/L, is called strain. (Precisely, this is called normal strain or longitudinal strain.) On the other hand, if compressive force is applied, the length L is reduced to L- ΔL. Strain at this time is (- ΔL)/L.

Supposing the cross sectional area of the material to be A and the applied force to be P, stress σ will be P/A, since a stress is a force working on a definite cross sectional area. In a simple uniaxial stress field, strain ε is proportional to stress σ, thus an equation $\sigma = E \times \varepsilon$ is satisfied, provided that the stress σ does not exceed the elastic limit of the material. "E" in the equation is the elastic modulus (Young's modulus) of the material [87].

When a bar is strained with a uniaxial force, as in Figure 6.1, a phenomenon known as Poisson Strain causes the girth of the bar, D, to contract in the transverse, or perpendicular, direction. The magnitude of this transverse contraction is a material property indicated by its Poisson's Ratio. The Poisson's Ratio ν of a material is defined as the negative ratio of the strain in the transverse direction (perpendicular to the force) to the strain in the axial direction (parallel to the force), or $\nu = -\varepsilon T / \varepsilon$. Poisson's Ratio for steel, for example, ranges from 0.25 to 0.3.

When a metal (resistor) is expanded or contracted by external force, it experiences a change of electrical resistance. By bonding a metal (resistor) on the surface of a specimen with an electrical insulator between them, the metal changes its dimension according to the expansion or contraction of the specimen, thus resulting a change of its resistance. Strain gauge (electrical resistance strain gauge) is a sensor to detect the strain of a specimen by this resistance change.

While there are several methods of measuring strain, the most common is with a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain in the device. For example, the piezoresistive strain gauge is a semiconductor device whose resistance varies nonlinearly with strain. The most widely used gauge, however, is the bonded metallic strain gauge. The metallic strain gauge consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern. The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction as seen in Figure 6.2. The cross sectional area of the grid is minimized to reduce the effect of shear strain and Poisson Strain. The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen. Therefore, the strain experienced by the test specimen is transferred directly to the strain gauge, which responds with a linear change in electrical resistance.

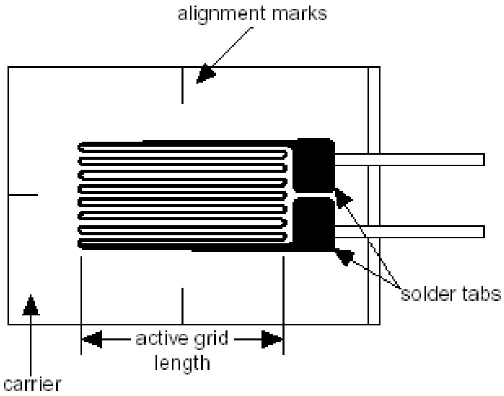


Figure 6.2 Bonded metallic strain gauge

It is very important that the strain gauge be properly mounted onto the test specimen so that the strain is accurately transferred from the test specimen, though the adhesive and strain gauge backing, to the foil itself. A fundamental parameter of the strain gauge is its sensitivity to strain, expressed quantitatively as the gauge factor (K). Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain). The Gauge Factor for metallic strain gauges is typically around 2.

The strain generated in the specimen is transmitted to the resistor (foil or wire) through the gauge base (backing), where expansion or contraction occurs. As a result, the resistor experiences a variation in resistance. This variation is proportional to the strain as indicated in the following equation:

$$\varepsilon = \Delta L/L = (\Delta R/R)/K \qquad (6.1)$$

ε: Strain, R: Gauge resistance, ΔR: Resistance change due to strain, K: Gauge factor as shown on the package, L: Original length

Ideally, it would be liked the resistance of the strain gauge to change only in response to applied strain. However, strain gauge material, as well as the specimen material to which the gauge is applied, will also respond to changes in temperature. Strain gauge manufacturers attempt to minimize sensitivity to temperature by processing the gauge material [86].

Strain gauges are provided with many convenient features as follows.

- Simple construction with a small mass and volume so as not to interfere with the stresses on the specimen

- Small gauge length for evaluation of localized stress
- Good frequency response for tracking rapid fluctuations in stress
- Simultaneous measurement of multiple points and remote points.
- Electrical output for easy data processing [87].

In practice, the strain measurements rarely involve quantities larger than a few milistrain. Therefore, to measure the strain requires accurate measurement of very small changes in resistance. To measure such small changes in resistance, and compensate for the temperature sensitivity discussed in the previous section, strain gauges are almost always used in a bridge configuration with a voltage or current excitation source. The general Wheatstone bridge consists of four resistive arms with an excitation voltage, which is applied across the bridge.

Changes in resistance caused by mechanical strain are measured in a bridge circuit, which produces an out-of-balance voltage. This voltage needs to be amplified and displayed or stored, or both, after manipulating (or processing) it to represent units. This manipulation may be by means of controls in the hardware (analogue), e.g. gauge factor control. In a computer based system, all the manipulation may occur in the software (digital) either in test programming, or in the data reduction and analysis, before and after storage. Figure 6.3 shows the schematic strain measurement system.

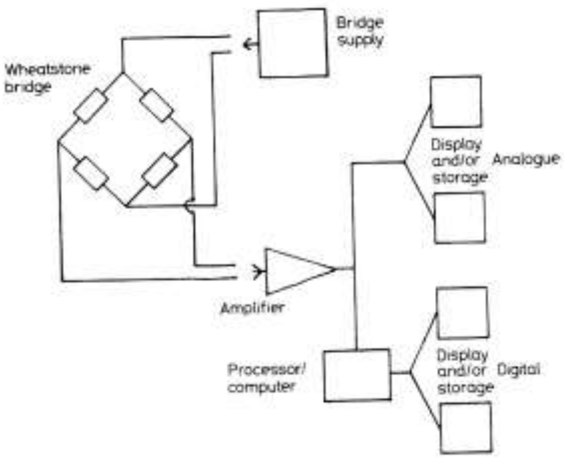


Figure 6.3 Schematic strain measurement system

The Wheatstone bridge illustrated in Figure 6.4 is most commonly used for converting the small change in the resistance of the strain gauge (or gauges) into a voltage suitable for amplification and processing.

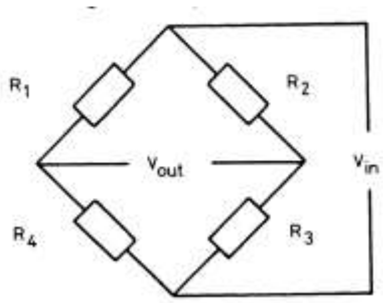


Figure 6.4 Wheatstone bridge

Consider Figure 6.4, in which R_1, R_2, R_3, R_4 are resistors. Assuming that the condition $R_1/R_4=R_2/R_3$ is satisfied then the output voltage V_{out} will be zero, i.e. the bridge is balanced. A change in resistance R1 will unbalance the bridge and produce a voltage across the output terminals. For strain gauge purposes, the output equation for the bridge is

$$V_{out} = (K\varepsilon\ N\ V_n)/4 \qquad (6.2)$$

Where;

K= gauge factor, V_n=bridge volts, ε =strain and N=number of active arms of the bridge

There are three bridge types:

Quarter bridge: When a signal gauge is used at the measurement point, with perhaps resistors within the strain indicator completing the bridge, then that is termed ‘quarter bridge’ operation.

Half bridge: When two gauges are used in adjacent arms of the bridge, it is known as a half bridge system, shown in Figure 6.5. For this work, one gauge must see tension and the other compression, i.e. one increasing and the other decreasing in resistance, or one gauge must see zero mechanical strain[88].

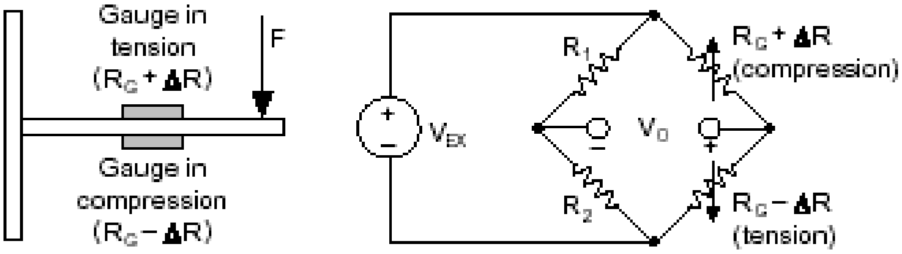


Figure 6.5 Half-bridge circuit

Full bridge: The full bridge, shown in Figure 6.6, using gauges as all four arms of the Wheatstone bridge, is a logical extension of the half bridge and can be used to further increase the sensitivity of a measuring system putting two gauges on each side of a beam; mounting two gauges in tension and two gauges in compression, instead of one, gives a value of N= 4, i.e. the output is four times that of a single gauge quarter bridge installation, with possibly improved temperature compensation and the cancellation of unwanted signals [87].

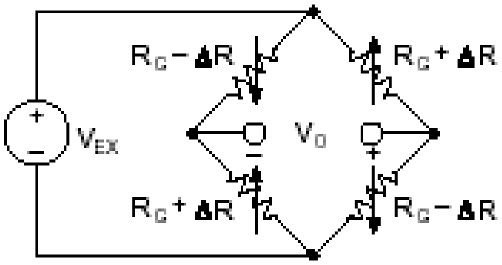


Figure 6.6 The full-bridge circuit

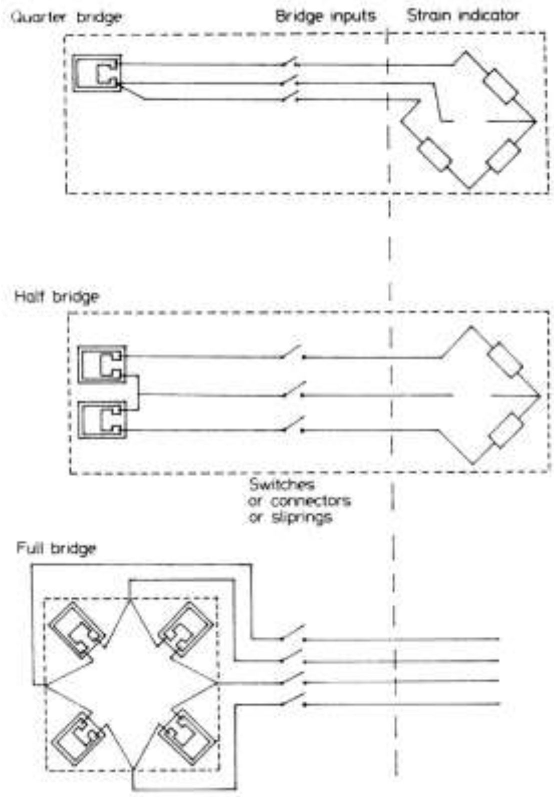


Figure 6.7 Bridge configurations

The equations given here for the Wheatstone bridge circuits assume an initially balanced bridge that generates zero output when no strain is applied. In practice however, resistance tolerances and strain induced by gauge application will generate some initial offset voltage. This initial offset voltage is typically handled in two ways. First, you can use a special offset-nulling, or balancing, circuit to adjust the resistance in the bridge to rebalance the bridge to zero output. Alternatively, you can measure the initial unstrained output of the circuit and compensate in software.

In most strain measurement systems, there is a provision for initially balancing the bridge to compensate for resistance tolerances of the gauges and lead wires. Some means of establishing this arbitrary zero at the start of a test is needed for two reasons.

- To enable the strains to be read directly without having to add or subtract the initial offsets;
- To ensure that the linear range of the amplifier is used to its full extend for the required signal and not taken up by the initial offsets.

With a computer-based equipment, to take account of initial offsets in the software is also possible. The value of the offset would be stored and then added to, or subtracted from, subsequent readings as the polarity dictates [88].

6.4 Data Acquisition Systems

Data acquisition instruments collect, digitise and process multiple sensor or signal inputs for the purpose of monitoring, analysing and/or controlling systems and processes. They are configured in a wide variety of instrumentation and modular systems. Applications include manufacturing testing of all types of technical products, safety, environmental, certification and research projects.

6.4.1 Data Acquisition and Signal Conditioning

Data Acquisition and Signal Conditioning is the processing of multiple electrical or electronic inputs from devices such as sensors, timers, relays, and solid state circuits for the purpose of monitoring, analysing and/or controlling systems and processes. Major technologies and related instruments of signal generation and transmission include voltage and current signals (conditioned transducers), concentration measurement (high impedance probes), power signals from power supplies, temperature measurement (thermocouples), resistance, strain measurement (strain gauge bridges), excitation, angular position measurement (encoders), speed and flow measurement (count-timers) and digital signals. Major families of data acquisition and signal conditioning are: data acquisition (high level), signal converters, recorders and loggers, and signal conditioning [89]. Figure 6.8 shows the general concepts of data acquisition [88].

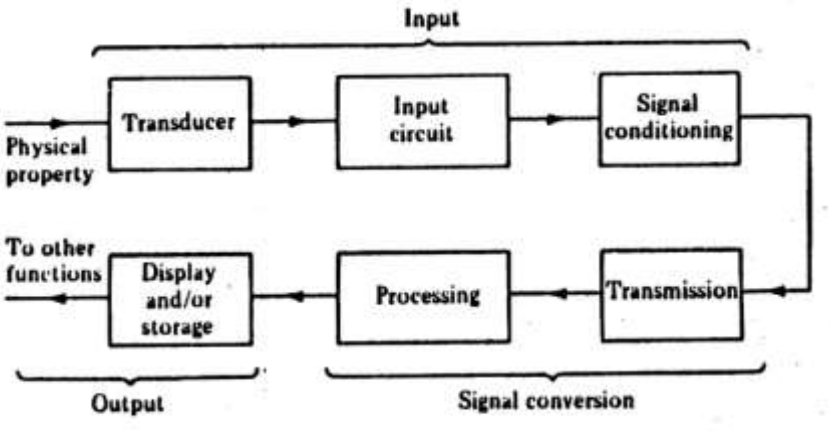


Figure 6.8 General data acquisition system

Signal conditioners are devices that receive sensor output, then refine, and output the signal (generally as digital or digitised data) so that it can be read by a data acquisition computer board. These include bridge conditioners (for Wheatstone bridge style sensors, such as quarter, half, or full bridge strain gauges and accelerometers), instrumentation and signal amplifiers, signal filters, and temperature signal conditioning units.

The family of signal converters includes various data acquisition devices that accept a signal, then filter and output the signal in a different fashion. Mostly, the signal frequency is changed, although some converters may change frequency to voltage and vice versa. Major instruments within this family include: analogue-to-digital converters (ADC), charge converters / amplifiers, current loop converters, current-to-voltage converters, digital-to-analogue converters (DAC), frequency converters / translators, frequency-to-voltage converters, signal converters, voltage converters / inverters, and voltage-to-frequency converters.

Charge amplifiers/systems are, signal conditioning modules or systems that amplify, attenuate, filter and/or convert a charge signal from an accelerometer, load cell, pressure transducer, displacement transducer or another type of capacitive sensor. Amplifiers accept signals from sensors and other devices which are often too low-level to be usable in analysis. They amplify them to levels suitable for further processing or digitisation by computer elements such as data acquisition devices. The amplification ratio, or gain, may be fixed or programmable, and amplifiers may incorporate multiple channels and other signal conditioning functions such as filtering. Signals measured during data acquisition are usually disturbed by unwanted noise or influenced by other signals. Noise or harmonic signals have usually higher frequency than the measured signal. They can be removed before acquisition by electronic filter connected to signal before amplifier input.

Recorders and loggers are devices that acquire digital data from sensors and other signalling instruments. They are primarily used to store this data for future download (to a PC) although some styles do have real-time features including monitors and alarms. Others are used to generate charts or graphs, either on a screen, or as continuous printouts for tracking or monitoring. This family includes data loggers and recorders, and chart recorders and strip charts.

Data acquisition instruments collect, digitise and process multiple sensor or signal inputs for the purpose of monitoring, analysing and/or controlling systems and processes. They are configured in a wide variety of instrumentation and modular systems. Applications include manufacturing testing of all types of technical products, safety, environmental, certification and research projects [89].

7. EXPERIMENTAL

7.1 Materials

- Fabrics: Five 100% cotton grey denim fabrics, commonly used for clothing, were supplied from the industry for this investigation. The fabric thickness was measured on James Heal R&B Cloth Thickness Tester, Type 252, according to the ASTM-D1777 test method. Fabric weight was measured with an electronic weighing balance. Yarn counts were measured according to the ASTM-D1907 method. Air Permeability was measured according to the ASTM D737-96. Table 7.1 shows the fabric properties.

Table 7.1 The properties of the denim fabrics

Code	**Weave**	**Fabric Weight [g/m^2]**	**Thickness [mm]**	**Air Permeability [Lt.dm^2/min-10 mm water column]**	**Densities**		**Yarn Count (OE Rotor Yarn) [Ne]**		**Cover Factor**	
					Weft [Ends/cm]	**Warp [Picks/cm]**	**Weft**	**Warp**	**Weft**	**Warp**
1	Twill 3/1	538,2	0,98	2050	17,3	26,8	4,9/1	6,6/1	25,8	34,4
2	Twill 2/1	374,2	0,74	2600	15,4	26,5	11,/1	6,5/1	15,2	34,3
3	Plain	374,1	0,79	2730	14,2	25,3	11/1	6,7/1	14,1	32,3
4	Twill 2/1	275,73	0,64	8600	15	27,6	11,6/1	10,6/1	14,5	27,9
5	Twill 3/1	416,9	0,85	2350	18,4	26,7	10,9/1	6,6/1	18,4	34,3

- Sewing threads: They were chosen according to their Tkt yarn number and ply. Compositions were chosen the same, only differentiating in materials and yarn counts. Table 7.2 shows the thread properties.

Table 7.2 Sewing thread properties

Thread Code	Composition	Ticket number (Tkt no.)	Ply	Twist [T/m]	
				3 ply [(Z)	1 ply (S)
1	Corespun(cotton/poly)	40	3	606	422
2	Corespun (poly/poly)	20	3	720	622

- Sewing Needles: Three different needle sizes were used according to the fabric thickness and weights. During choosing the needles, ASTM-D1908 method was also taken into account. Needle no. 16, 18 and 22, produced by Orange Needles Company, were used to sew the samples. Needles have normal points, shown as R, which can be used for sewing of the majority of textile materials. The needle point is lightly rounded. The shank diameter and blade length of Singer 18 needle are dfferent than the others. Table 7.3 shows the needle properties.

Table 7.3 Needle properties

Needle code	Needle No (Singer System)	Definitions given by producer	Point Shape	Shank Diameter (mm)	Blade Length (mm)
1	16	DPX5	R	2,00	21,3
2	18	DBX1/257	R	1,62	17,8
3	22	DPX5	R	2,00	21,3

- Sewing was done on the Singer 591 D300A lockstitch machine.

- A pair of HBM Strain gauges US-TYPE 3/120LY61 were used during the experiments. They bonded to the needle bar oppositely and full-bridge configuration was used. Figure 7.1 shows one of the strain gauge BONDED to the needle bar surface.

Figure 7.1 A closest look to HBM strain gauge on the needle bar.

- Data acquisition was done using ESAM Traveller amplifier and ADC converter. ESAM (Electronic Signal Acquisition Module) is a measuring system used during the experiments. It consists of a high technology acquisition and conditioning device and very sophisticated software to control processing data. ESAM cooperates with wide family of acquisition boards, which can measure from 50,000 up to 300,000 samples per second. The board is mounted inside desktop or laptop computer or in a special box attached to computer via USB or parallel interface. ESAM Traveller can measure up to 16 analogue channels (or 32, 64 channels in special 32 or 64-channels version) and up to four digital channels. Analogue channel means that input voltage range is maximum – 10V to + 10V. Digital channel has only two levels: 0 and 1. Number of impulses per second on a digital channel can be treated as impulse channel and calculated to form additional analogue channel. ESAM stores all channels parameters like name, number, gain, calibration, limits, etc. for all defined tests. Software used in ESAM measuring system was designed and written to provide maximum simplicity in measuring and processing data. ESAM Traveller Plus is the high speed 12 bit ADC converting data acquisition system designed to be used with IBM PC or compatible computer system [90]. Figure 7.2 and 7.3 show amplifier unit used during the experiments respectively.

Figure 7.2 ESAM Traveller amplifier unit

Figure 7.3 Sewing machine and ESAM Traveller amplifier unit

- The system used Pentium processor and Windows 2000 operative system during the experiment.

Figure 7.4 shows the general view of the “sewability tester”.

Figure 7.4 General view of the system

Figure 7.5 shows how the cables, coming from the strain gauge to the amplifier unit with a full-bridge connection, were protected from the harsh sewing conditions occurred because of the high sewing speeds and inertial forces.

Figure 7.5 Side view of sewing head and needle bar arrangement

7.2 Method

Since warp seams are more important to overall garment appearance, sewing measurements were done in warp directions. 10 cm x 120 cm samples were prepared from five denim fabrics in warp directions, as described in ASTM-D 1908. The reason why this standard was chosen is to examine the needle penetration forces on needle damage as a further study.

Machine speed was kept around 1100 rpm. Machine settings were adjusted for every new fabric type to give a balanced stitch. For 40 Tkt sewing thread, each test was done for five times, because there was a risk that strain gauge may get damaged, or gauge cables may be broken for the high sewing dynamics.

Unfortunately the experiments, which we used 20 Tkt yarn could not be done repeatedly because there was a risk for tearing of the strain gauge. One strain gauge was torn because of the yarn balloon produces by 20 Tkt yarn. During sewing, difficulties were experienced with 20 Tkt yarn. Because this thread tended to clog the needle eye and finally broke during stitching. Also, at the end, strain gauge was torn from the surface of the needle bar because of the yarn ballooning. Because it is so time consuming to wait for a strain gauge packet to come from abroad, it was decided to present the data gained so far through the experiments. Other experiments will be done in the near future as a further study.

Fabric and thread samples were conditioned under standard atmospheric conditions and these conditions were maintained during the tests.

The tension of the bobbin thread was adjusted so that a slight unwinding occurred when the bobbin case was held by the end of the thread and a light repetitive jerking applied. The tension of the needle thread was adjusted so that the seam was best balanced. Thread tension was adjusted for each fabric and each sewing thread.

Stitch density was chosen as 4 stitch/cm

Table 7.4, Table 7.5 and Table 7.6 show the codes given to the samples. Fabric, sewing thread and needle, codes were given in the previous part. For four numbered codes, the first number stands for the needle number, as it is the most important parameter, the second for sewing thread, the third for fabric, the fourth for plies. For three numbered codes, the first number stands for the needle, the second one for the fabric, and the third one for the ply number.

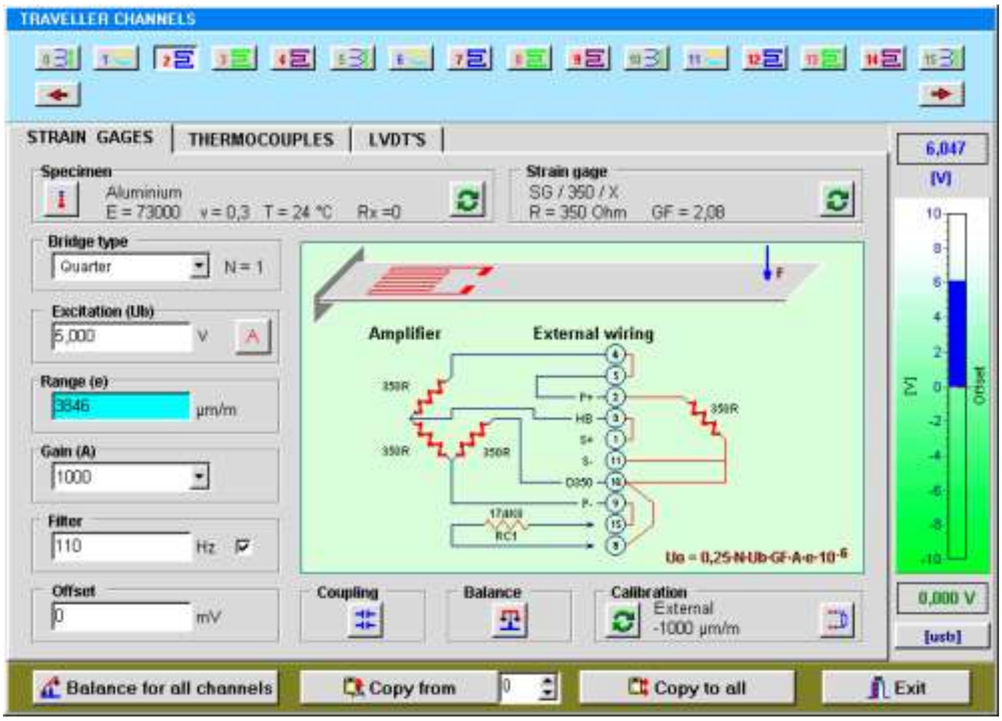
Table 7.4 Samples' codes

1111	1112	1211	1212	2111	2112	2211	2212	3111	3112	3211	3212
1121	1122	1221	1222	2121	2122	2221	2222	3121	3122	3221	3222
1131	1132	1231	1232	2131	2131	2231	2232	3131	3132	3231	3232
1141	1142	1241	1242	2141	2142	2241	2242	3141	3142	3241	3242
1151	1152	1251	1252	2151	2152	2251	2252	3151	3152	3251	3252

Table 7.5 Samples sewn without yarn

111	112	211	212	311	312
121	122	221	222	321	322
131	132	231	232	331	332
141	142	241	242	341	342
151	152	251	252	351	352

Before taking the data, the full bridge must be balanced. Figure 7.6 shows the ESAM screen seen during balancing the bridge.



Specimen: Aluminium, E = 73000, v = 0,3, T = 24 °C, Rx =0

Strain gage: SG / 350 / X, R = 350 Ohm, GF = 2,08

Bridge type: Quarter, N = 1

Excitation (Ub): 5,000 V

Range (e): 3846 μm/m

Gain (A): 1000

Filter: 110 Hz ☑

Offset: 0 mV

Calibration: External, -1000 μm/m

$Uo = 0{,}25 \cdot N \cdot Ub \cdot GF \cdot A \cdot e \cdot 10^{-6}$

6,047 [V]

0,000 V

Copy from: 0

Figure 7.6 ESAM screen while balancing the bridge

Data were started to be taken after certain amount of stitches, to reach the stable sewing speed. The acquisition time was limited to 10 seconds because there was a risk for the strain gauges to be torn apart during sewing.

ESAM has filters built on the acquisition board, but sometimes it is necessary to "improve" strongly noised signals by means of computer digital filters. The software also supports this feature. Signals were processed after sewing to eliminate the noises. Figure 7.7shows the typical traces before and after filtration. Low-pass filter was selected for the filtration. Cut-off frequency was chosen as 50 Hz. and FIR filter type was selected.

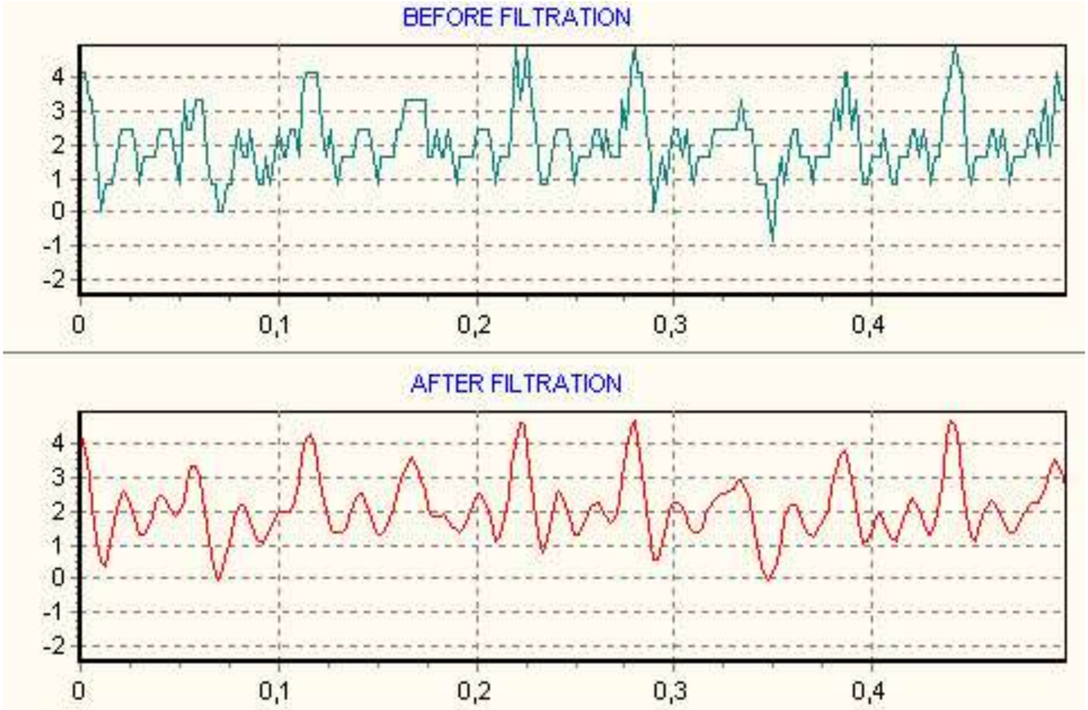


Figure 7.7 Waveforms before and after filtration

8. RESULTS AND DISCUSSION

Results showed that, the real-time sewing force measurements can be obtained and data can give the adequate information to identify number of plies, fabric type being sewn and the problems occurring during sewing process. So, machine/fabric interaction can be monitored simultaneously. The speed of data acquisition used in this study is relatively slow, 1100 rpm, when compared to the real production speeds.

Table 8.1 shows the minimum and maximum values of the needle penetration forces, according to the fabrics sewn. Then, histograms were drawn for needle penetration forces.

Table 8.1 Forces obtained during sewing

	Code	**Minimum force**	**Maximum force**
Fabric no.1	1111	-1,9388	2,7697
	1112	-1,4541	4,1546
	1211	-0,8309	4,1546
	1212	-1,6618	3,3237
	2111	-1,6618	3,9469
	2112	-2,3265	3,8222
	2211	-1,6618	3,3237
	2212	-2,4927	4,9855
	3111	-1,8695	3,5314
	3112	-2,0773	4,1546
	3211	-0,8309	4,1546
	3212	-0,8309	4,9855
	111	-1,9388	2,2157
	112	-3,3236	2,2157
	211	-2,0773	3,3237
	212	-2,4927	3,4899
	311	-2,7697	3,0467
	312	-1,6618	4,8239
Fabric no.2	1121	0,8309	1,6618
	1122	0,0000	3,3237
	2121	-0,8309	3,3237
	2122	-0,8309	4,1546
	3121	-0,8309	2,4927
	3122	0,0000	4,1546
	121	-0,8309	1,6618
	122	-1,6618	1,6618
	221	-0,8309	2,4927

Table 8.1 Forces obtained during sewing (continued)

	Code	Minimum force	Maximum force
	222	-1,6618	3,3237
	321	-0,8309	3,3237
	322	-1,6618	3,3237
Fabric no.3	1131	0,0000	2,4927
	1132	-1,6618	1,6618
	2131	-0,8309	3,3237
	2132	-0,8309	4,1546
	3131	0,0000	2,4927
	3132	-1,6618	3,3237
	131	-1,6618	0,8309
	132	-1,6618	1,6618
	231	-2,4927	1,6618
	232	-1,6618	4,1546
	331	-1,6618	1,6618
	332	-0,8309	4,1546
Fabric no.4	1141	-1,1079	2,2158
	1142	-1,4541	2,9082
	1241	-0,8309	1,6618
	1242	-1,6618	2,4927
	2141	-0,5539	3,6007
	2142	-1,1633	3,8222
	2241	-1,6618	2,4927
	2242	-1,6618	3,3237
	3141	-1,2464	3,1160
	3142	-1,6618	2,9913
	3241	-0,8309	3,3237
	3242	-1,6618	3,3237
	141	-1,0386	2,2848
	142	-1,6618	2,4927
	241	-1,1079	2,2157
	242	-1,3848	3,6007
	341	-2,4927	1,3848
	342	-2,2158	3,3237
Fabric no.5	1151	-0,8309	1,6618
	1152	-2,4927	2,4927
	2151	-0,8309	4,1546
	2152	-0,8309	4,1546
	3151	-0,8309	3,3237
	3152	-0,8309	3,3237
	151	-0,8309	1,6618
	152	-1,6618	2,4927
	251	-1,6618	2,4927
	252	-2,4927	2,4927
	351	-0,8309	2,4927
	352	-1,6618	4,1546

Maximum values represent the needle penetration forces, when the point of the needle penetrated the fabric. The minimum forces represents the withdrawal forces because the needle passes through the formed hole. Generally, it was observed that needle penetration forces are greater than the needle withdrawal forces. These results get along well with the results found by Matthews and Little and Mallet and Xu.

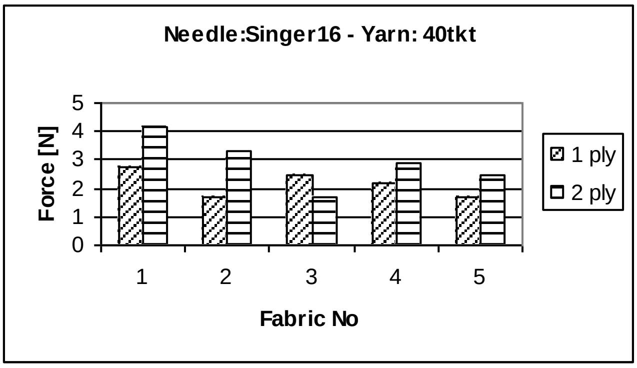


Figure 8.1 Effects of plies to needle penetration forces, for Singer 16 and 40 Tkt sewing thread

As seen in Figure 8.1, it was observed that, for Singer 16, needle penetration forces are generally higher for all samples having more plies than sewing one ply fabrics. The reason of that can be said that impact forces increase as plies increase resulting an increase in frictional forces between the needle and the fabrics. When comparing the needle penetration forces among the fabrics, Fabric 1 has the biggest force values, for both ply values. It is an expected result; because, Fabric 1 has the highest cover factors, thickness, weft and warp densities and weight. As the fabric areas letting the needle to penetrate without subjecting to any frictional forces decrease, higher penetration forces are obtained. For other fabrics, some of the calculated values presented a great variability, which is expected since the needle enter the fabric through the yarn, gaps between yarns or yarn crossovers, resulting in different penetration forces.

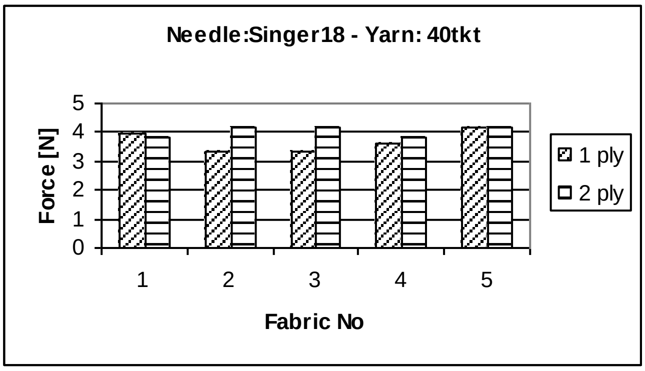


Figure 8.2 Effects of plies to needle penetration forces, for Singer 18 and 40 Tkt sewing thread

In Figure 8.2, it is seen for Singer 18 needle that two ply samples' penetration forces are generally higher than one ply samples': The penetration forces are higher than Singer 16's values, as expected.

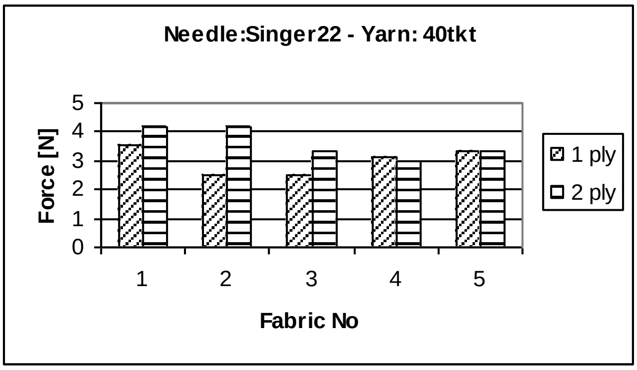


Figure 8.3 Effects of plies to needle penetration forces, for Singer 22 and 40 Tkt sewing thread

In Figure 8.3, it is seen that for almost every fabric, needle penetration forces for two plied sewn samples are greater than one ply samples', as expected. For Fabric 3, Fabric 4 and Fabric 5, needle penetration force values are lower than the values presented for Singer 18. This reason is a bit unexpected, because according to the constructional parameters, considering that Singer 22 has higher length and needle number, resulting higher frictional forces; this needle type must have given higher force values than Singer 18. Apart from this, it is evident that Singer 16's values are lower than the others, as expected. As the needle number, or needle diameter, increases, friction forces will increase because of increasing needle surface area. Results are closely resemble with Khan's, Bühler and Hennrich's, Zeto et.al.'s, Rocha et.al.'s and Matthews and Little's results; as fabric layers are increased, needle penetration forces are increased. According to the results found by the previous researchers, fabric structure has an important effect on needle penetration force. With respect to them, it is a bit surprising that these results shown above did not clearly reflect the effects of the fabric structures clearly, except for the Fabric 1.

In a second step, to see the effects of the sewing thread on needle penetration forces, samples were sewn without thread. Results showed the importance of sewing thread, which has a significant importance on needle penetration forces.

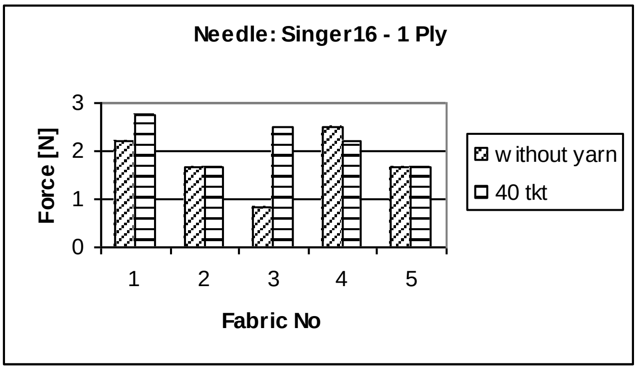


Figure 8.4 Effects of the sewing thread presence according to the needle numbers and fabrics, on the needle penetration forces, for Singer 16 and for 1 ply

As seen from Figure 8.4, for Singer 16 and 1 ply, generally needle penetration forces are higher for 40Tkt yarn than the forces obtained with the sample sewn without yarn.

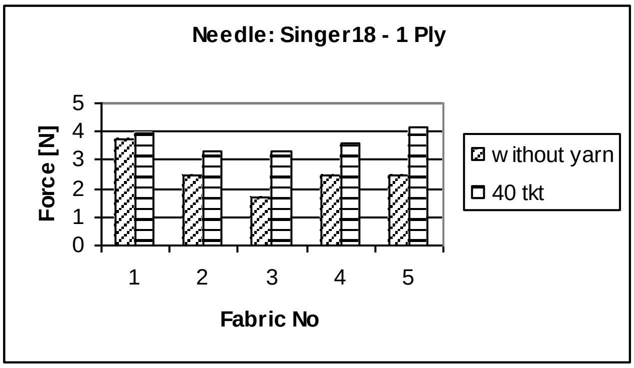


Figure 8.5 Effects of the sewing thread presence according to the needle numbers and fabrics, on the needle penetration forces, for Singer 18 and for 1 ply

As seen in Figure 8.5, for Singer 18 and 1 ply, forces are higher for all fabrics when samples are sewn with the thread. Also, the values are higher than the Singer 16's values, because increasing needle diameter causes increasing frictional force.

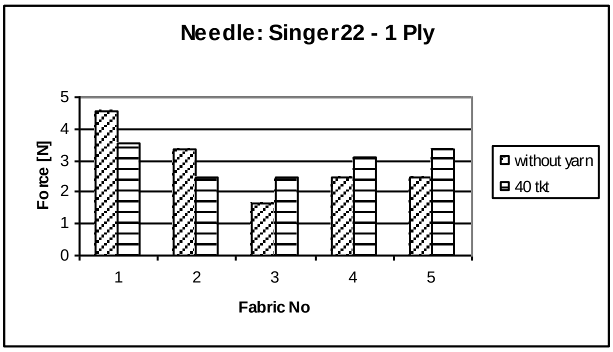


Figure 8.6 Effects of the sewing thread presence according to the needle numbers and fabrics, on the needle penetration forces, for Singer 22 and for 1 ply

As shown in Figure 8.6, for the 1st and 2nd fabrics, the forces seen for the samples sewn without thread are higher than the others. This might be caused because of the changing tension settings. During the study, thread tensions were adjusted according to have a balanced stitch. Tension settings did not remain the same. The reason of the obtaining different values for these five fabrics, which are opposite to the expected results, may be explained like that.

As seen from the figures, sewing threads have a direct influence on needle penetration forces. If there is no sewing thread, than, it means that there is no additional tensional forces coming from the thread to the needle bar, resulting higher penetration forces.

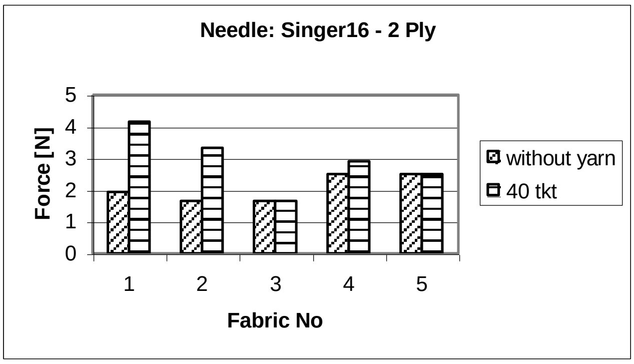


Figure 8.7 Effects of the sewing thread presence according to the needle numbers and fabrics, on the needle penetration forces, for Singer 16 and for 2 ply

As seen from Figure 8.7 for Singer 16 and 2 plies, forces obtained with sewing threads are higher than the others obtained with sewing without the threads. Also, nearly for all samples, forces are higher when compared to the forces of the samples sewn with Singer 16, 1 ply.

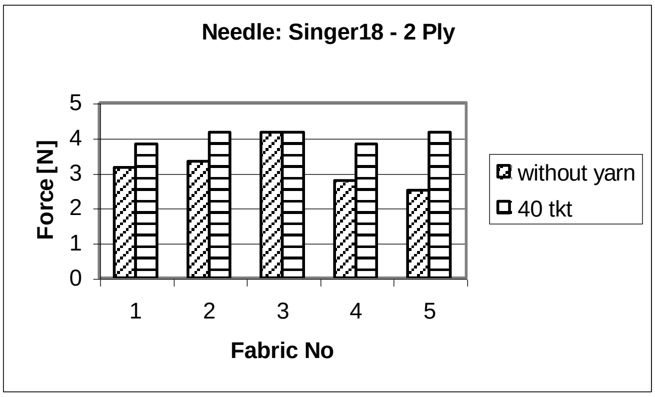


Figure 8.8 Effects of the sewing thread presence according to the needle numbers and fabrics, on the needle penetration forces, for Singer 18 and for 2 ply

As seen from Figure 8.8, forces for Singer 18, 2 ply samples are higher when the thread was used. When compared to the 1 ply values obtained with the same needle number, the forces are higher, as expected.

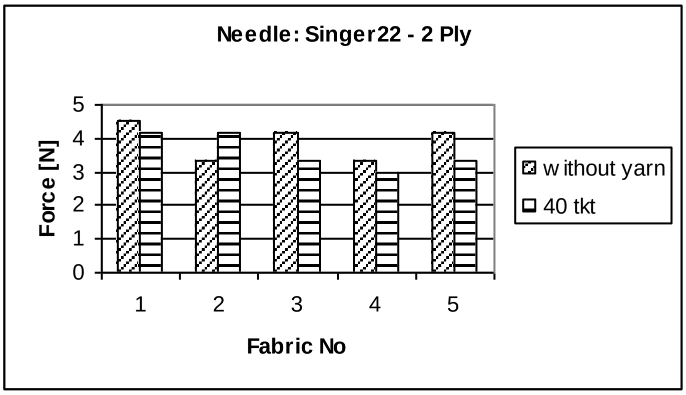


Figure 8.9 Effects of the sewing thread presence according to the needle numbers and fabrics, on the needle penetration forces, for Singer 22 and for 2 ply

As shown in Figure 8.9, there are seen different needle penetration force values for Fabric 1, Fabric 3, Fabric3 and Fabric 5. For them, forces obtained when sewing without thread are higher than the other values obtained when sewing with the thread. This result might have been occurred because of the improper tension settings.

Figures 8.10, Figure 8.11 and Figure 8.12 show the importance of needle thread numbers and their effects on needle penetration forces. Only Fabric 1 and Fabric 4 were compared because it was expected to see slight differences between two fabrics as Fabric 1 has the highest constructional values while Fabric 4 has the lowest values. In the histograms, Fabric No. shown in the horizontal axis are given as 1, which represents Fabric 1 and 2, which represents Fabric 4.

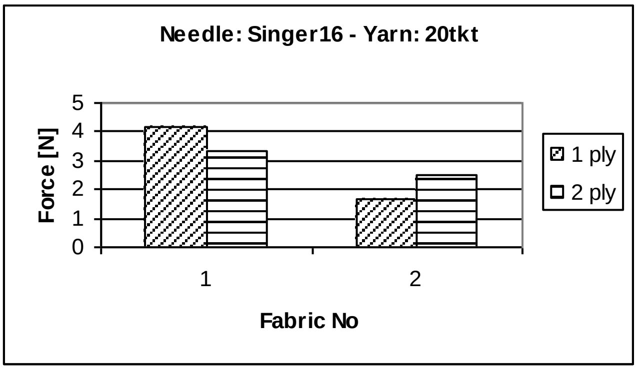


Figure 8.10 Effects of plies on the needle penetration forces, for Singer 16 and for 20 Tkt sewing thread

As seen from Figure 8.10, for Singer 16 and 20 Tkt thread, the penetration forces are higher for Fabric 1 than Fabric 4. Unlike the expectations, Fabric 1's penetration force values obtained for 2 ply are lower than its 1 ply values. This result shows the effect of fabric plies on penetration forces. When compared to the values obtained for 40 Tkt sewing thread, the values obtained for 20 Tkt yarn are nearly the same as shown in Figure 8.1

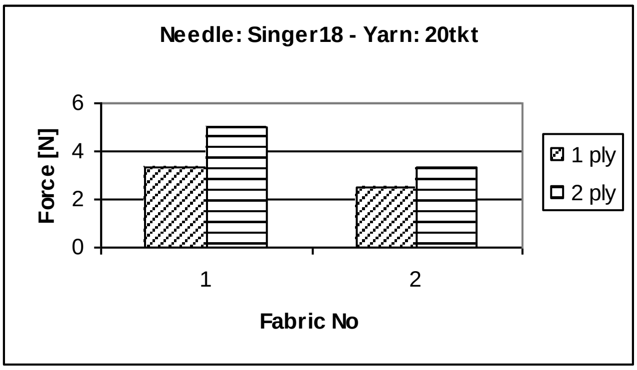


Figure 8.11 Effects of plies on the needle penetration forces, for Singer 18 and for 20 Tkt sewing thread

As seen from Figure 8.11, penetration forces are higher for 2 plied samples than 1 ply samples, for both fabrics. Fabric 1's penetration force values are higher for both situations than Fabric 4's values. When compared to the values seen in Figure 8.2, obtained for 40 Tkt yarns, Fabric 1's penetration force values are higher, as expected, because as needle thread number increases, the forces affected on needle are also increases. For Fabric 4, penetration forces obtained for 20 Tkt yarn are lower than 40 Tkt yarn. Another reason for obtaining unexpected values can be said that, experiments couldn't be repeated enough for 20 Tkt yarn, because of yarn balloon threaten for tearing the strain gauge.

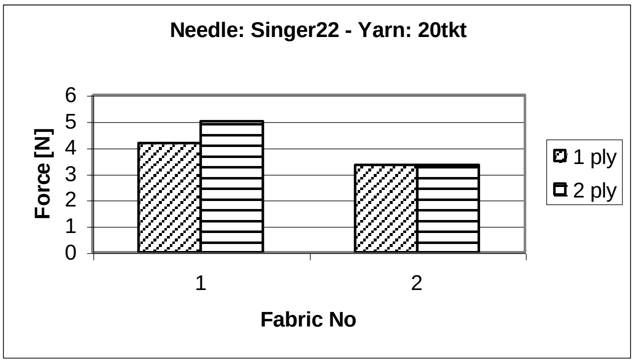


Figure 8.12 Effects of plies on the needle penetration forces, for Singer 22 and for 20 Tkt sewing thread

As shown in Figure 8.12, forces for 2 plied samples are nearly higher than the 1 ply samples. The values are about the same with sewing 40 Tkt for the same needle number.

During the study, it is possible to observe characteristic waveforms obtained from the sensor signals. They are the main parameters to understand the sewing dynamics and will form the database for the future studies. The results obtained during the experiment showed that, these waveforms certainly show the difference between the materials being sewn and the problems occurred during sewing, such as yarn breakage and fabric puckering. Such problems give different signals during the sewing process causing deviations from the characteristic waveforms. These deviations can be observed during the process. These results are in harmony with Rocha et.al.'s results. According to their findings, particular waveforms are characteristics of sewing faults. Carvalho et.al. also found that different needles and materials were detectable. Also, the waveforms obtained for a sewing cycle are similar to the waveforms found by several researchers as Mathews and Little, Mallet and Xu, Carvalho et.al. and Rocha et.al.

It would be helpful to indicate that in the waveform figures, vertical line shows the force values in Newtons and the horizontal line shows the time in seconds. Time intervals are taken from the waveforms at different seconds to reflect the characteristics of the sewing dynamics better.

Figures 8.13, 8.14 and 8.15 are given for Fabric 4 to see the effects of needle numbers and ply differences independent from the fabric construction.

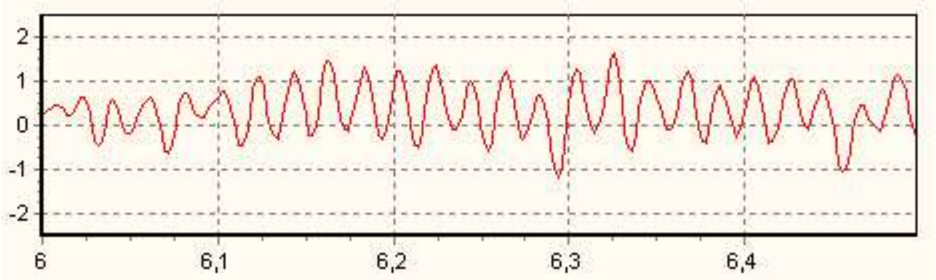


Figure 8.13 Waveforms for 142 coded sample

Figure 8.13 shows the waveforms taken for Singer 16 needle and superimposed sewn Fabric 4. The maximum needle penetration force was measured as 2,4927 N

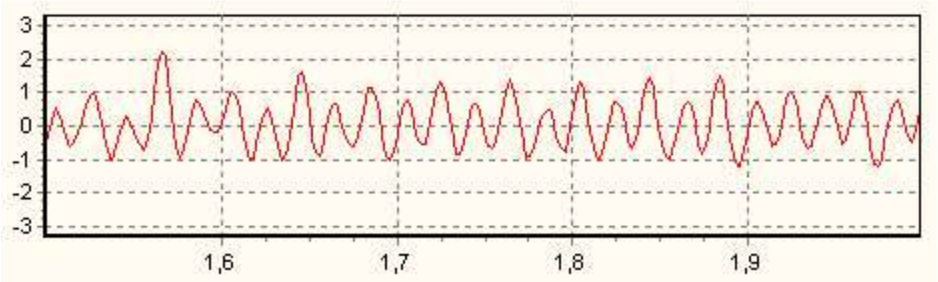


Figure 8.14 Characteristic waveforms for the 342 coded sample

For 342 coded sample, which shows that the Fabric 4 is sewn with Singer 22 with 2 plies, the maximum force was obtained as 3,3237 N. From the Figures 8.13 and 8.14, it can be said that forces are higher for the bigger needle numbers. This result is also evident form the waveforms. 342 coded sample's values reach to the higher value than 142 coded sample.

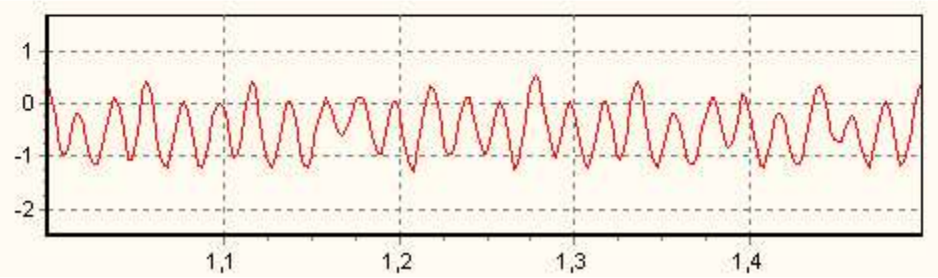


Figure 8.15 Characteristic waveforms for the 341 coded sample

As seen from Figure 8.15, forces are lower than the 342 coded sample. For 341 coded sample, the maximum force was obtained as 1,3848 N. This one ply value is also lower than the value measured when sewing the same fabric with the smallest needle number, Singer 16, in superimposed configuration. This emphasises that, the system established has an ability to detect the ply differences during working. Data gained from this system could be used for making sure all the plies were sewn.

To see the effects of the sewing threads, codes 3111 and codes 311 were compared. The waveforms are shown in Figure 8.16 and Figure 8.17

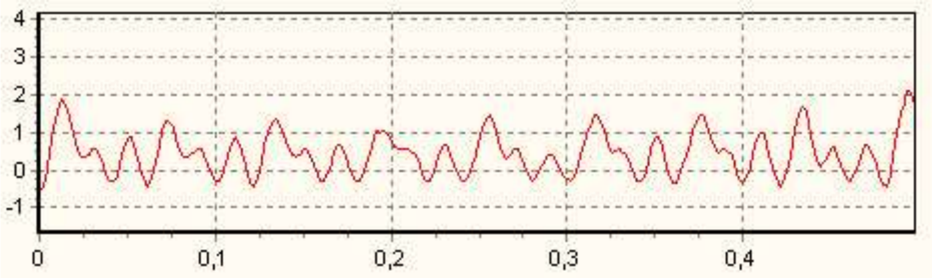


Figure 8.16 Characteristic waveforms for the 3111 coded sample

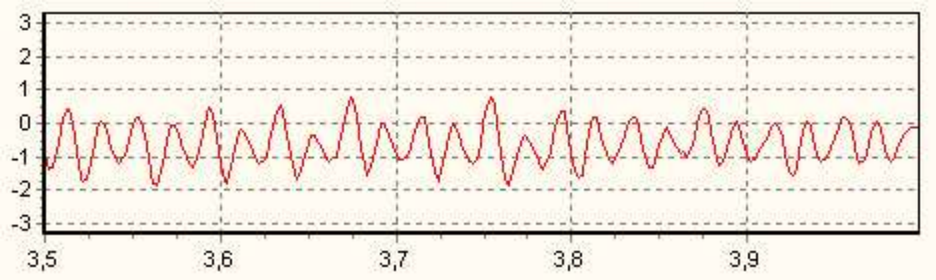


Figure 8.17 Characteristic waveforms for the 311 coded sample

As seen from the Figure 8.16 and Figure 8.17, forces are higher when compared to the forces obtained with the samples sewn without the yarn. For 3111 coded sample, the penetration value was found as 3,5314 N while for the 311 coded sample, it was found as 3,0467 N. Also, different waveforms are seen when using thread, showing the effect of yarn tension on the needle penetration force.

In the following figures, sewing problems occurred during sewing are given and explained step by step.

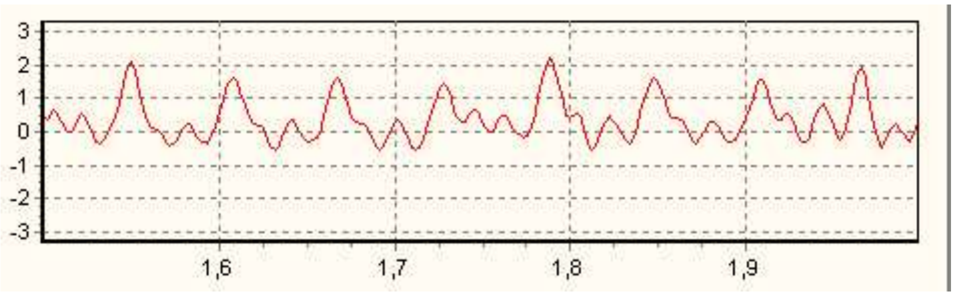


Figure 8.18 Characteristic waveforms for the 2112 coded fabric, in a normal condition

In the Figure 8.18, normal view of the sewing force waves is seen. In Figure 8.19, fabric starts to pucker during sewing and waveforms start to change in 9,8th seconds.

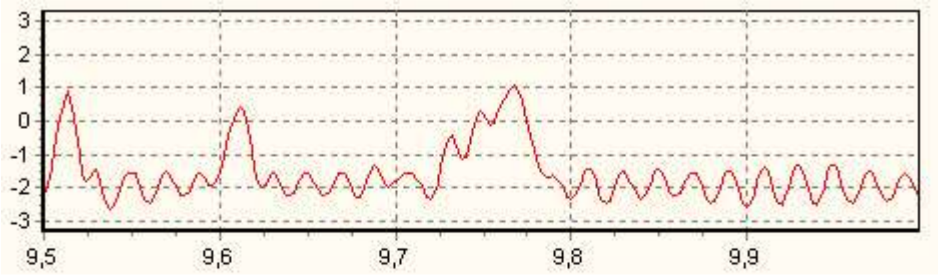


Figure 8.19 ‘Started to puckering’ waveforms for the 2112 coded fabric

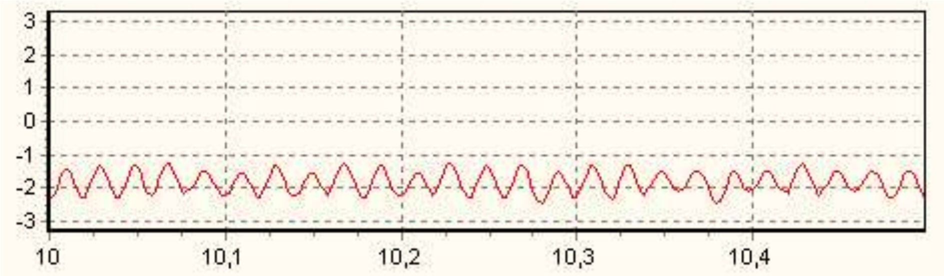


Figure 8.20 Puckered waveforms for the 2112 coded fabric

As seen from the Figure 8.20, fabric puckering occurred and the feed dogs couldn't move the fabric further. So, because the needle continuously enters to the same point, waveforms didn't change and they only represent the inertial forces, not penetration forces.

As will be seen from the Figures 8.21 and 8.22, a broken stitch can be observed during sewing. Figure 8.21 shows the normal stitch waveform, while the other one shows the upper thread breakage occurred after the 7th seconds. Waveforms change instantly in Figure 8.22 when the needle thread breaks.

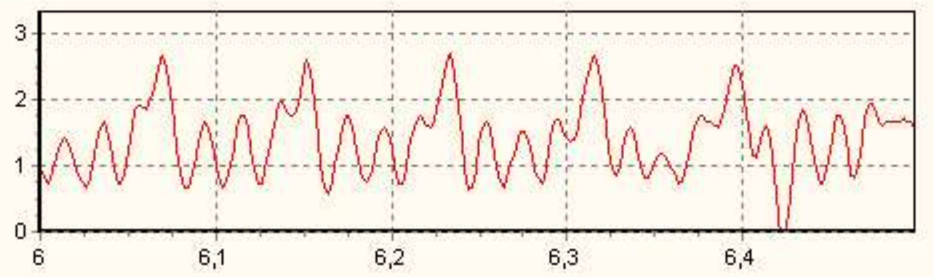


Figure 8.21 Characteristic waveforms for the 1122 coded sample

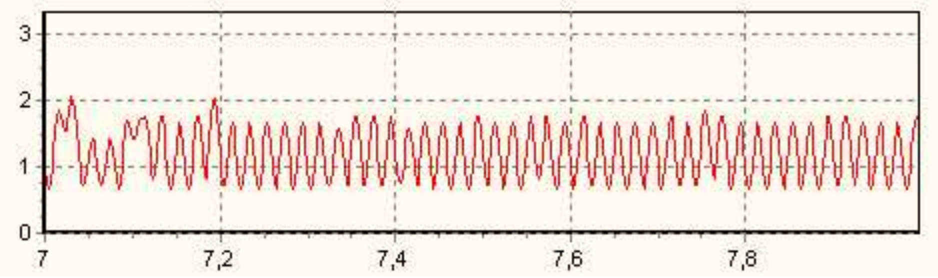


Figure 8.22 Waveforms for the 1122 coded sample, showing the yarn breakage

9. SUGGESTIONS FOR FUTURE STUDY

Results of this study showed that, the established system could recognize the different needle types, seam types and in some situations, different material types. This study is one of the rare studies attempting to monitor the needle penetration forces during lockstitch process and has a different approach to control the sewing process in terms of using different measurement system; unlike the other researches that have been done before.

The following are suggestions for future studies:

- The experiments should be done to see the needle penetration forces' effects when sewing in weft direction.
- Samples should be stone washed to see if there would be any damage seen after the washing process. The relationship between the needle penetration forces and the needle damage should be investigated.
- Different types of fabrics, woven or knitted fabrics, should be sewn in order to collect data to modify this system to an intelligent sewing system by using fuzzy logic algorithms.

KAYNAKLAR

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CURRICULUM VITAE

Fatma Baytar was born in Bulgaria in 1978. She graduated from Kocaeli Körfez Science High School in 1995 and from Uludag University, Textile Engineering Department in 2000. After her graduation, she continued her education in İstanbul Technical University, Textile Engineering Department and also started her academic career in the same year. She is still a research assistant in I.T.U