ABSTRACT

THAVAMANI, ANITHA. **Interaction of Yarn with Metallic Surfaces**. (Under the guidance of Dr.Oxenham, William)

Accelerated needle wear when using rotor spun yarn rather than ring spun yarn is an unresolved problem faced by the knitting industry. Rotor spun yarn provides numerous advantages; but the economic disadvantage caused in the form of the accelerated needle wear is a great impediment to its popularity. Various unsuccessful attempts have been made to find the reason behind this phenomenon. Many parameters like yarn twist, yarn count, wax levels were considered by other researchers and were found not to influence the accelerated needle wear.

The main objective of the study was to find the parameters that essentially contributed to the increased abrasiveness of the rotor spun yarn over ring spun yarn when they interacted with different metallic surfaces. The following aspects were studied: the tension variations of the yarns while passing over different metallic surfaces, the changes in resistance across the metallic wires when the yarns pass over them, the temperature differences observed on the metallic wire, caused by friction between the yarn and the metallic wire. An analysis of the experimental findings is presented.

INTERACTION OF YARN WITH METALLIC SURFACES

By

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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

Raleigh

2003

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BIOGRAPHY

The author, Anitha, is the second daughter born to Mr.Thavamani and Mrs.Naga on January 8, 1977, in Madurai, India. She was married to Mr.Illangovan on April 27, 2001 and had her child, Daryl Nathaniel, on April 1, 2003.

She received her Bachelor of Science degree in Home Science from Fatima College an autonomous institution affiliated to Madurai Kamaraj University. She was awarded Junior Research Fellowship from Indian Council of Agricultural Research (ICAR). As an ICAR nominee, she completed her Master of Science degree in Home Science with a Textiles and Clothing concentration. Her masters thesis was on the 'Effect of Laundry Blue and Optical Brightening Agents on Cotton Fabrics'. The results were published as an article 'Effect of Whitening Agents on Cotton Fabrics' in The Indian Textile Journal, May 2000. After working as a part time lecturer for a few months, she was accepted in North Carolina State University and went on to pursue a second masters in Textile and Apparel, Technology and Management. While she was working on her masters program, she worked as a research assistant under Dr. William Oxenham.

ACKNOWLEDGEMENTS

Glory and praise be to God for enabling me to complete my thesis.

My heart fills with gratitude to Dr. William Oxenham for all the guidance and support he gave me throughout the course of this program at NCSU. He was very approachable and always had answers to my questions.

I am thankful to Dr.Pam-Banks Lee, who has shown me the way of education in USA, hers being one of the first courses I took in my masters program. She was a very caring person and helped me as a committee member in my research work.

I would like to extend my thanks to Dr. Timothy Clapp, who accepted to be in my committee. He was a helpful person with kind words and encouragement. I am glad to have hadthis remarkable committee of excellent persons.

I fondly remember all the teachers and my friends who helped me in my progress towards the completion of my masters program. Last but not the least I would like to remember my family for all their support; My husband who accompanied me and stood by my side always; my father who got me going for higher studies; my mother who was my guide and ever supportive with her counsel; my sisters and brother who were ready with words of encouragement when needed; my uncle who directed me in this direction towards pursuing higher studies in the US; my cousins who were my prayer partners and my baby who was calm and quiet in the womb and also after birth, letting me carry on my work to completion.

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CHAPTER I

1 INTRODUCTION

Interaction of yarns with metallic surfaces is a complex phenomenon, which is affected by many factors like friction, tension, the angle of contact and the fields created around the point of contact. When a yarn passes over a metallic surface, either it gets abraded or it abrades the metallic surface, which is an undesirable effect causing wear of machine parts. The knitting industry has been facing this problem, in the form of excessive wear of knitting needles, sinkers and cams, since the introduction of rotor spun yarns into mainstream production.

Rotor spinning evolved as a breakthrough in yarn production technology approximately three decades back when ring spinning was the conventional method of yarn production. Rotor spinning had some advantages over the conventional ring spinning in that it eliminated the winding process. This was a great advantage as it was found that 50% of the knitting stops were related to winding. The large packages of rotor spun yarn with reduced materials handling job helps a lot in knitting industry (Alterman, 1985). Even in the quality of the knitted fabric, rotor spun yarns being more even produced even fabric and proved to be better in many respects. Overall, knittability, knitting machine stops, and fabric appearance of rotor spun yarn were favorable. When comparing the two systems, it was found that in some properties, the ring spun yarns still reign supreme and in others, the rotor spun yarns prove to be advantageous. Hyrenbach et al (2002) found that the rotor yarn offered a clear advantage in terms of physical characteristics and yarn character as seen from Table 1.1

Table 1.1 Comparison between rotor and ring spun yarn (Hyrenbach et al, 2002)

Physical Characteristics		Yarn character	
Utilization coefficient	-	Yarn evenness	+
Breaking strength	-	Slubs and thin areas	+
V% breaking strength	+	Hairiness (less)	+
Stretch	=	Volume (Higher)	+
Shrinkage	=	Fiber intimate blend	+
Fastness to chafing	+		

\- Rotor spun yarn is not better than ring spun yarn
= Rotor spun yarn and ring spun yarn are similar
\+ Rotor spun yarn is better than ring spun yarn

Due to the production of continuous lengths of unspliced rotor yarn on larger packages yarn breakages in knitting were tremendously decreased. The number of defects in rotor spun yarn was reduced up to 80 per cent (Brown, 1986). Rotor spun yarn offered wide yarn count ranges, without sacrificing profitability and yarn quality. It had enhanced textile-physical properties, to accommodate the ever-increasing performance demands of downstream processing. It had less strength variations than ring spun yarn. Due to the surface characteristics and the stable nature of the yarn the fabric knitted from rotor spun yarn has little or no tendency to spiral when slitting open the knitted tube (H.Ernst, 1993). It had a very low degree of hairiness and a good surface resistance (Prof.Dr. -Ing.habil, 1997). Rotor spun yarns have good abrasion resistance as the wrapping fibers on the surface acted as a protective layer against frictional stress.

The unresolved problem that persisted over the advantages of rotor spun yarn was the excessive wear of machine parts when using rotor spun yarns as compared to using ring spun yarn. There are many theories and reasons proposed for this phenomenon but no concrete answers. Some of the unsubstantiated causes attributed to the increased abrasiveness of rotor spun yarn are as follows:

- Knitting machine variables such as needle timing, dial height, machine speed etc
- Higher level of contamination (microdust) in rotor spun yarn
- Lower waxing levels on the rotor spun yarns
- Higher yarn stiffness
- Higher yarn tension
- Wrapper fibers on the yarn
- Presence of short fibers
- Needle composition

1.1 Need for the study

Rotor and ring spun yarns are essentially differentiated by the spinning method, which results in a completely different yarn structure (as shown in Fig 1.1), an important performance parameter. Structures of rotor and ring spun yarns being very different at the surface bring into consideration the surface phenomena like friction, tension, temperature generation and the electrostatic forces, which leave a marked impression on the surfaces that come in contact with the unwanted outcome of abrasion of the surfaces involved. By studying these conditions of abrasion, it may be possible to keep the negative attributes of abrasion at a minimum. In the knitting industry, reducing the frequency of needle changing, which at present is high due to excessive abrasion, can bring about a large saving in the cost of new needles. Furthermore, the labor for changing the needle and the down time that is involved in needle changing can also be reduced.

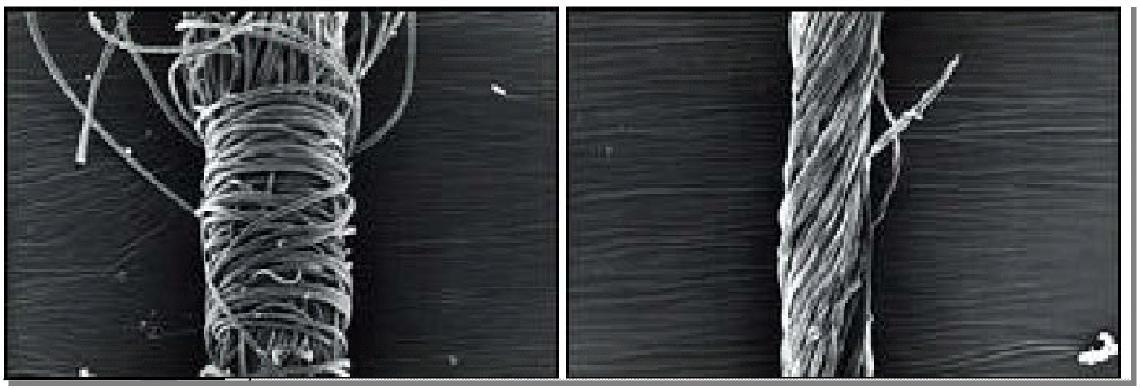

Figure 1.1 Yarn structure comparison (Jones.J, 2002)

1.2 Scope of the study

The focus of this study is the claimed excessive abrasiveness of the rotor spun yarn over the ring spun yarn. This phenomenon is seemingly related to the following factors, which are surface characteristics related to yarn structure:

- Tension buildup caused by the wrapper fibers
- Coefficient of friction between the yarn and different metallic surfaces
- Electrostatic forces between the yarn and the metallic surface
- Temperature increase at the point of contact

The study was organized to observe the changes in the yarn and the changes in the metallic wire. Tension variation in the yarn before and after the frictional interaction was monitored to enable determination of the effect of the wrapper fibers in tension buildup on the yarn. Moreover, the data collected was analyzed to find the coefficient of friction between the yarn and different metallic wires. Electrostatic force generated at the point of contact was noted as shown by the change in resistance of the metallic wire in order to study its contribution to the increased needle wear caused by the rotor spun yarn. The temperature differences of the metallic wires were observed using a contact and a non-contact temperature probe to see if they were differentiated between the rotor and ring spun yarns. The observations were studied in detail using appropriate statistical methods to make calculated inferences.

1.3 Objectives

The main objective of this study was to find the parameters that essentially contributed to the abrasive nature of the rotor spun yarn over ring spun yarn when they interacted with different metallic surfaces. This major objective was expected to be achieved with the following specific objectives:

1. To analyze the tension variations and coefficient of friction of the yarns while passing over different metallic surfaces.
2. To study the changes in resistance across the metallic wires when the yarns pass over them.
3. To study the temperature differences observed on the metallic wire, caused by friction between the yarn and the metallic wire.

CHAPTER II

2 REVIEW OF LITERATURE

Many studies have been undertaken considering the great implications of the problem of accelerated needle wear. In this chapter some of the significant works on accelerated needle wear are discussed along with the solutions proposed to overcome this problem. Other literatures that help in understanding the current work are also presented.

2.1 Significant research works on accelerated needle wear

2.1.1 Steve Ward's findings

Steve Ward (1986), a graduate student, examined the knitting needles at various stages of wear under the scanning electron microscope and found that as the number of knitted courses increased wear on both the hook tips and the corresponding latch spoons increased. As the knitting proceeded the width of the hook decreased and the probability of the latch missing the hook tip increased, thus forming a fabric defect (Little et al, 1986). At early stages of wear, it was suspected that the dust particles contributed to the wear. The contaminants become attached or entrapped in the latch spoon and the knitting action combined with the latch-closing forces during loop knock-over caused the wear as shown in figures 2.2 and 2.4. As the knitting proceeded, the saw slot, latch seat and the back of the latch spoon also became affected and wore out. The preliminary findings indicated that oiling and cleaning frequencies could affect needle life. It was thus suggested that the oiling and cleaning frequency be optimized to extend the needle life.

Figure 2.1 New Hook

Figure 2.2 Worn Hook

Figure 2.3 New Latch

Figure 2.4 Worn Latch

(http://gbu.groz-beckert.com/gbu/gbu_default_e.asp)

2.1.2 Eric Bryan's findings

Eric Bryan (1999) had the yarns spun using different spinning systems and tested the ring and rotor spun yarns for their abrasive effect on copper wire. The set up was facilitated using Constant Tension Transport machine produced by Lawson-Hemphill. He concluded that overall there was insignificant difference in the abrasion characteristics of ring spun and rotor spun yarns. In cases where there was any difference, the ring spun yarn was slightly more abrasive than rotor spun yarn. He also tested the effect of twist, wax, rotor-speed, and found the following:

- Abrasiveness decreased with higher twists in ring spun yarns
- Increase in wax levels did not affect abrasiveness

- Rotor yarns produced with higher rotor speeds were more abrasive
- Ring spun yarn that was produced from dirty cotton was more abrasive
- Excessive amount of fall out was seen when using ring spun yarn
- Finer yarns were more abrasive than the coarser ones
- Lower twist levels resulted in more abrasion

He concluded that the abrasiveness depended on the fiber quality. He couldn't find any correlation between the yarn structure and abrasiveness. He failed to provide any explanation for the claimed increased abrasiveness of rotorspun yarns, over ring spun yarns, in the knitting industry.

2.1.3 Jeremy Jones's findings

In his master's thesis, Jeremy Jones (2001) continued the earlier work on the abrasion characteristics of ring spun and open-end yarns. However, unlike Bryan who assessed attrition by length of yarn needed to cut through a copper wire, Jones assessed the attrition by observing the damage to the copper wire after a preset length of yarn had passed over it. He found that open-end spun yarn produced slightly more attrition than ring spun yarn. For both open-end and ring spun yarns, those of lower yarn counts resulted in increased attrition. The level of yarn twist had almost no influence on yarn abrasion. In his study, the most abrasive yarn type was 30Ne open-end yarn and the least abrasive yarn was 20Ne ring spun yarn. The results did not yield any general trend relating to twist. The greatest gradient in the abrasion of knitting needles appeared to exist when the yarns contained unequal levels of impurities. Level of abrasion was not significantly different between yarn types, counts, and twists. This was due to the fact that the abrasion level of the yarns varied no more than 10% between the least and the greatest.

Fiber mobility was suggested to be the possible cause for increased abrasiveness of rotor spun yarn. The open-end yarn structure allowed lower fiber mobility and hence wore an abrasion region on the wire that widened as the yarn count increased. Conversely, ring spun yarn that had greater fiber mobility, resulting in a similar abrasion width as the yarn count varied. The ring spun yarn fanned out (figure 2.5) giving a greater surface area of contact while passing over the wire, which decreased the force per unit area of the wire. The lower level of stress on the wire was suggested to be the cause for lower attrition by ring spun yarn.

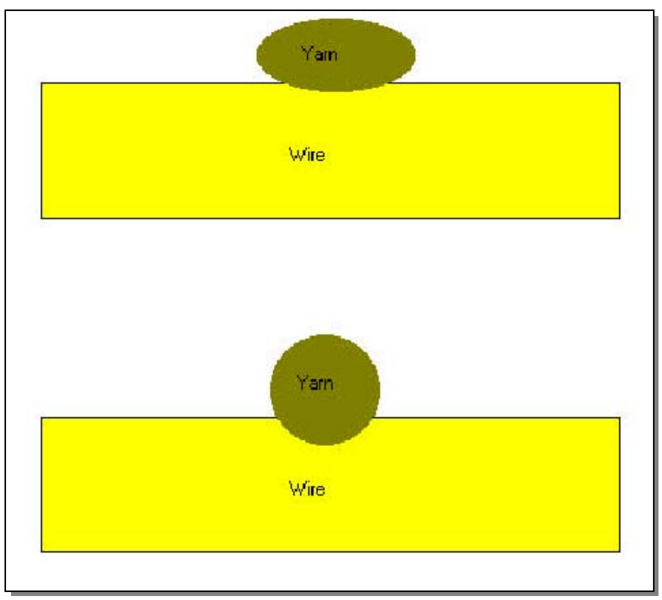

Figure 2.5 Sketch to compare abrasion with yarns of different fiber mobility (Jones, 2001)

2.1.4 Groz-Beckert's findings

Some yarns spun from synthetic fibers that contain matting agents such as titanium dioxide can induce needle wear. Cotton fibers containing foreign particles exhibit a similar effect. Depending on where they are cultivated, the harvesting method, weather conditions and gin treatment cotton fibers can contain varying amounts of impurity. Some cotton is contaminated by sand and dust, which is not eliminated by the preparations for spinning and during the subsequent processes these contaminants result in the wear of machine parts. The marked influence of the contaminants can be seen from the graph in figure 2.6.

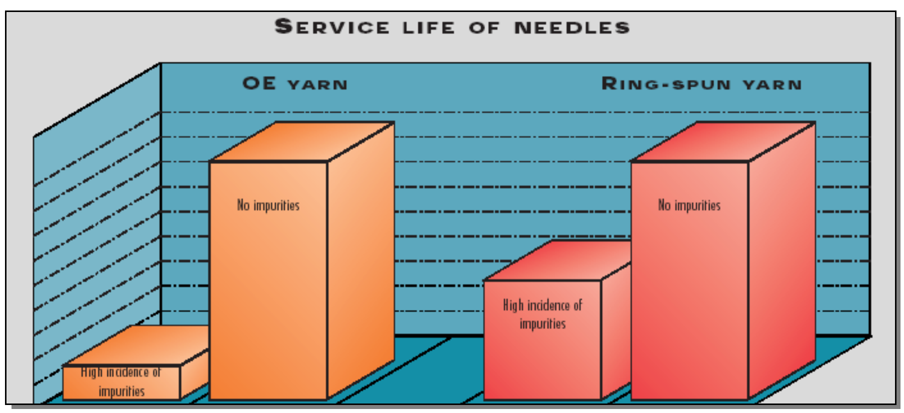

Figure 2.6 Effect of contaminants (http://gbu.groz-beckert.com/gbu/gbu_default_e.asp)

According to Groz-Beckert (1995), these abrasive particles end up between the moving parts of the knitting needle producing a grinding effect on them. The grinding effect joins the abrasive grains with a bonding agent to form a cohesive mass, which is moved over a surface. Such abraded needle will have grooves as seen in figure 2.7, which shows the abrasion on the side of the needle.

Figure 2.7 Abraded needle (http://gbu.groz-beckert.com/gbu/gbu_default_e.asp)

Another reason pointed out for the abrasive nature of the rotor-spun yarns was the belts of fiber found in the structure of the rotor spun yarn. The untidy lengthways and crossways fiber pattern with wrapping fibers was thought to favor greater transverse vibration of the needle and unsteady needle action. Moreover, rotor spun yarn was thought to exert greater friction on the needle causing a higher contact pressure on the needle, which could accelerate needle wear. On the other hand, the fiber pattern of the ring spun yarn being smooth and parallel was presumed to cause less marked transverse vibration leading to lesser needle wear. However, this has not been shown experimentally.

2.2 Solutions Attempted

Many solutions were sought to reduce the problem of wear of knitting needles. One of the proposed solutions is to modify the knitting needle to make a lighter latch so that it can not only move faster but also not damage the hook as before. These are named as High Speed Heads. The lightweight latch is expected to facilitate high-speed knitting and is technically called the Primm latch (figure 2.9). The Primm latch replaces the regular latch (figure 2.8) in many high-speed knitting applications. The latch is made thinner and lighter by moving the spoon of the regular latch onto the hook tip, which allows the latch to knit at increased speeds. However, this solution doesn't solve the problem of accelerated needle wear.

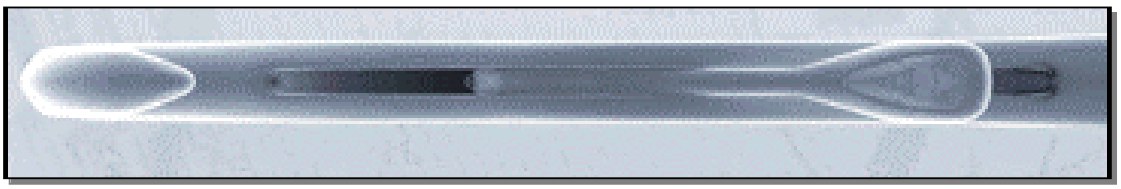

Figure 2.8 Regular Latch (http://www.exeltor.com/an/knitting/index.php)

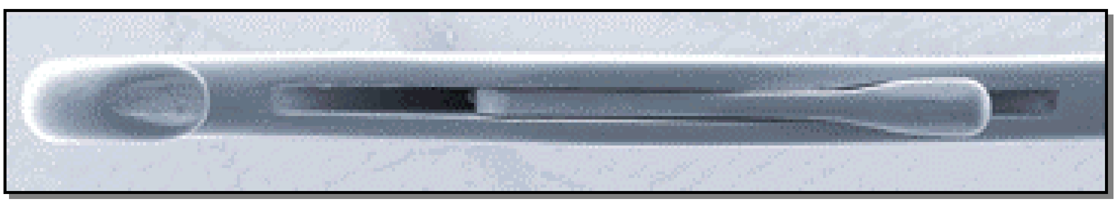

Figure 2.9 Primm Latch (http://www.exeltor.com/an/knitting/index.php)

Apart from modifying the latch, the extent of polish was increased to decrease abrasion. Mirror polish inside the hook was expected to prevent yarn breakage and filamentation during knitting. The interior of the hook was polished by an exclusive Exeltor process, which resulted in a perfectly smooth surface (figure 2.11). This process was expected to eliminate yarn breakage and filamentation from the moment the needles start knitting. This could not be an apt solution for accelerated needle wear.

Figure 2.10 Without Polish (http://www.exeltor.com/an/knitting/index.php)

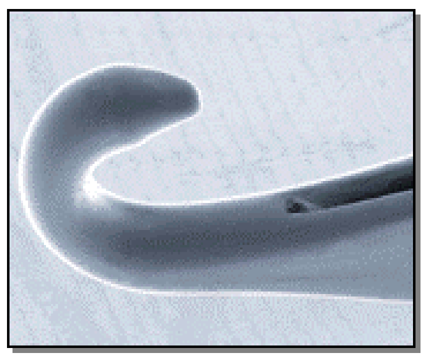

Figure 2.11 With Exeltor Exclusive Polish

(http://www.exeltor.com/an/knitting/index.php)

During loop-formation, the tension was found to cause some problems. So, modifications were introduced to significantly reduced tension. The Yarn Tension Release Notch (figure 2.12) was developed to solve the problems related with splitting yarn filaments by the latch and unwanted tuck stitches. The notch allowed the latch standing to be lowered which results in an easier castoff while maintaining the same clearance underneath the latch. This could reduce loop deformation, which enabled the needles to withstand the stresses caused by high-speed knitting. Additionally, the notch delayed the closing of the latch sufficiently to minimize the latch scissoring the new yarn. An added advantage that the Yarn Tension Release Notch provided is that the inherent reduction in tension during loop formation also created less lint and so helped to prevent many problems associated with lint buildup but did not help accelerated needle wear.

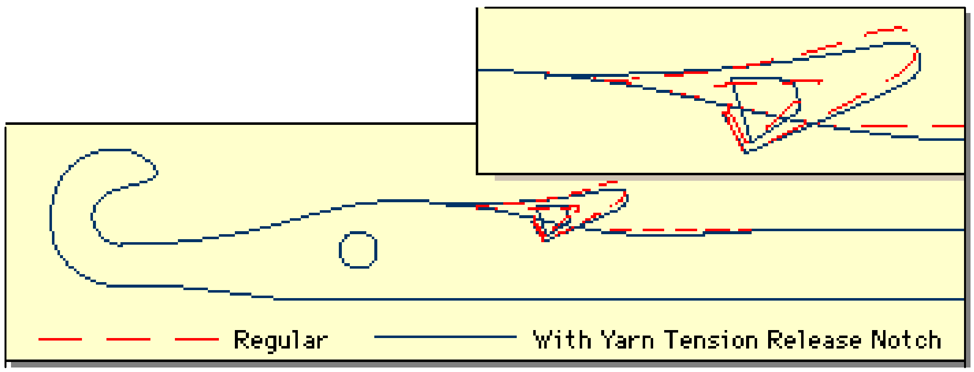

Figure 2.12 Needle with yarn tension release notch

(http://www.exeltor.com/an/knitting/index.php)

Wear resistant needle production was also tried to decrease the problem of accelerated wear. It was assumed that improved needle wear resistance was directly related to raw material and heat treatment methods. Exeltor worked closely with raw material suppliers in developing optimal steel alloy and heat treatment combinations to ensure highly wear resistant needles. Thus, the quest for a solution continues without any clear solution. Unless the cause for accelerated needle wear is clearly established, it would be difficult to reach the correct solution.

2.3 Studies on Yarn structure

The abrasive effect of yarn is a property based on the surface characteristics of the yarn. The differences in the structure of yarns could affect the abrasiveness significantly. Hence, it was deemed important to look into the studies on the differences in the yarn structure of ring spun and rotor spun yarn. Some of the observed differences in the characteristics and properties of the yarns could be attributed to the differences in the yarn structure if this were well understood. The microscopic view of the yarn shows that the ring spun and rotor spun yarns have significantly different yarn structure. A ring spun yarn may be characterized as an assembly of helically arranged, will aligned fibers with a hairy surface while a rotor spun yarn is an assemble of disorderly arranged twisted fibers. The ring spun yarns have uniform twisted structure while the rotor spun yarns have belts (tightly wrapped perpendicularly disposed fibers) distributed along the length of the yarn.

The belts present in the yarn significantly contribute to the strength of the yarn. It was noticed that the yarns produced from smaller rotor have significantly improved yarn strength. The presence of the tighter belts on the surface of the yarns, produced by smaller rotor has contributed into the greater fiber cohesion and friction inside the yarn body with the other factors such as twist levels. These properties in turn have influenced the yarn strength in a favorable way. Increasing the fibers length and twist level is usually accompanied by an increase in the frequencies and sizes of the belts. Larger rotor was found to produce yarns with less wrapper fibers than a smaller one. Furthermore, longer fibers are likely to build tighter belts than the shorter fibers whereas the rotor size and the twist level greatly affect the configuration of the belts, besides their effects on their sizes and density (Ibrahim, 1980).

2.4 Studies on Abrasion Resistance of yarns

Barella and Manich (1989) compared the abrasion resistance of ring spun and rotor spun yarns and found that the rotor spun yarns have better abrasion resistance than the ring spun yarn. The abrasion resistance was found to be dependent on the twist and the linear density. Higher linear density and higher twist had better abrasion resistance. A later study of ring-spun and rotor open-end-spun yarns by Offermann (1997) confirmed that, compared to ring yarns, rotor yarns have a much better abrasion resistance.

According to Chand, abrasion resistance of yarn depends on the type of fiber, yarn structure and yarn thickness. Moreover, he proposes that the abrasion resistance of rotor spun yarns must be lower than that of the ring spun yarn due to the poor wrapping of the fibers in the outer layer of the rotor spun yarn while the contrary is true (Chand, 1995). He argues that poorly integrated surface fibers will be easily plucked out during abrasion leading to poor abrasion resistance.

The effect of the rotor size on the open-end fabric abrasion resistance was found to be inconsistent with regard to the type of fiber used. The discrepancy, which was observed for the smaller rotor with the shorter fiber, was thought to be possibly due to fabric deformation, but more probably due to the presence of excessive loose belts on the surface of that particular yarn. However, both the yarn abrasion and the fabric abrasion results are dependent on the testing method as well as the mechanisms of the abrasion itself. It was shown that though the direct or indirect influence of the wrapper fibers cannot be determined, they play a significant role in terms of the rotor spun yarns abrasion resistance as well as the other properties.

2.5 Studies on Yarn Friction

The yarns spun from different systems usually differ in their structural characteristics. Friction being a surface phenomenon, it is expected that any difference in the surface structure of yarns will also be reflected in their frictional behavior. Hence, a comparative study of the frictional behavior of yarns spun on different spinning systems using the same fiber was done by Chattopadhyay et al (1996). It was found that the increase in twist lead to a reduction in frictional force of both ring and rotor spun yarns. The ring spun yarn was found to have a higher frictional force on running over a guide than that of the rotor spun yarns made of cotton fibers. It was also noticed that the finer yarns had a higher level of friction than coarser yarns. Nevertheless, it is assumed that the belts being perpendicularly disposed could enhance friction.

According to El Gaiar and Cusick, the abrasion resistance is higher for yarns with lower coefficient of friction and for combinations of high coefficient of friction the abrasion resistance is low. In contrast, Subramaniam et al (1987) found that the abrasion resistance is low for lower coefficient of friction and higher for higher coefficient of friction. The reason suggested is that when the friction is high, the cohesion is high owing to the smooth surface presented on the yarn.

Jeddi and Sheikhzadeh (1994) found no general correlation between the properties of abrasion resistance and friction of yarn. Any possible relation between yarn abrasion resistance and yarn friction was therefore attributed to external factors. The yarn abrasion resistance was found to increase as yarn friction decreased. Experiments confirmed that abrasion resistance increased as yarn twist increased. For the yarns with low twist, at the first stage abrasion caused elongation in the yarn and then, owing to slippage of fibers, they were ruptured. In cases of high twist the yarn rupture occured because of fiber damage (Jeddi, 1994). In this study friction between the abradant and the yarn was estimated by the relation between the input and output tensions (T_2/T_1).

Yuksekkaya (1999) in his doctoral thesis remarks that the basic method to measure the yarn friction is the Capstan method. If the coefficient of friction is constant, the basic equation ($T_2=T_1e^{\mu\theta}$) may be used to calculate μ. Lawson and Hemphill has designed an instrument - Yarn friction tester that gives a direct reading of the coefficient of friction based on the capstan method.

2.6 Studies on tension

Djordjevic and Gligorijevic (2002) studied the yarn tension in the compensational and knitting zones of flat weft cotton machines. The yarn tension forces depended upon yarn features, the yarn tension input, the coefficient of friction between the yarn and the knitting elements, the weft depth, the resilience of the knitted fabric and other factors. In the knitting zone, yarn tension was found to be one of the most important parameters. When the yarn was in direct contact with the loop forming elements yarn tension increased continually upto a certain maximum value. The oscillations in the knitted fabric dimensions could be avoided by maintaining a constant input tension. This could also probably throw some light on the accelerated needle wear.

2.7 Summary

From the literature review, we know that there are some factors that do not have any influence on the abrasiveness of rotor spun yarn like twist, count, speed of yarn and wax levels but there are some that have been shown to have some effect like the presence of contaminants and the yarn type. However, there is still no specific reason suggested for the increased needle wear. It is possible that there is a combined effect of some parameters, which does not show up when we test them individually. There are few other factors, which have not been considered and tested for their influence on the accelerated wear of knitting needles.

Table 2.1 Effect of different parameters on accelerated needle wear

S.No	Parameters	Effect
1	Yarn type	No significant difference
2	Yarn structure	No significant difference
3	Wax level	No significant difference
4	Speed	No significant difference
5	Count	No significant difference
6	Twist	No significant difference
7	Abrasive particles on the yarn surface	Significant

In general, the properties that influence the surface characteristics could influence the abrasiveness of the yarn. Some of the untested properties that are affected by the surface characteristics of the yarn are the tension buildup due to friction, temperature, and thickness of the abradant and metal type.

CHAPTER III

3 MATERIALS AND METHODS

The experiments were planned in accordance with the main objective of this study, which is to find the parameters that essentially contributed to the excessive abrasive nature of rotor spun yarn over ring spun yarn when they interacted with different metallic surfaces.

The specific objectives were expected to be achieved by analyzing the tension variations, by studying the changes in resistance across the metallic wires and by observing the change in temperature of the wires during abrasion. The observations on the yarns for tension variations and those on the metallic wires for changes in resistance and temperature were done separately.

3.1 Materials Used

In any research, the materials used have a decisive role in the results obtained and the inferences reached. Hence, careful attention has been given to the selection of materials used in this research work. The following materials were used: –

- Instruments
    - Lawson Hemphill Constant Tension Transport
    - Enka Tecknica Tensiometer
    - Fluke rms digital multimeter

- Software
    - Labview
    - FVF – SC 2
    - Statistical Softwares
- Yarns
    - Rotor spun yarn
    - Ring spun yarn
    - Synthetic yarns
- Metallic wires
    - Copper
    - Lead
    - Brass
    - Needle

3.1.1 Instruments:

Importance of measurements and measuring instruments can never be understated, since the precision and reliability of the instruments are crucial to any successful experimentation. To arrive at proper inferences the right measurements have to be taken using the right instruments. With this in mind, the instruments used in this research were selected after careful consideration. The information about the instruments used, their suitability to this research and the reasons for selecting them are discussed in this section.

3.1.1.1 Lawson Hemphill's Constant Tension Transport (CTT)

The CTT, developed by Lawson-Hemphill Inc (USA), is a dynamic yarn transport system with the ability to maintain a specific yarn tension and let the yarn run at any selected speed up to 360 m/min. It simulates the product performance in the testing laboratory and reduces the need to test products in the production line. This is one of the advantages utilized in this research work. Instead of testing the wear of knitting needles in the knitting machines, metallic wires were used in CTT to simulate the abrasive effect of the yarn on the knitting needles.

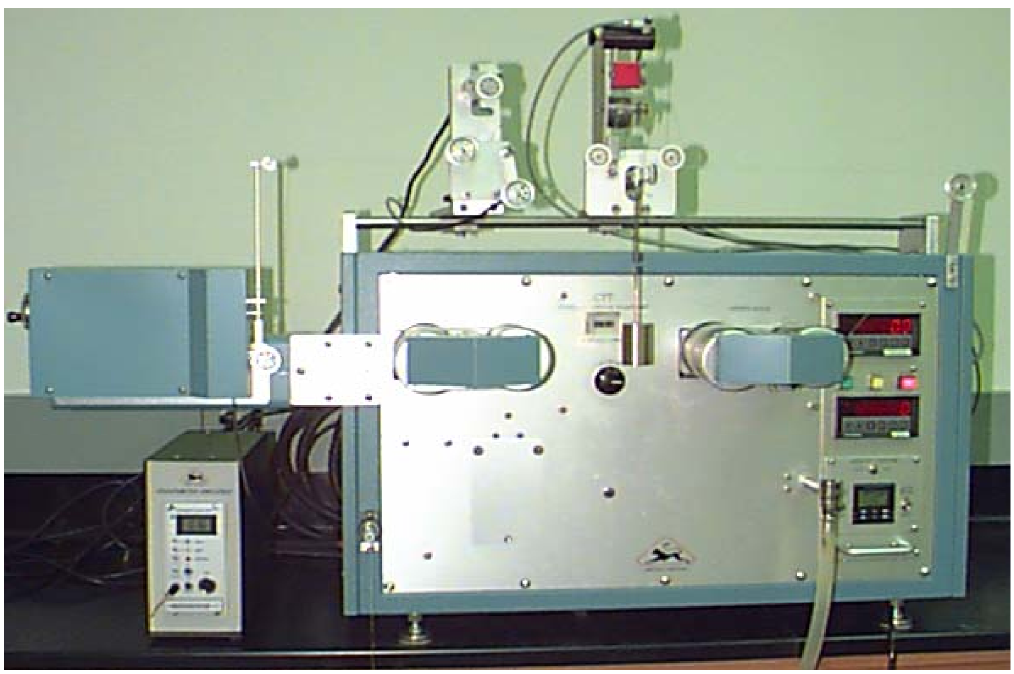

Figure 3.1 CTT Basic Unit with Abrasion Attachment

Constant tension maintenance in CTT eliminates the tension variation of the yarn coming off the package and helps to proceed with the tests at specific input tension. The tension control unit of the CTT is shown in Fig 3.2. It has a tension control box and a tension arm. The unit comes with three different tension arms for different tension range requirements between 0.5g and 700g. In this experiment tension arm #2 with the tension range between 10-350 gms and an accuracy of ± 0.2 gms was used.

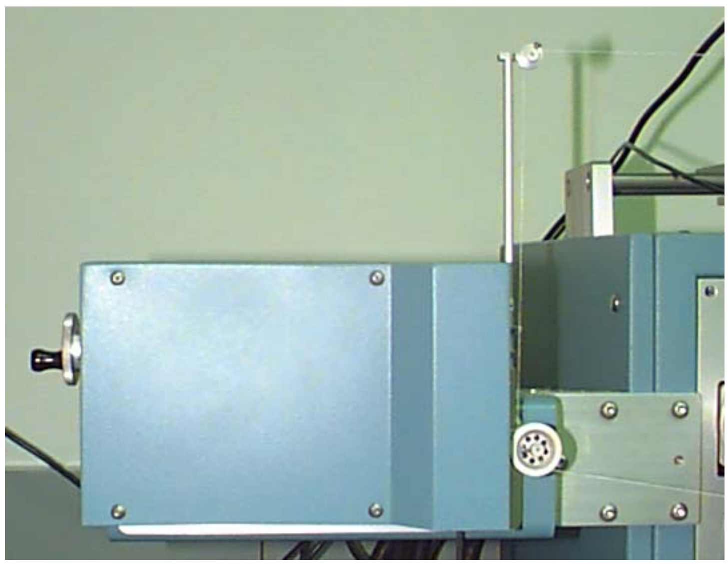

Figure 3.2 Tension Control Unit

The versatility of CTT allows for modification and change of accessories in order to run many different tests from a single basic unit. Any measuring head or testing apparatus can be mounted on the basic unit and inserted into the constant tension zone. Hence in this research, the accessory for abrasion testing was mounted on CTT and set to abrade a metallic wire in the constant tension zone. The required measurements were made on the abrading yarn and the abraded wire using other instruments like Enka Tecknica's High Frequency Tensiometer and Fluke digital multimeter respectively.

3.1.1.2 High Frequency Tensiometer

The Enka Tecnica's Tenstec is a high frequency tensiometer with a natural frequency of 14kHz. This tension-measuring unit comprises of a high frequency measuring transducer (figure 3.3), an evaluation unit and a charging unit (figure 3.4). The measuring head with its tension sensor can measure even the slightest variations in the yarn tension. Moreover, the sensor is insensitive to the interfering vibrations caused by the machines.

Figure 3.3 Measuring Head with Tension sensor

The tensiometer was capable of measuring up to 4000 readings per second. These readings were recorded as tension values in a text file using an interfase with the computer. The data collection was facilitated using LabView® software.

Figure 3.4 Enka Tecnica Tensiometer charging Unit

3.1.1.3 Fluke digital multimeter

In this research, Fluke True RMS Digital Multimeter Model 189 (figure 3.5), a hand held meter with enhanced performance, was used to take required measurements on the wire. It had a rotary switch, which gave an option of utilizing different functions as required. Hence, the changes in the resistance of the wire and the temperature changes were measured using the same instrument with different accessories. The accessories mainly used in this research work were as follows: -

- Test leads (Figure 3.6)
- Crocodile clips (Figure 3.7)
- Non-contact temperature probe (Figure 3.8)

Figure 3.5 Fluke Digital Multimeter

The readings taken can be logged in the meter's memory and retrieved. The average reading for each logging interval can be viewed on the meter's display. The logging interval can be set according to the user's convenience. A scheduled logging interval may contain stable and unstable logged readings. The meter also stores the high, low and average value for each set of stable and unstable logged readings. The logged readings can also be transferred to a computer using the Fluke View Forms software. Apart from using the test leads to find the temperature of the wire by contact method, an infrared temperature probe was also used to measure the temperature differences by non-contact method.

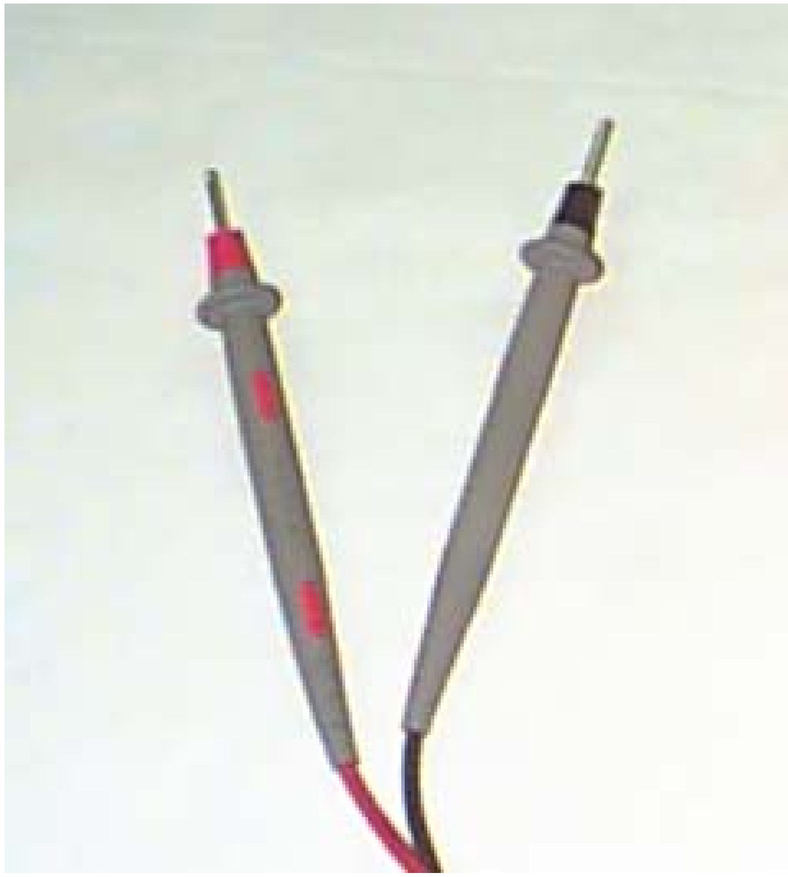

Figure 3.6 Test leads for Fluke digital multimeter

Figure 3.7 Crocodile clips

Figure 3.8 Non-Contact Temperature Probe

3.1.2 Software

3.1.2.1 Lab View

LABVIEW is software developed by National instruments as a graphical tool for instrumentation and measurement. This software enables specification of system functionality by assembling block diagrams (figure 3.10). The programmed code in the block diagram can be activated using a specifically designed control panel (figure 3.9).

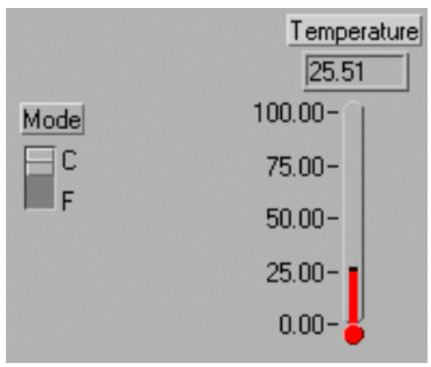

Figure 3.9 Example of LabView Control Panel

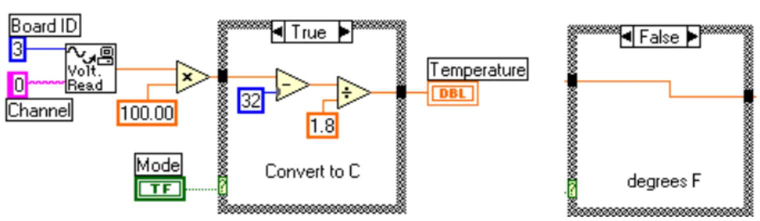

Figure 3.10 Example of LabView Block diagram

3.1.2.2 Fluke View Forms SC2

The FVF SC2 software is exclusive software designed to log and download data from Fluke multimeter to a PC. It can acquire and document readings from supported digital meters through IR serial communication. The readings logged in the digital multimeter can be accessed only using the Fluke View Forms. Some of the readings can be accessed using a PC running the Fluke View Forms software. It displayed the data in graphical form (figure 3.11). The contents of the meter can be transferred to the computer's memory using IR communication link.

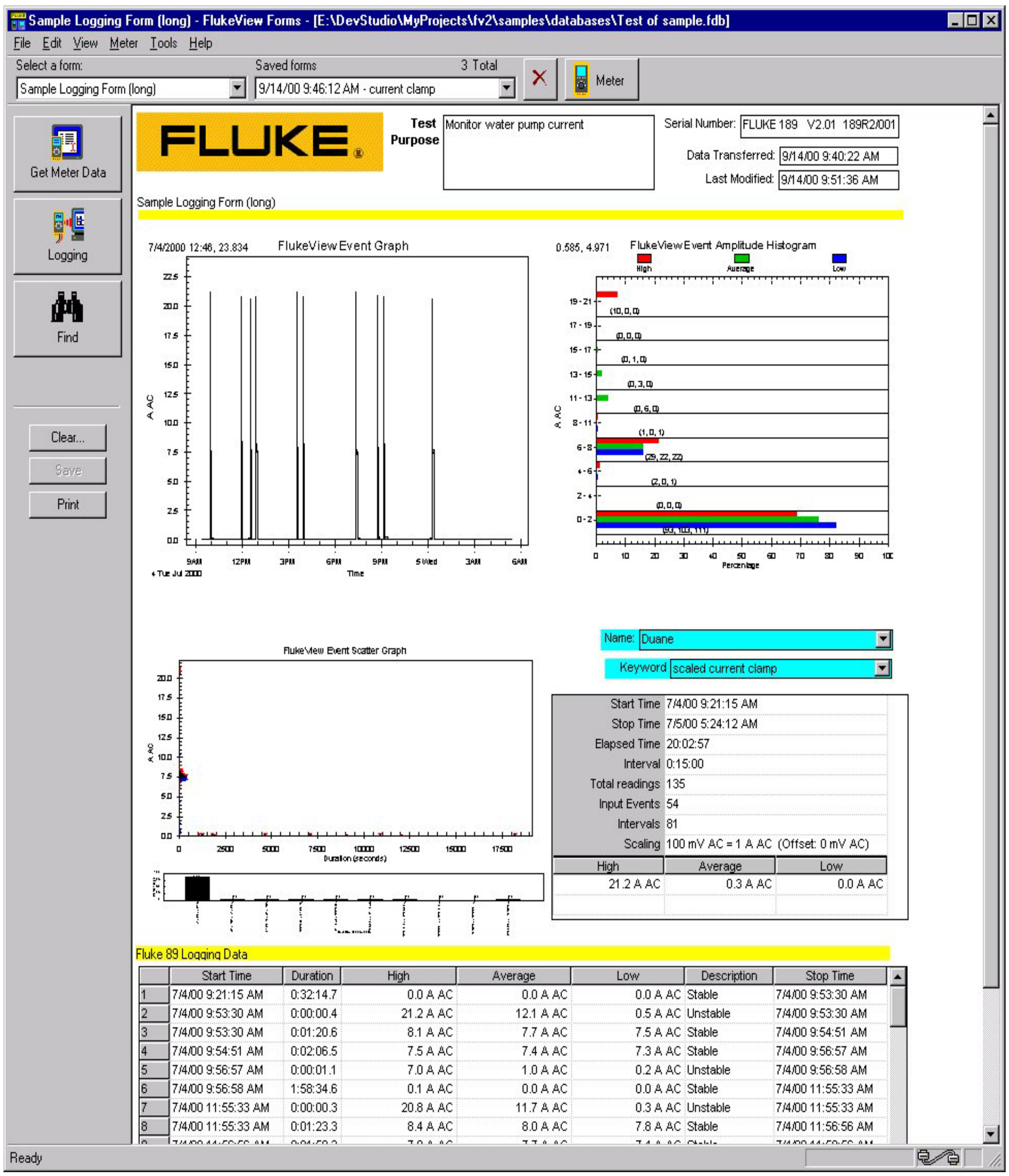

Figure 3.11 Example of Fluke View Forms Display

3.1.2.3 Statistical Software

Matlab and Excel are the softwares that were used for data analysis. Matlab is an integrated technical computing environment that combines numeric computation, advanced graphics and visualization, and a high-level programming. In this work, it was used to analyze the data and find the periodicity of the tension values. Periodicity was necessary to determine if there was any specific bumping action caused by the presence of belts along the surface of the rotor yarn. Excel was used to manage the data and find the statistical information associated with the data.

3.1.3 Yarns

In finding the tension buildup on the yarn after passing over the metallic wire, 100% cotton yarns were used. Rotor and ring spun yarns of 18s count were used in this research. The yarns chosen were waxed since yarns are used in the knitting machines only after waxing. In measuring the resistance, initially the experiment was designed only to compare the difference between rotor and ring spun yarns of 18s count. Later some synthetic yarns were incorporated into the experimental design to establish the veritability of the resistance measured across the wire. Some of the synthetic yarns were spun while the others were filament yarns and one of them was textured yarn. The yarns referred as black, red and white are polypropylene filament yarns. Texblack is polypropylene filament yarn that had been textured by intermingling. Yarn referred as green in acrylic spun yarn and the yarn referred as spun is polypropylene spun yarn. All the above-mentioned synthetic yarns had similar count as the rotor and ring spun yarns.

3.1.4 Metallic wires

Copper, lead and brass wires of different thickness were used in this research. In finding the tension build up on the yarn, copper and lead wires were used to see if metallic content had any influence on the tension variations. Each of the metallic wire used was of two different diameters. The diameters were comparable to the diameters of the knitting needle hooks suitable for the counts of the yarns used in this experiment. In proceeding with the tests for the resistance across the metallic wire, lead, brass and the knitting needle itself were used.

3.2 Experimental work

The experiments were designed after careful consideration. As there were no suitable standard tests available to be used in this experiment, the tests were refined with preliminary tests and measurements were taken.

In using the CTT, some standard settings were used, which were selected based on the parameters used in earlier research and on the preliminary tests done. The testing standards used for the experiments in this research were as follows: -

Speed of the yarn: The tests done in this research being dynamic, the yarns were threaded and run at 360m/min in the CTT machine. This was the maximum speed possible in the CTT and was chosen because speed had no significant impact on the abrasive effect of yarn and the higher speed allowed for time to do more experiments.

Tension: The tension was set according to the count of the yarn. It was maintained around .5 CN/tex, as this was the standard tension generally used for yarn testing. So the following table of yarn tension in grams corresponding to the yarn counts used was prepared and used to select the suitable tension range for the tests.

Table 2 Tension values according to count

Yarn Count		Tension in gms
In Cotton Count	In Tex	
10s	59	30
20s	30	15
30s	20	10

Weight on wire: In the CTT machine, the wires used in testing were secured at one end, stretched over a pulley and secured at the other end to a lever as shown in figure 3.11. When the wire was cut, the weight hanging on the lever enabled the activation of auto stop mechanism. Suitable weight had to be used on the lever to give support to the wire to keep it straight when the wire is passing over it without stretching it unnecessarily. It was found from the preliminary experiments that a weight of 100 gms for thin wires and 200 gms of weight for thicker wire gave sufficient support to the wire.

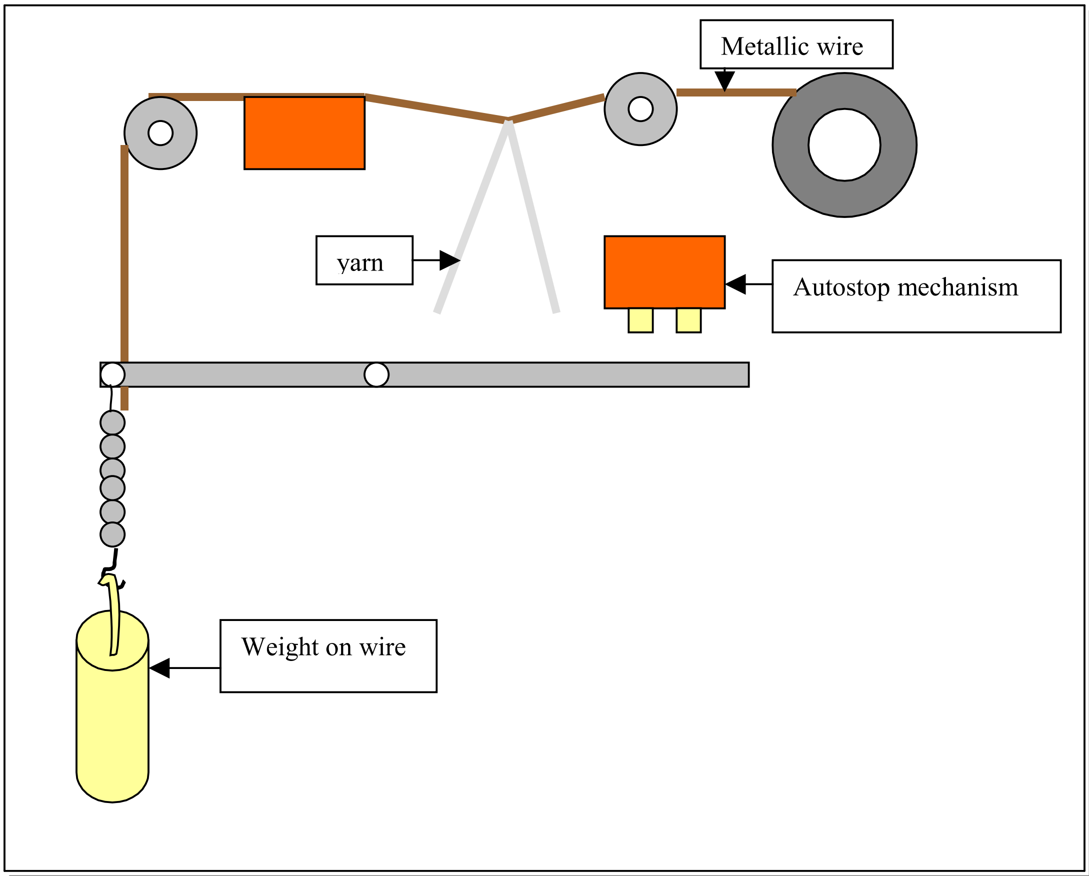

Figure 3.11 Diagram to show the CTT set up of yarn and metallic wire

3.2.1 Test procedures

3.2.1.1 Test to find the tension of the yarn after rubbing over the wire

The CTT machine was set at its standards, the metallic wire was secured, the weight was hung and the yarn was made to run passing over the wire. The tension of the yarn after passing over the wire was measured using the high frequency tensiometer - Enka Tecnica's Tenstec. The readings were directly read into the computer with an interfase and saved as a text file. These values were statistically analyzed using Excel and Matlab.

The experiment was so designed as to find the tension values of the rotor and ring spun yarn on two different thickness of lead and copper wires. Each test was repeated three times for confirmation.

3.2.1.2 Test to find the Resistance across the wire

The CTT machine was used to keep the metallic wire in position for ease of measurement. The wire was secured in its place, the weight was added to the wire, the yarn was placed on the wire and then the machine was run.

Fluke multimeter with the test leads and crocodile clips was used to measure the resistance across the wire. In the earlier tests, the test leads were directly made to touch the wire and measurements were taken. Based on the optimum distance at which the measurements were taken, it was decided to secure the crocodile clips at 1 cm away on either sides of the point of abrasion of the yarn on the wire. This was decided, because at this distance the crocodile clips did not interfere with the passing of the yarn and were sufficiently close to point of abrasion to record the change in resistance caused by the thinning of the wire. Once the set up was ready, the multimeter switch was rotated to point at Ω. The data was logged into the computer using documenting software that reads the value from the multimeter into the computer using an IR logging device. After 5 seconds the CTT machine was started. This practice was followed so that the resistance value of the wire before abrasion could also be documented. The logging was continued for 50 seconds and stopped. It was found from previous trials that the changes in resistance reached a stable level within 30 seconds of running the CTT machine and other changes in resistance were found only at the endpoint. Then the yarn type was changed and the test was repeated. For each condition, the test was repeated ten times. FVF-SC2 software was used to log the real time data. Then the data was transferred to excel sheet and statistically analyzed.

3.2.1.3 Test to find the Temperature of the wire at point of contact during abrasion

The CTT machine was used to hold the wire in position to be abraded by the yarn and the temperature at the point of abrasion was measured using the Fluke multimeter with Temperature probes. The temperature was measured using both contact and non-contact methods. For contact method the test leads were used. The multimeter switch was rotated to point at °C. The test leads were connected and were held as close as possible on either sides of the point of abrasion and the readings in the multimeter was recorded. For the non-contact method, the Infrared temperature probe was used. The rotary switch in the multimeter was rotated to mV dc. The probe switch was switched on and the probe was pointed at the point of abrasion. The probe was taken as close as possible to the wire without disturbing the yarn passage. The reading displayed in the multimeter was recorded.

The experiment was designed to note the temperature change on lead wires of two different diameters when rotor and ring spun yarns were passing over them. The experiment was repeated for ten times and the data was recorded. The recorded data was statistically analyzed to find if there was any significant change in temperature during the abrasion.

CHAPTER IV

4 RESULTS AND DISCUSSION

The data obtained from the tests were analyzed using different statistical methods and the results are presented. The inferences based on the data analysis are discussed in detail.

4.1 Tension on the yarn

From the data obtained using Enka Tenstec Tensiometer, a statistical summary with the mean, standard deviation and coefficient of variation of the values was obtained (Appendix 1). The mean value of the tension on the yarns after passing over the metallic wires was graphically analyzed (figure 4.1). The input tension in the CTT machine was fixed at specific levels suitable to the count of the yarn and hence any difference in the output tension on the yarn after passing over the metallic wire was expected to be the influence of the interaction between the yarn and the metallic wire. From the graph, (figure 4.1) it was observed that the mean tension on the yarn was higher when it passed over copper wire than when it passed over lead wire. More over the mean output tension on the ring spun yarn was higher than that of the rotor spun yarn.

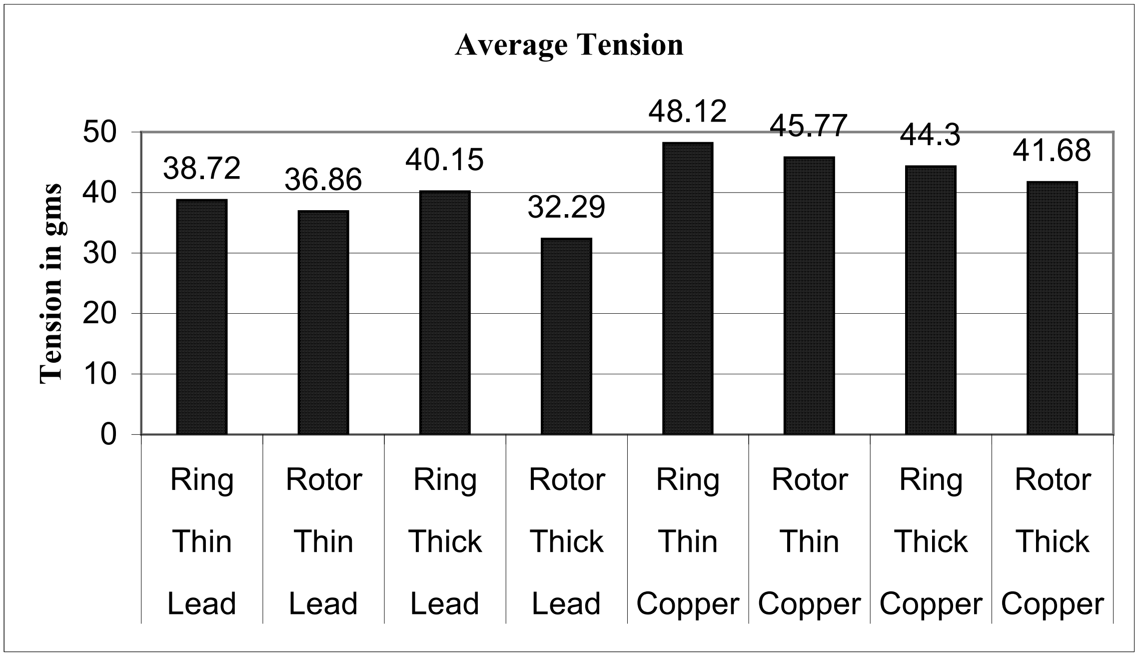

Figure 4.1 Average Tension on the yarns after abrasion

The mean tension values were subjected to ANOVA using excel spreadsheet to check if the differences observed in figure 4.1 were significant. The effect of yarn type, the effect of using different metallic wires, and the effect of the variations in the thickness of the wire on yarn tension were analyzed separately. The averages were used in proceeding with these statistical analyses.

Table 4.1 ANOVA results for mean tension values

Source of variation	**F value**	**P value**	**F critical**	**Significance**
Yarn type	27.90788	0.006158	7.70865	Significant
Metals	18.72815	0.012373	7.70865	Significant
Thickness	80.3282	0.000857	7.70865	Significant

It became obvious from the ANOVA results (Table 4.1) that the differences observed between the yarn types were significant. Rotor spun yarns did have lower mean output tension than ring spun yarns. There was also significant difference in the mean yarn tension when the yarn passed over different metals and different thickness of metallic wires.

The yarns gained more tension when passing over copper wire than while passing over lead wires. The input tension being maintained constant, this significant difference in the output tension could be understood from the Capstan equation [$T_2=T_1e^{\mu\theta}$(figure 4.2)] to show that the coefficient of friction of the yarn with the different metallic wires was significantly different. The results further showed that the coefficient of friction of the yarn with the copper wire was higher than the coefficient of friction of the yarns with lead wire as the tension was higher on the yarn after abrasion with the copper wire than after abrasion with the lead wire.

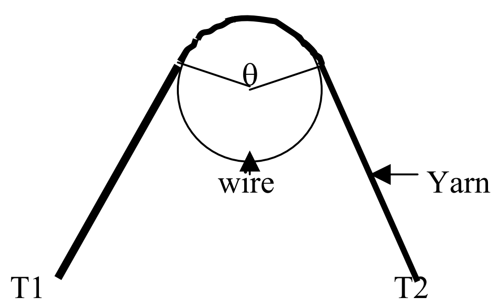

Figure 4.2 Sketch to show the symbols in capstan equation

Tension was found to be higher when passing over thinner wires than while passing over thicker wire. This statistically significant difference might be due to the effect of the angle of contact that the yarn makes with the wire while passing over it.

For further analysis, the tension values recorded by the tensiometer were plotted in a graph using MS Excel and the general trace of the tension was observed. From the graph (figure 4.3 and 4.4), it was seen that the trace of rotor spun yarn tension was rugged. On observing the trace of the ring spun yarn tension, (figure 4.5 and 4.6) an almost constant mean tension value was seen with a slight downward trend. It was of interest to note that the trace of tension was different for the rotor and ring spun yarns.

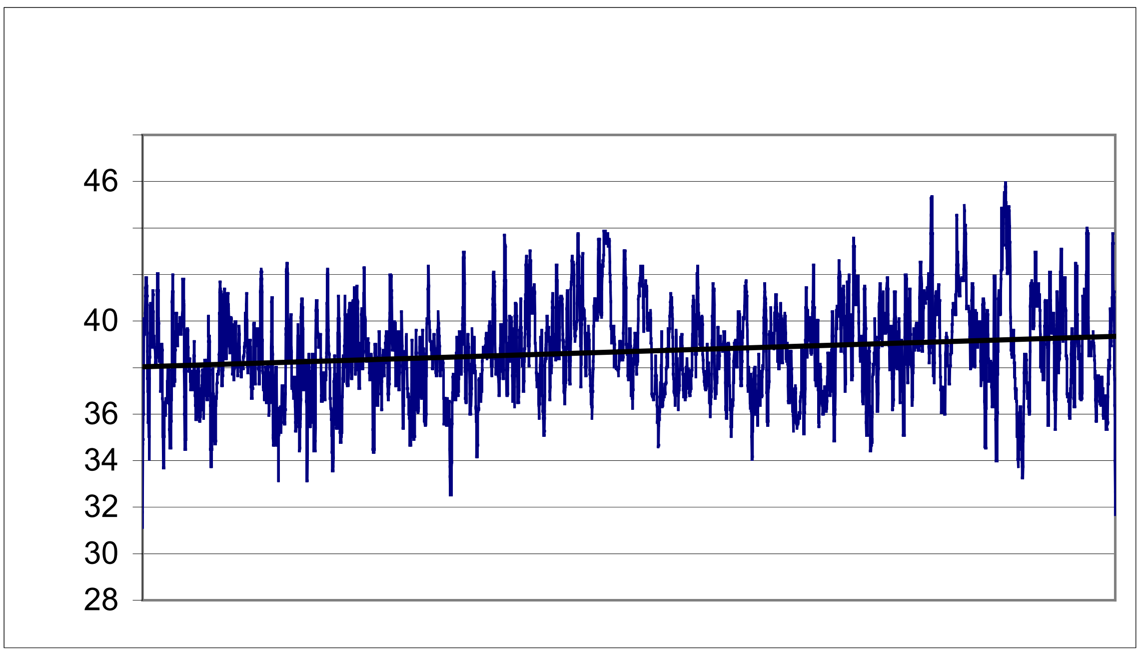

Figure 4.3 Trace of tension on rotor spun yarn after passing over thin lead wire

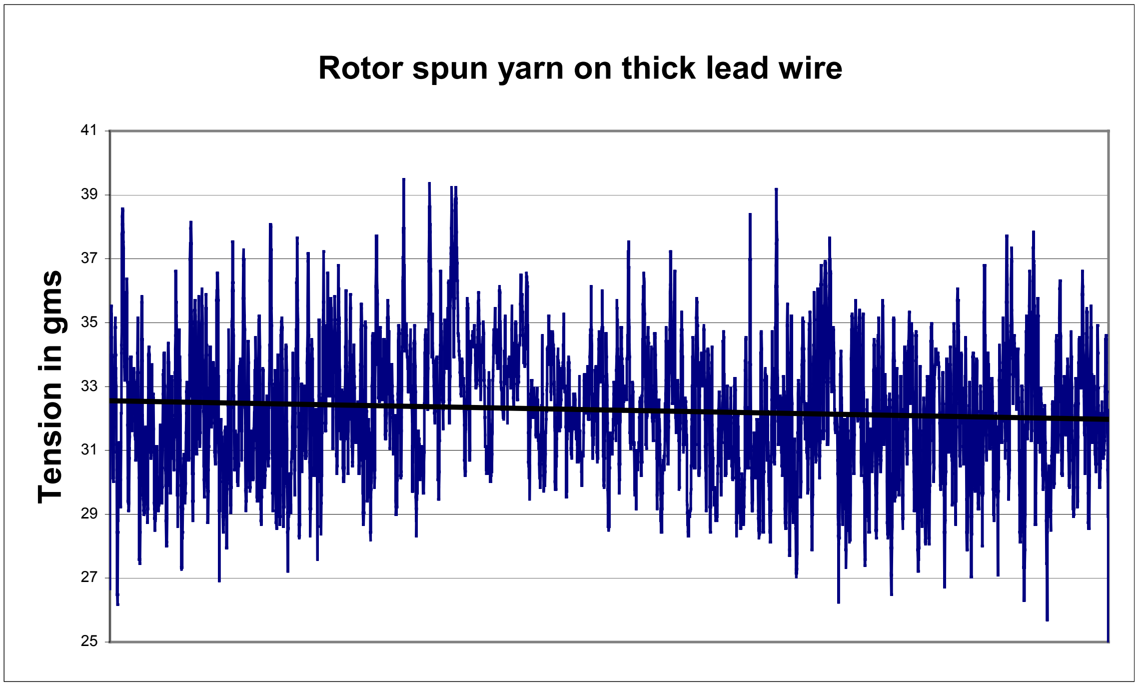

Figure 4.4 Trace of tension on rotor spun yarn after passing over thick lead wire

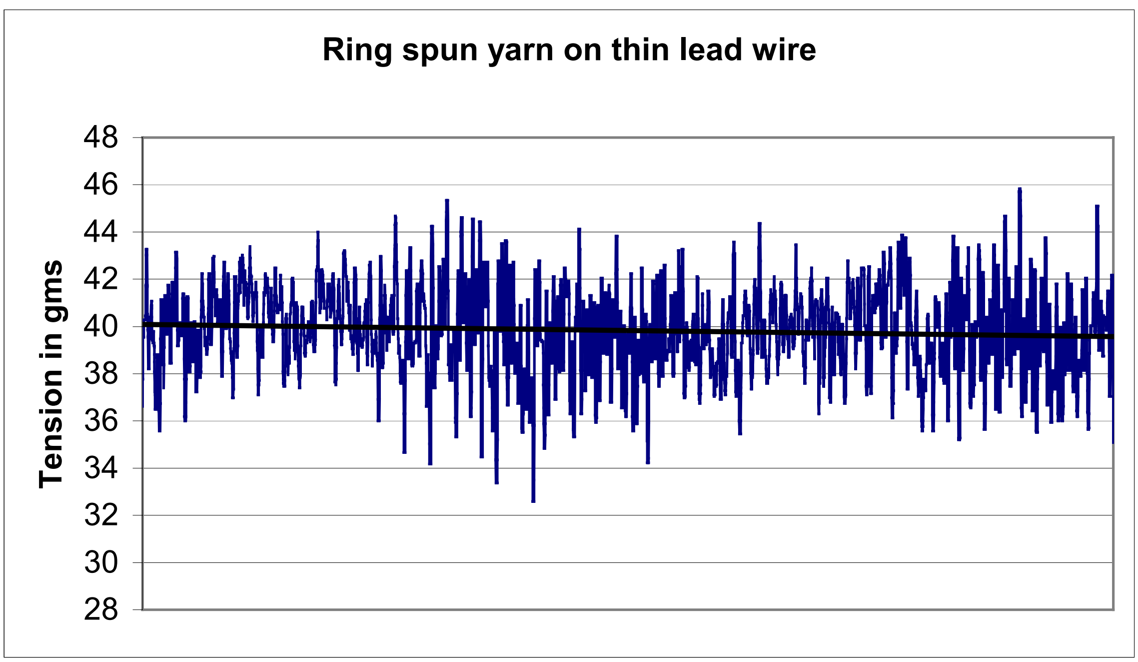

Figure 4.5 Trace of tension on ring spun yarn after passing over thin lead wire

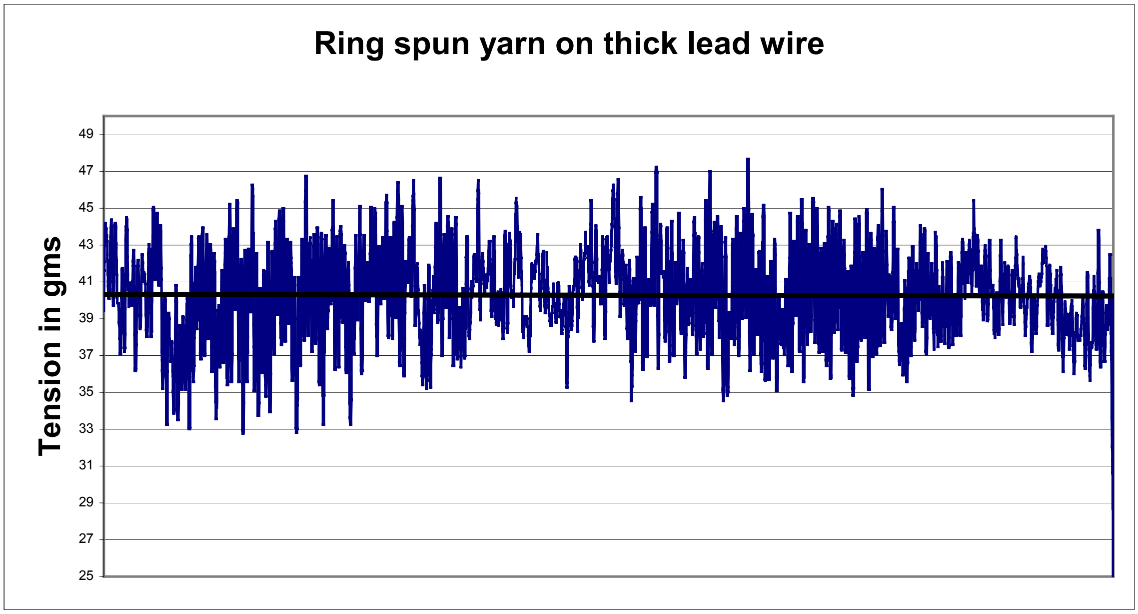

Figure 4.6 Trace of tension on ring spun yarn after passing over thick lead wire

The graph had too many data points to show a clear trend. Hence moving average of thousand values of the tension data was calculated using excel spread sheet. The moving averages thus obtained were plotted in a graph and were analyzed.

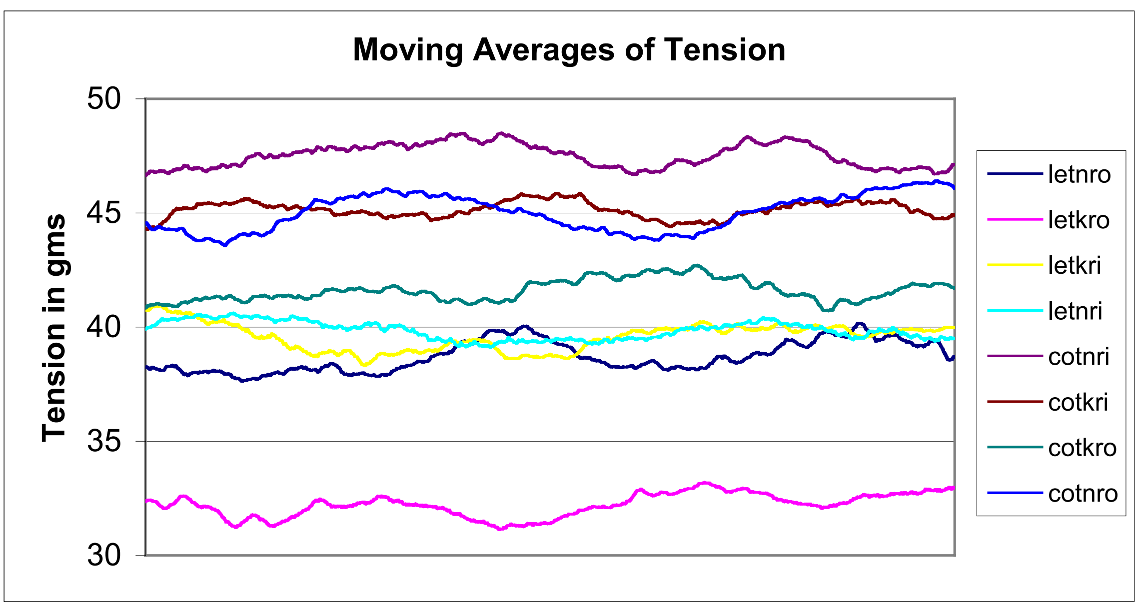

Figure 4.7 Moving Averages of Tension

(The names used in the legend are formed with the metal type + metal thickness + yarn type. So letnro means lead wire + thin + rotor spun yarn and cotkri means copper wire + thick + ring spun yarn. Co = copper wire, Le = lead wire, tk = thick wire, tn = thin wire, ro = rotor spun yarn, ri = ring spun yarn.)

On observing the trend in the graph (figure 4.7) with moving averages, there appeared to be some form of sinusoidal function. Hence, it was deemed important to determine if any cyclic regularity existed in the yarn tension values. The data was transformed using Fast Fourier Transformation. MATLAB statistical software was used to find the period (i.e. the time span before a particular value is repeated in a sinusoidal function). The periodicity obtained for each condition in thousandth of a second was calculated as the distance between the noted readings on the yarn.

The high frequency of the tensiometer allowed recording of 1000 readings per second. The CTT machine was run at a speed of 360m/min. Hence, six meters of yarn was sensed by the tensiometer in one second. Readings were taken at every .6cm of yarn. The time duration for the cyclic repetition of the sinusoidal curves in thousandth of a second were plotted in a graph (figure 4.8) and compared. The values are given in Appendix II.

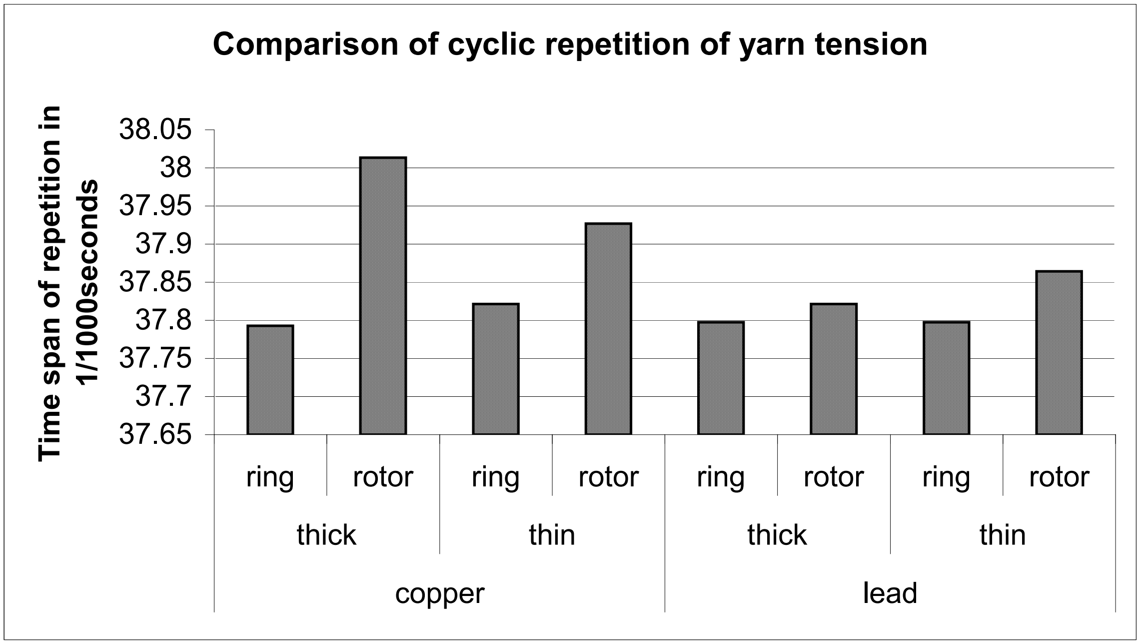

Figure 4.8 Cyclic repetitions of tension values

It was found that the rotor spun yarns had a longer time cycle before being repeated than the ring spun yarns (figure 4.7). The effect was more pronounced when using copper wire than while using lead wire. The thickness of the wires used did not influence the periodicity of the tension values significantly (Table 4.2). Though the results of the tests show significant difference statistically, the differences in the actual period of repetition of tension values do not seem to be high enough to be significant in practical applications.

Table 4.2 ANOVA results for time span of repetition

Source of variation	**F value**	**P value**	**F critical**	**Significance**
Yarn type	24.15171	0.007961	7.70865	Significant
Metals	10.41349	0.032067	7.70865	Significant
Thickness	0.032995	0.864694	7.70865	Not significant

From observing the graphs and the tables, it was obvious that though the actual cycle of repetition calculated for the tension data does not show much difference, the differences are significant statistically. The rotor spun yarn had a higher repetitive cycle than the ring spun yarn showing that the structural irregularities do have an effect on the tension values.

The metal type does not have any significant influence on the cycle of repetition of the yarn tension while the thickness has some significant effect. Hence, choice of the right gauge of knitting needles according to the count of the yarn run on the knitting machine can significantly affect the tension variations, which might influence accelerated needle wear.

4.2 Resistance across the wire

In order to study the pattern of accelerated wear of the knitting needles, the resistance across the wire during abrasion was observed. The cross-sectional area of the needle at the point of abrasion was expected to decrease as needle wear increased. The assumption was based on the physics that the resistance of a wire is proportional to the length and cross-sectional area of the wire and the reduction in the cross-sectional area of a wire causes the resistance across that wire to increase.

$$R \propto \frac{L}{A}$$

(or)

$$R = \rho \frac{L}{A}$$

Where, R = Resistance of the wire

L = Length of the wire

A = Cross sectional area of the wire

ρ = Resistivity of the metal

In contrast to the above knowledge, the resistance values were found to decrease instead of increasing as in figure 4.9. The test was repeated ten times and the same trend was observed. The condition was true for all types of yarns. Hence, it became of interest to seek other parameters that affect resistance. It was noted that resistance is influenced by the voltage and current flow. Resistance is directly proportional to voltage and indirectly proportional to current flow.

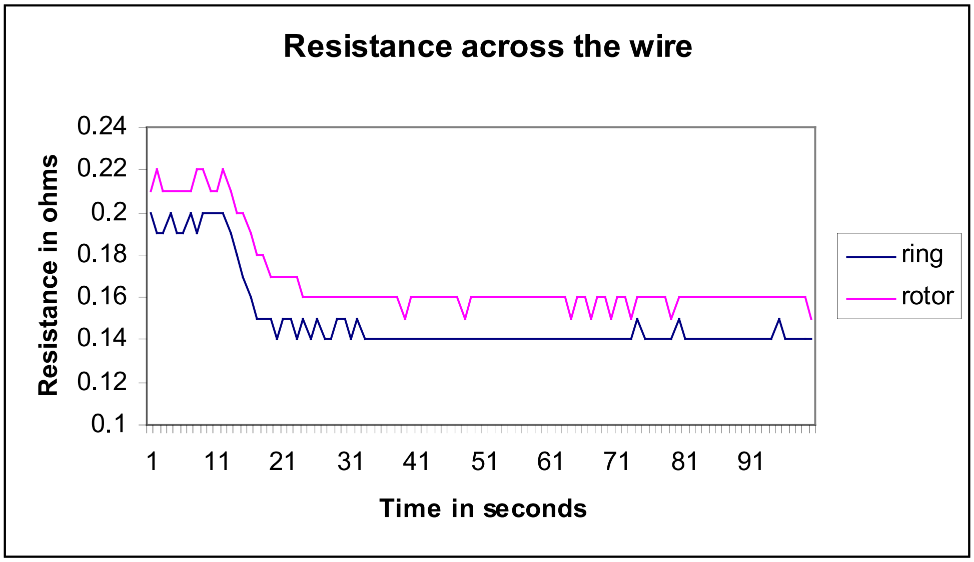

Figure 4.9 Resistance decreasing with increasing abrasion

The formula given below shows the relationship between resistance, voltage and current flow.

$$R = \frac{V}{I}$$

Where, R= Resistance of the wire

V= Voltage potential of the wire

I= Current flowing through the wire

On further observation, it was noted that the lowest resistance was reached within the first 30 seconds of abrasion of the yarn with the metallic wire. The voltage was found to be constant during the duration of the test. It was inferred that the drop in resistance might possibly be explained by an increase in current flow because the multimeter measured the resistance by creating a known flow of current at a specific voltage through the circuit. Any difference that is noted between the terminals is the resistance offered by the circuit (figure 4.10). If current is induced into the circuit apart from what the multimeter sets, then the observed resistance could show a drop while there is actually an increase in resistance. Therefore, if a drop in resistance is observed, it is possible that there is some induction of electricity into the circuit.

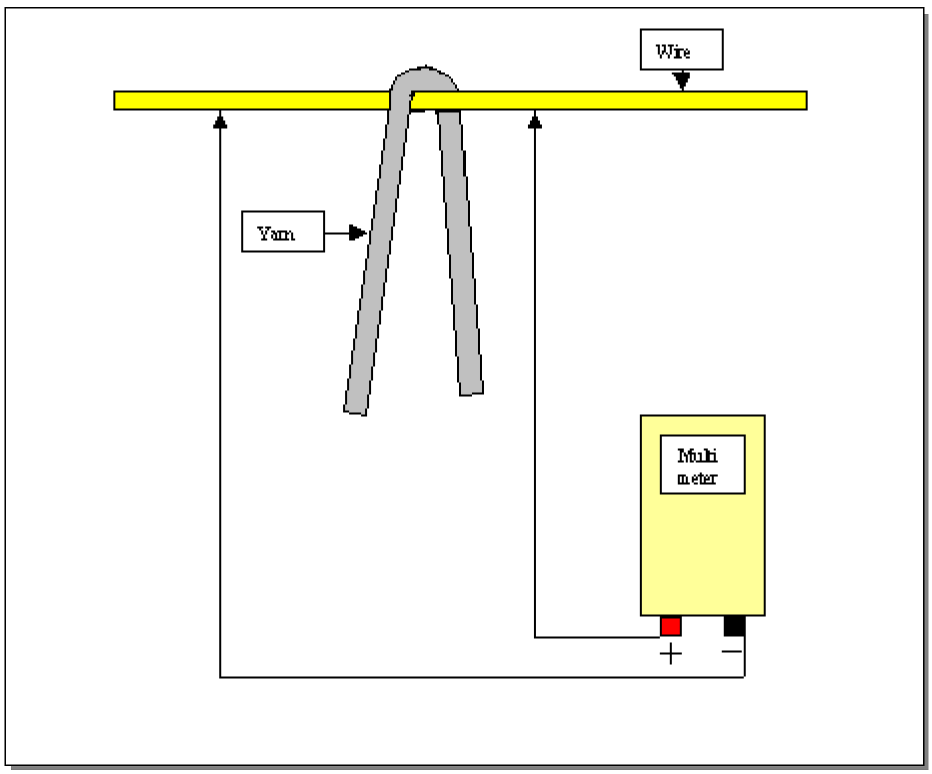

Figure 4.10 A sketch showing the circuit

On further literature review, it was found that when two dissimilar materials are rubbed together and separated static electricity is generated. This triboelectricity produced by the rubbing of the yarn and metal wire could possibly induce increased flow of charges and cause the apparent drop in resistance.

Testing was continued to find the change in resistance for different yarn types on different metals. The actual change in values observed is given in Appendix III. As it is known that synthetic filaments induce more static electricity, some synthetic yarns were also tested. The statistical summary of the results obtained is given in Appendix IV. The results can be seen in the graph below.

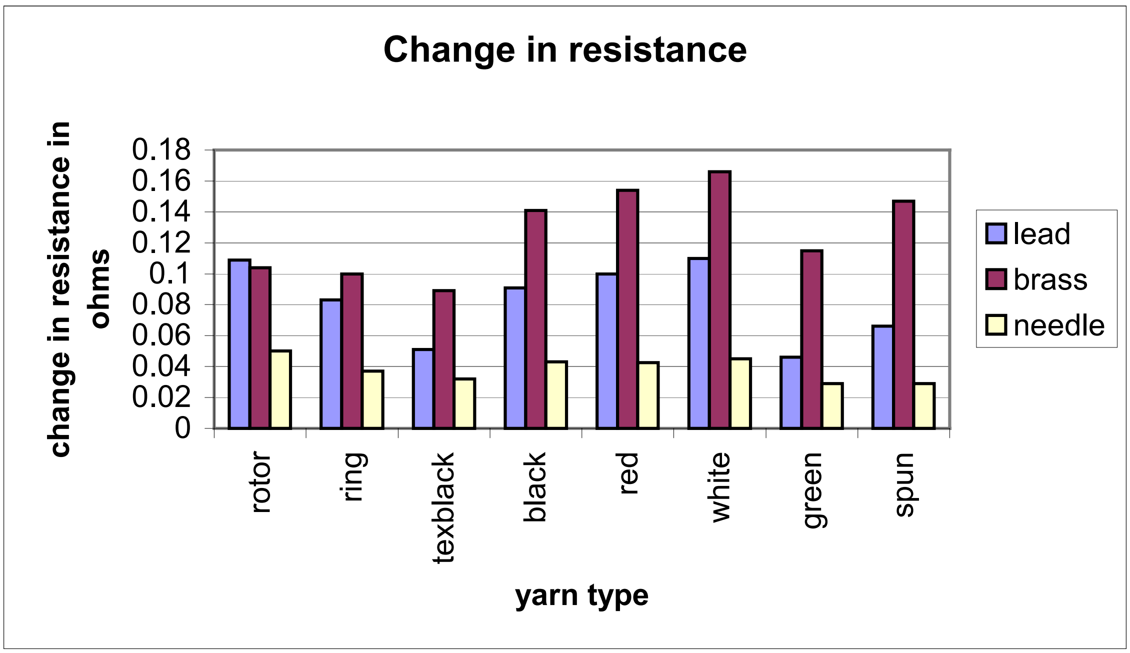

Figure 4.11 Change in resistance across wire

A general trend was observed between the yarns as they interacted with different metals. The effect was pronounced when using brass wire and subdued when using the knitting needle itself. Though subdued the relationship was evident. Ring spun yarn had significantly lower drop in resistance than rotor spun yarn, which could mean that there was more electricity being induced while using ring spun yarn than while using rotor spun yarn.

Table 4.3 ANOVA for change in Resistance

Source of Variation	F	P-value	F crit	Significance
Yarn type	8.6	0.004923	4.01954	Significant
Metal type	57.8093	3.79E-14	3.168246	Significant
Interaction	1.706977	0.191056	3.168246	Not significant

To compare the changes in terms of electricity induced the reciprocal of the values were used, as the resistance is inversely proportional to the current flow. It was assumed that the voltage potential is constant across the wire. The values obtained were graphically analyzed.

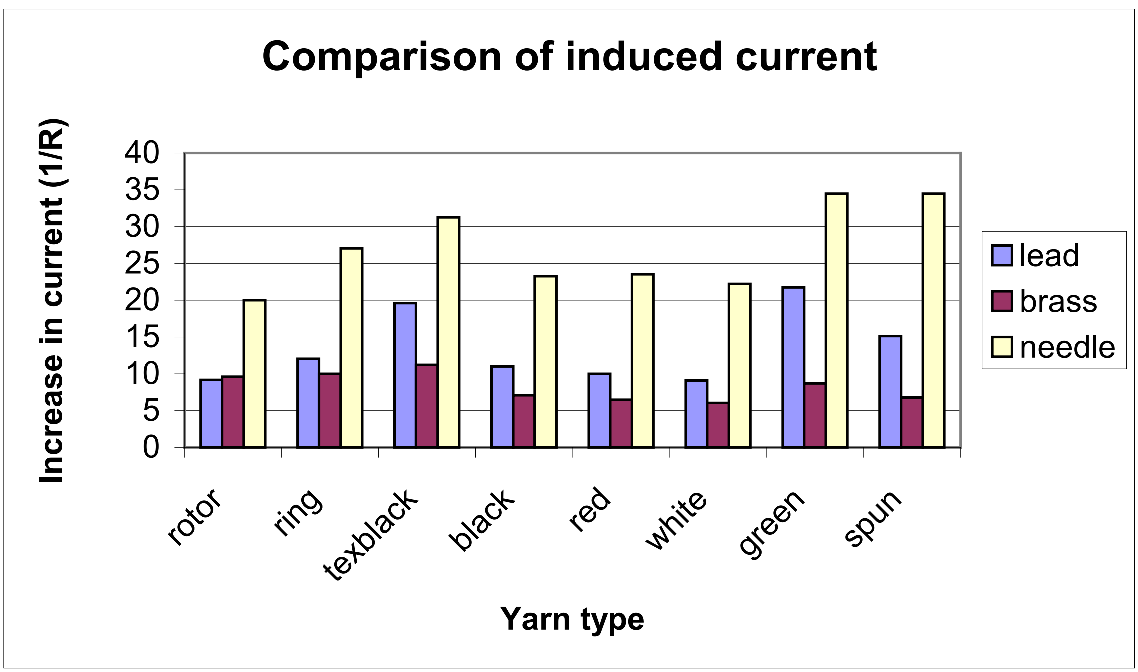

Figure 4.12 Increase in current flow

It was observed from figure 4.12 that the ring spun yarn did induce more electricity than the rotor spun yarn. The spun synthetic yarns induced more electricity than the filament yarns. Yarn that was textured tended to induce more static electricity. The extent of triboelectricity induced could be attributed to the structure of the yarn. The more hairy structure of ring spun yarn than rotor spun yarn could induce more static electricity, as it is known that hairiness enhances generation of static electricity.

Proceeding with the tests on static generation reflected by the drop in resistance across the wire, it was found that there is significant difference in the generation of static electricity between rotor and ring spun yarns. When triboelectricity is induced, the needle gets charged. With their different attractive forces, the differences in charges accumulated could influence the abrasive characteristics of the rotor and ring spun yarns.

4.3 Temperature change

The temperature was measured using the contact pins and the non-contact temperature probe. There was an observed difference in the temperature measured using the contact and non-contact type temperature probes. The non-contact type of measurement showed a higher temperature at the point of contact in all different conditions. This could be because the contact type temperature probe can be taken as close as possible to the point of contact but cannot be placed directly on the point of contact. Hence, the temperature measured could be less than the actual temperature generated at the point of contact. On comparing the increase in temperature of rotor and ring spun yarns, it was found that there was considerably more increase in temperature when using rotor spun yarn than when using the ring spun yarn.

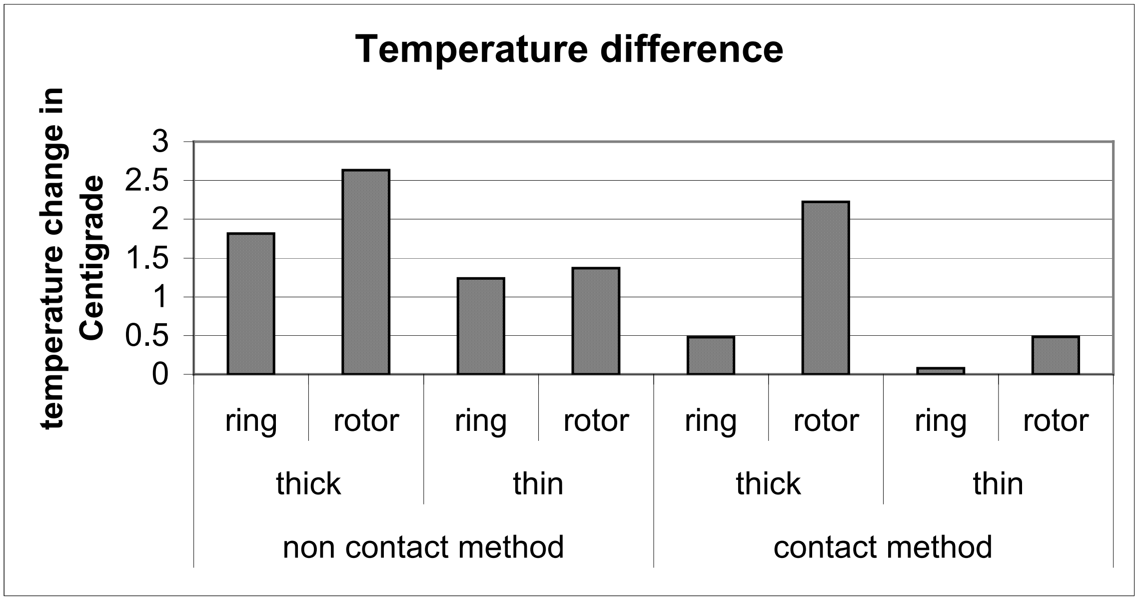

Figure 4.13 Temperature difference during abrasion

Table 4.4 ANOVA for change in Temperature

Source of Variation	F	P-value	F critical	Significance
Measurement type	2.817702	0.168531	7.70865	Not Significant
Yarn type	11.58906	0.001348	4.042647	Significant
Thickness	11.42409	0.001448	4.042647	Significant

The ANOVA results showed that there is a significant difference in the change in temperature associated with the rotor and ring spun yarn. Moreover, the change in temperature is higher while passing over thicker wires than while passing over thinner wires. However, the actual change in temperature observed does not seem to be high enough to be of practical importance. Though there is some observed difference in the change in temperature as shown by the two different measurement types, the difference is not statistically significant.

The significantly higher temperature change caused by rotor spun yarn could be a reason for accelerated needle wear if the temperature is high enough to cause softening of the metal used in knitting needles. The change in temperature noted in this experimentation are for shorter periods of time and when the knitting machine runs for long time, it is possible that more heat is generated by the abrasion, high enough to cause damage to the machine parts.

CHAPTER V

5 SUMMARY AND CONCLUSION

Accelerated needle wear when using rotor spun yarn than when using ring spun yarn is an unresolved problem faced by the knitting industry. In spite of numerous advantages provided by the rotor spun yarn, the economic disadvantages caused by the accelerated needle wear is a great impediment in its popularity. Various studies have been undertaken to find the reason behind this phenomenon in vain. Many parameters like yarn twist, yarn count, wax levels have been considered by other researchers and were found not to influence the accelerated needle wear.

The main objective of the study was to find the parameters that essentially contributed to the increased abrasiveness of the rotor spun yarn over ring spun yarn when they interacted with different metallic surfaces. The specific objectives of the study were the following:

1. To analyze the tension variations of the yarns while passing over different metallic surfaces.
2. To study the changes in resistance across the metallic wires when the yarns pass over them.
3. To study the temperature differences observed on the metallic wire, caused by friction between the yarn and the metallic wire.

Earlier works studied the abrasiveness of the yarn with respect to the endpoint (complete cutting of the wire by the yarn) and the extent of abrasion (reduction in thickness of wire after specific length of yarn passed over the wire). The current work analyzed - the tension variations, resistance changes and temperature increase during abrasion.

From the experiments done, the following results were obtained: -

- There was a significant difference in the tension variations between the ring and rotor spun yarns
- The thickness of the wire had a significant impact on the tension buildup on the yarn
- Metal type had a significant influence on the tension on the yarn after passing over the metallic wire
- There is some form of sinusoidal function in the variation of the tension on the yarn during abrasion
- The cycle of repetition of tension on rotor spun yarn is higher than that of the ring spun yarn and it is more pronounced over copper wire
- The resistance of the metallic wire drops with increasing abrasion
- There is significant difference in the change in resistance based on the yarn type-rotor or ring spun yarn and metal type- copper or lead wire
- The rise in absolute temperature is small though they are significantly different between yarn types and thickness of the metallic wires.

The significant difference found between the rotor and ring spun yarn in their properties of tension build up, triboelectricity induction and temperature generation could possibly cause the accelerated wear of knitting needles. As these properties were not considered in the earlier works that directly tested the abrasiveness of ring and rotor spun yarn over metallic wires, the laboratory results could not reflect the actual condition in the industry.

Rotor spun yarns had high variations in their tension build up during abrasion. Though the mean tension was less than that of ring spun yarn, the extent of variation in the tension values could affect the needle wear. The lesser resistance measured across the wire during the abrasion by ring spun yarn signified higher levels of induced electricity. This might be due to more hairy structure of ring spun yarn, which had the capacity to generate more triboelectricity when it comes in contact with other materials.

5.1 Suggestions for further research

The results of the current work indicate many interesting avenues for further research.

- Since the metal used influences the tension variation on the yarn, it would be worth studying the tension on the yarn when it passes over the alloy that is generally used in the knitting needle.
- More research is necessary to optimize the thickness of the needle used since it could have lots of influence on the tension variations on the yarn.
- There is need to check if there is significant triboelectricity generation on the knitting needle during knitting using other standardized tests.

Appendix 1

Summary Statistics of Tension data from Tensiometer (10000 values for each test)

Test #	Yarn type	Metal type	Thickness	Average	Std Dev	CV
1	Ring	Lead	Thick	40.54	3.21	7.92
2	Ring	Lead	Thick	39.63	2.01	5.08
3	Ring	Lead	Thick	40.28	2.81	6.97
4	Ring	Lead	Thin	37.92	2.83	7.45
5	Ring	Lead	Thin	38.41	2.96	7.69
6	Ring	Lead	Thin	39.83	2.09	5.24
7	Ring	Copper	Thick	45.08	2.01	4.45
8	Ring	Copper	Thick	44.61	2.23	5.01
9	Ring	Copper	Thick	43.21	1.58	3.66
10	Ring	Copper	Thin	49.23	2.35	4.78
11	Ring	Copper	Thin	47.44	2.45	5.17
12	Ring	Copper	Thin	47.68	1.85	3.88
13	Rotor	Lead	Thick	32.25	2.09	6.47
14	Rotor	Lead	Thick	32.34	2.13	6.57
15	Rotor	Lead	Thick	32.27	2.22	6.89
16	Rotor	Lead	Thin	35.26	2.52	7.16
17	Rotor	Lead	Thin	36.63	1.81	4.94
18	Rotor	Lead	Thin	38.69	2.12	5.48
19	Rotor	Copper	Thick	42.09	2.34	5.56
20	Rotor	Copper	Thick	41.56	1.94	4.66
21	Rotor	Copper	Thick	41.40	2.27	5.48
22	Rotor	Copper	Thin	46.82	2.20	4.70
23	Rotor	Copper	Thin	45.44	1.94	4.28
24	Rotor	Copper	Thin	45.06	1.81	4.02

Appendix II

The time duration for the cyclic repetition

Test #	Yarn type	Metal type	Thickness	Time duration (1/1000 of second)
1	Ring	Lead	Thick	37.8215
2	Ring	Lead	Thick	37.8215
3	Ring	Lead	Thick	37.8215
4	Ring	Lead	Thin	37.7929
5	Ring	Lead	Thin	37.7929
6	Ring	Lead	Thin	37.7929
7	Ring	Copper	Thick	37.9363
8	Ring	Copper	Thick	37.9219
9	Ring	Copper	Thick	37.9219
10	Ring	Copper	Thin	37.8358
11	Ring	Copper	Thin	38.1098
12	Ring	Copper	Thin	38.0952
13	Rotor	Lead	Thick	37.8072
14	Rotor	Lead	Thick	37.7929
15	Rotor	Lead	Thick	37.7929
16	Rotor	Lead	Thin	37.8072
17	Rotor	Lead	Thin	37.7929
18	Rotor	Lead	Thin	37.7929
19	Rotor	Copper	Thick	37.8644
20	Rotor	Copper	Thick	37.8644
21	Rotor	Copper	Thick	37.8644
22	Rotor	Copper	Thin	37.8215
23	Rotor	Copper	Thin	37.8215
24	Rotor	Copper	Thin	37.8215

Appendix III

Change in Resistance in ohms

Trial #	Ring			Rotor		
	Lead	Brass	Needle	Lead	Brass	Needle
1	.09	.10	.01	.09	.10	.06
2	.08	.09	.02	.08	.07	.03
3	.09	.08	.04	.17	.08	.04
4	.08	.08	.05	.15	.11	.05
5	.09	.07	.05	.08	.12	.05
6	.10	.12	.04	.09	.11	.05
7	.09	.12	.04	.10	.11	.06
8	.07	.11	.04	.07	.10	.05
9	.07	.11	.04	.13	.12	.05
10	.07	.12	.04	.13	.12	.06

Appendix IV

Statistical summary of the change in resistance observed

	Rotor	Ring	Texblack	Black	Red	White	Green	Spun
Mean	0.109	0.083	0.051	0.091	0.1	0.11	0.046	0.066
Median	0.095	0.085	0.055	0.1	0.09	0.1	0.05	0.07
Mode	0.09	0.09	0.06	0.11	0.07	0.11	0.05	0.07
Std Deviation	0.034	0.011	0.014	0.038	0.037	0.033	0.008	0.013
Range	0.1	0.03	0.04	0.11	0.12	0.11	0.03	0.03
Minimum	0.07	0.07	0.03	0.03	0.07	0.09	0.03	0.05
Maximum	0.17	0.1	0.07	0.14	0.19	0.2	0.06	0.08
Sum	1.09	0.83	0.51	0.91	1	1.1	0.46	0.66
Count	10	10	10	10	10	10	10	10

Appendix V

Change in temperature in centigrade

	Non contact		Contact	
	Thick	Thin	Thick	Thin
Ring	2.9	0.6	0.6	0.5
	2.2	1.0	0.2	-0.2
	1.6	0.7	0.8	-0.1
	0.8	2.0	0.6	0.4
	2.6	0.8	0	0
	3.5	2.6	0.3	-0.4
	0.9	0.8	0.4	-0.1
	2.3	1.5	0.9	-0.1
	2.5	1.4	1.2	1.2
	1.5	1.0	0.5	0.2
	-0.8	0.6	0.4	0.3
	0.5	1.4	0.1	-0.2
	3.0	1.4	0.2	-0.5
Rotor	1.2	2.6	1.5	0.4
	1.5	3. 4	0.1	-0.1
	3.8	0.5	1.7	0.6
	3.5	0.4	8.2	0.2
	4.4	1.1	-1	0.7
	3.9	1.5	3.3	0.5
	2.4	1.3	1.3	0.5
	4.0	2.4	2.5	1
	2.4	2.5	1.4	-0.1
	1.2	2.0	3.1	0.7
	1.9	0.3	2.3	-0.4
	1.1	-0.4	1.6	1.2
	3.0	0.3	2.9	1.1

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