EFFECT OF VIBRATION ON THE TWISTING RATE OF RING SPINNING FOR THE PRODUCTION OF YARN

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Ph. D. Thesis

Mechanical Engineering
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June 2011
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October 2011
1 INTRODUCTION

1.1 Background
No sooner Adam and Eve ate the forbidden fruit of knowledge than they felt the desire of hiding their shame and also protecting themselves from the inclemency of weather; they and their descendants developed the technique of spinning, weaving, dyeing, printing, finishing and fashionable apparel manufacturing. From the start of civilization to till today the science and technology is moving forward according to the interest and the necessity of human being. Among their five basic needs, clothing is one of the most important elements. From a newborn baby to a dead body different types of clothing are needed at different stages of life for different purposes. The manufacturing of clothing involves not only one sequence but also different sequences, techniques and systems that directly play different roles for only one piece of apparel manufacturing. Actually there are so many different types of applied sciences and technologies involved from the fiber to the end use product of manufacturing. The main sequence of textile product manufacturing starts with selection of fiber for manufacturing desired quality yarn. After that the fabric is produced by the technique of weaving or knitting process. Most of the time, grey fabric is not attractive for end users. It needs chemical processing for attractive, colorful and comfortable effects. Then that is ready for apparel manufacturing or another specific use, which is the target of a textile manufacturing plant.

Among the different technologies of textile product manufacturing, yarn manufacturing is one of the complicated processes because of desired fineness and uniformity of yarn manufactured from million of non uniform fibers. These fibers are generally containing different types of dust, trash and foreign materials irrespective of stringent precaution taken during their manufacturing. There are some Neps, short and immature fiber present in cotton fiber. Opening, cleaning, individualization, parallelization, attenuation and finally twist formation operations are used to manufacture a yarn. Nowadays, different types of yarn are produced in the world from different raw materials through different manufacturing processes for different end uses. As for example, the production of synthetic yarn manufacturing is totally different from natural type of fiber spinning. According to length of natural fiber (cotton, jute, wool and flex) yarn manufacturing technologies are different; e.g. short and long staple fiber processing systems. According to insertion of twist on yarn, for bundling of fibers together as a continuous yarn, spinning
is classified as flyer, ring, mule, rotor, friction, air vortex, air jet and anti-static spinning etc.

Some of the spinning techniques are well known for more than 200 years and a few are newly invented within four decades in this sector. New modern spinning technologies are rotor, air-jet, friction and anti-static etc. The twist insertion principles of these new systems are different from conventional one but the rate of twist insertion is very high, as a result these have large amount of production capacity per unit time. Among the new modern spinning methods only rotor spinning has better acceptability than others, only for the production of coarse yarn. In addition to this, the quality of rotor yarn is not good enough compared to that of ring spun yarn. This open-end rotor yarn has low strength, stiff in nature and yarn is only used in the manufacturing of coarse fabric (jeans, denim etc). There are wrapping fiber present in the surface of the yarn which makes less feasible in knitting process.[2-7]

The method of formation of yarn by air-jet is totally different from ring or rotor spinning. In that case yarn is formed by false twisting principle and the binding of fibers in yarn with wrapping fibers. This yarn has also lower strength than ring yarn and the surface characteristics of yarn are not good but through this technique coarse to medium count yarn manufacturing is possible. The twist insertion rate of air-jet spinning is also higher than rotor spinning system although it has less acceptability than rotor spinning.[4,6,7]

Twisting is the final step for the formation of yarn by the binding of many small fibers together. Alternatively, twist is the spiral disposition of the components of a thread, which is usually the result of relative rotation of two ends. This twist is given in yarn by the spinning technique and the term spinning has probably been derived from the spin motion of the spindle.[1] Through the rotation of the spindle, actual kind of twist can be given in yarn by a system of ring and traveller and this system is familiar to all over the world and has an excellent acceptability to manufacture coarse to fine count yarn from different types of fiber by this ring spinning method.[1,6,7] This ring spun yarn, is actually twisted yarn, has good strength and ready to use for any kind of next processing. Ring spun yarn is better, stronger and softer than any another yarn, which are manufactured by modern systems. Any kind of fabric (heavy, strong to delicate) can be manufactured from ring spun yarn for its desired properties (fineness, strength and softness etc).
Still today all over the world more than 80% of total yarn is produced by ring used for the
different types of fabric manufacturing although the production capacity of this system is
very low, because of low twist insertion rate. The yarn has good strength and softness
properties and can be manufactured in wide range (1-200)Ne of fineness. Another name
of ring spinning machine is Universal Spinning machine. Ring spinning system is a
conventional but most usable spinning system that is able to produce highest quality
product at low production rate. [1,2,6,7]

Further development on ring spinning is required to increase the traveller life. The
amount of heat generated in the traveller at high speed is very difficult to dissipate as it is
extremely difficult to transfer this heat from the traveller in the available short time.

In spite of this, the ring spinning machine will continue to be the most widely used
spinning machine for its significant advantages in comparison with the new spinning
processes:

• It is universally applicable and any short to medium length fiber can be spun to
  manufacture fine (1-200Ne) yarn.
• It delivers a yarn with good characteristics.
• It is simple and easy to maintain.
• The operational procedure of the machine is well established and acceptable to
everyone.
• It is flexible regarding product types and qualities.

For these above mentioned reasons modern high productive spinning machine, has
difficulty in gaining widespread acceptance. The current renaissance of the ring spinning
machine can be attributed to the fact that these realities have been clearly recognized in
the specialized area of yarn manufacturing. [2,6,7]
1.2  **Present State of the Problem**

In a Ring Spinning machine, spindle, ring and traveller are arranged to impart twist to the yarn, and enables winding of the produced yarn on the cop. One revolution of traveller around the ring circumference inserts one twist on yarn. Traveller has no direct drive and it rotate by the draw of yarn through spindle rotation. During rotation of the traveller a centrifugal force is generated, which creates high contact pressure (35N/mm\(^2\)) on the ring. High centrifugal force of the traveller creates high pressure on the contact surface of the ring, induces strong frictional forces and in turn leading to significant generation of temperature (300°C-400°C). As a result, traveller has short length of life and it burns and also flies out from the ring surface [2]. The size of traveller is very small, has low weight and cannot dissipate the large amount of generated heat within a very short time. Due to high centrifugal force and metal to metal friction the maximum speed of traveller that can be achieved is at the highest 40m/sec.[2] This is the prime problem of ring-traveller combination of a ring spinning machine and for this reason twist insertion rate is low compare to modern spinning machines.

Figure 1.1 shows the ring and traveller of the ring spinning machine. Traveller is very small compared to ring. Both of the ring and traveller are made from steel, which are specially treated in different ways for high speed running.

![Fig 1.1: Ring and Traveller of a Ring Spinning Frame.](image)
In the following flow diagram ring spinning method is explained with its prime problem.

![Flow diagram of the ring spinning methods problem.](image)

**Fig 1.2:** Flow diagram of the ring spinning methods problem.

There are also some others problems present in ring spinning system:

- Small bobbin and ring size
- Small mass of yarn stored in bobbin length
- Frequent doffing
- High power consumption

However, the ring spinning system can compete with others in long term if further success is achieved to reduce the friction between the ring and traveller for the target of high production and automation of the spinning process. It is also needed to mention here that spinning cost is a factor, which should be comparable with other systems. [7]

### 1.3 Problem Solving Technique

There are two possibilities for getting rid of this problem. One is to reduce the generation of heat and the other is too rapid by transfer the generated heat out of the traveller. Many works had been done to prevent the generation of heat by reduction of friction with the following ways:-

- By giving different shapes and sizes of ring and traveller
- Surface modification of ring and traveller
- Surface finishes with different materials and methods
- By introducing live ring
It is recommended that ring radius and traveller-ring contact surface should be kept as small as possible for higher twisting rate to keep traveller speed within the tolerable limit and also for optimum production condition.

Rotating ring or living ring, means that the ring and traveller must be rotating in the same direction such that the friction between ring and traveller could be less occurred. [20] This one could not gain popularity for (i) increasing machine cost, (ii) increasing noise level and (iii) the problem of speed increasing and shuts down the ring and traveller. Due to the complexity of this system it could not gain significant attention. Some researcher also tried to cool the ring by refrigeration but the method was not accepted in the field of application as it is costly.

Some new attachments have already been introduced in ring spinning machine to bring modification of yarn structure and properties to manufacture new product (core-spun, slub, compact, siro-spun and solo-spun yarn).

Recently published research works on ring spinning machines are mainly on yarn structure, balloon theory, power consumption, shape and surface of ring and traveller. [22-30]

From seventeenth century to until today many researches have been done continually improve ring spinning machine performance. They have done many improvements, which makes ring spinning machine famous, remarkable, well accepted and most usable spinning machine to manufacture spun yarn. But still the ring spinning machine has some limitations. One of the strong limitations is the friction between ring and traveller, which restricts or limits the traveller to rotate around ring at not more than 40m/sec.

Normally friction depends on the following:-

- Surface area of the contacting surface
- Surface finish of the contacting materials
- Lubrication of the surfaces
- Type of material
From different research works[15-19] it is known that vibration of the contacting surfaces can reduce the friction. The amount of reduction depends on frequency, amplitude and direction of vibration and the materials of the contacting surfaces. But till today there is no research work is going on to find out the effect of vibration to reduce the friction between the ring and the traveller of ring spinning machine for better twisting rate and more production of yarn.

The present study is aimed to investigate the effect of vibration on the friction force between the ring and the traveller also yarn and the traveller in ring spinning machine in detail. Three set up are designed, fabricated and introduced in ring spinning machine to vibrate the ring and traveller of Ring Spinning Machine with variation of frequency, amplitude and velocity. In this way the friction force between the ring and the traveller is reduced (10- 20%) and hence, the heat generation in the contacting surface is also reduced. Frictional force reduction is one of the main objectives of this work. As such the traveller speed can be higher than present status. Higher Traveller speed gives higher twisting rate and finally higher production rate. In addition to the above, different properties of yarn are measured to ensure the yarn quality.

The basic principle of ring traveller friction reduction is presented by the following flow diagram in Figure 1.3.

![Figure 1.3: A way to reduce friction between ring and traveller of a ring spinning.](image)

Many research works have been done to improve the surface characteristics of the ring and the traveller for reduction of friction. Till today no one has done any research about the effect of opposite force and vibration on ring and traveller combination.
1.4 Objectives

Ring spinning system is a widely popular spinning method to spin the staple fibre mainly cotton and wool, although wool yarn producing ring frame is a slightly different from that of cotton. The fineness of most suitable shirting and sheeting apparel yarn is 40-80 Ne and this type of staple yarn is produced only by ring spinning system. The production rate of ring yarn is 6 to 10 times less than that in modern spinning but the yarn has 30-40% better strength[4]. This is the reason to look for the ways to speed up the production of ring spinning machine.

Further, one step development of ring spinning machine could be achievable with the application of the following techniques:

- To design and fabricate a system which can generate opposite force and vibration of different frequency, amplitude and velocity in the ring-traveller system.
- To study the effect of opposite force and vibration on ring traveller frictional force and the temperature of the traveller.
- To analyse the effect of friction and temperature on traveller speed.
- To study the effect of opposite force and vibration on yarn properties (end breakage rate, melted spot on synthetic yarn, strength and elongation, twist, evenness and hairiness).

With the introduction of this method, it is possible to reduce friction between ring and traveller, so it will be a new approach to exceed the existing traveller speed (40 m/sec). It is not only a new idea but with the addition of this technique, higher production rate is possible without affecting the yarn quality.

With the addition of this technique, it can be possible to attain 20-25% higher traveller speed and consequently 10-20% higher production without hampering the properties of yarn. Furthermore the surface characteristics of yarn will be better for lower scraping of yarn in contact of traveller and also at the same time scraping agglomerated fibre have no chance to remain between traveller and yarn. Consequently, more fiber dust can easily come in contact of ring and traveller as a lubricant, which will also help to better running of traveller at the contact of ring.
2.1 Fundamentals of Spinning

2.1.1 Early Stage Spinning

For several thousand years, staple yarns were produced without the aid of any mechanical power. In those earliest days, twist was inserted by the use of fingers and the produced yarn was wound by hand into a crude form of bobbin. The greatest single invention in the cultural history was the simple device of twisting, which can grip each other or a series of long flexible and a parallel material that could produce a continuous strand having considerable tensile strength.

As the centuries passed by, the spinners probably began to experience problem with the varying momentum of the suspended spindle when they tried for increased demand of finer yarns. Consequently, an ingenious device of a combination of one large wheel and one small wheel and of an endless cord around the rims of the both, into a simple machine known to the world even today as charka. Nobody knows when this charka was first invented in India, by the creative mind of Indo-Pak Spinner[20]

Probably at Seventeenth Century the mechanical principle of charkhia was modified by the European countries and converted into Jersy hand wheel. In that century Jersy Hand Wheel and the Brunswick Spinning wheel with a foot treadle were commonly used for spinning. This is the start of journey for invention of spinning technique to produce a little bit large scale production. A brief idea is given here to introduce with conventional spinning technique.

**FLYER SPINNING:** At the same time (Seventeenth Century) a new ingenious method was invented, in that case twist was inserted by *Flyer* and that new flyer frame was named Saxony Wheel.

Between 1750-1757 an English Weaver invented a Spinning machine which could spin many thread at a time and named Hargreaves Spinning Jenny. At first he used a series of spindle instead of one. At that case manual spinning operation was converted into mechanical, but the main drive was attained by a hand wheel.

Arkwright’s Spinning Frame was developed by Richard Arkwright with the combination of both Saxony Wheel and Hargreaves Spinning Jenny. At that frame Flyer was for
twisting and putting a series of spindle for one Frame. Arkwright’s Spinning Frame was often called water frame or sometime water wheel.

**MULE FRAME:** Crompton’s spinning frame was called the Mule frame. It was the combined form of Hargreaves Spinning Jenny and Arkwright’s water frame and that was the actual mechanical spinning frame. Mule was an intermediate spinner, its work being Drafting, Twisting and Winding intermediately. With the invention of Mule spinning frame, the supply of yarns and necessarily the production of cloth were greatly increased.

**CAP SPINNING:** In 1828 Danforth patented a cap-spinning spindle that could be run at speeds up to 7000 rev/min. The bobbin was rotated inside a stationary cap, the bottom edge of the cap guiding the yarn onto a bobbin. Cap spinning is still used in the worsted-spinning industry. [1,20]

### 2.1.2 Invention of Ring Spinning

**Primary Age**

By replacing the flyer, Thorp in 1828, patented a system consisting of a ring concentric with the spindle, the ring having a hook attached to it by which it was dragged around by the yarn, the bobbin being driven. This rotating hook was replaced by Traveller within short time.

Between 1860 and at the end of the nineteenth century were a period of intense development of different types and shapes of ring and traveller. At that time improved type of spindle with good lubricating system and different ball or roller bearing and improved damping used in different places of drafting zones and spindle respectively. In 1888 it became a perfect form and could be given production effectively.

This ring spinning was much more productive, simpler in mechanism, easier in manipulation and more economic. This was the origin of ring twisting, probably the most extensively used system for the processes of simultaneously twisting yarn and winding it onto a package.

In 1913 Fernando Casablancas, of Sebadale, Spain, Invented a better system of drafting and was named Casablancas Double Apron High Draft System. Following this work Saco-Lowell shops of U.S.A. developed three different single apron system. At the same
time H&B Company of U.S.A. developed Four Roller Long Draft System. At that time research had been carried on extensively for the production of large package and economical production.[1-3,20]

**Developing Age of Ring Spinning**

Super draft and semi-super draft was developed in 1953 by Japanese machine manufacturer. Different manufacturer had done so many research works about the development of drafting system. Again at that time both American and British machine manufacturer further developed in large package spinning with ring rail lift as high as 12 inches and Thread Guide Traverse up to 6 inches. Single-spindle-belt-drive was also achieved at the end of 1958 through the development of mechanical changes.

**Modern Trend of Ring Spinning**

For the trend towards larger packages sizes as well as the ring sizes were increased at the same time and for that reason some technical difficulties were raised. These are followings :-

- increased traveller path for one revolution
- More power required
- Formation of larger balloon

Two or three balloon control rings were necessary to control balloon, which decreased yarn quality and increased yarn tension and later it was modified by using separators and one balloon control ring

The important development in last three decades is as followings

- Higher spindle speed as maximum 20,000 rpm
- More production
- Introducing small ring instead of large
- Traveller speed up to 40 m/sec

Now this final stage of ring spinning frame can give highest production 18-20gm/hr/spindle. Naturally the package size has also stayed at limit for small ring radius. [1-3,6,7]

*This is the conventional but most usable spinning frame, which is able to produce highest quality product at low production rate.*
2.1.3 Yarn Formation

The characteristics of yarn depend mainly upon the characteristics of its fibers, as well as on the structure of yarn itself. The following factors are especially significant on the properties of yarn:

A) Fiber Properties (length, strength, fineness and maturity)
B) The number of fiber in yarn cross-section
C) Fiber alignment
D) Fiber binding system
E) The over-all structure
F) Amount of twist

A. Fiber Properties

Fiber properties play an important role on yarn properties. Finer yarn is produced from long and fine fiber. Presence of more short fiber in raw material makes irregularity of yarn. Processing of immature fiber produced neps in yarn and this yarn also has different affinity of dye take up. Yarn strength is directly proportional to fiber strength.

B. Number of Fiber in Yarn Cross-section

The number of fiber in yarn cross-section and process parameters also determines the properties of yarn (e.g. count, strength, evenness, handle). After research work, the following number is well established for ring and rotor yarn. This is also the spinning limit of raw material(cotton).

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Yarn kind</th>
<th>Yarn type</th>
<th>No of fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>Ring-spun yarn</td>
<td>combed</td>
<td>33 fibers</td>
</tr>
<tr>
<td>Cotton</td>
<td>Ring-spun yarn</td>
<td>Carded</td>
<td>75 fibers</td>
</tr>
<tr>
<td>Cotton</td>
<td>Rotor-spun yarn</td>
<td>carded</td>
<td>100 fibers</td>
</tr>
<tr>
<td>Synthetic</td>
<td>Ring-spun yarn</td>
<td>carded</td>
<td>50 fibers</td>
</tr>
<tr>
<td>Synthetic</td>
<td>Rotor-spun yarn</td>
<td></td>
<td>100 fibers</td>
</tr>
</tbody>
</table>
To form a yarn, minimum number of fibers must remain at its cross-section. How much finest yarn can be manufactured from a given fiber is calculated by the following formula:

\[ n_F = \frac{tex_{yarn}}{tex_{fiber}} \]  

where, \( n_F \) = the number of fiber in yarn cross-section

\[ Tex = \text{gm per 1000 meter of fiber / yarn} \]

For a blended yarn, formula is as following:

\[ tex_{fiber} = \frac{(P_x \cdot tex_x + P_y \cdot tex_y)}{100} \]  

where \( P \) represent the proportion of the type of fiber as a percentage of total fiber , and \( P_x \) and \( P_y \) represents the percentage of x type and y type fiber respectively.[2-6]

C. Fiber Alignment

The arrangement of fiber in yarn cross-section plays an important role on the properties of yarn. Yarn strength, evenness and handle properties (softness, hardness and stiffness) are affected by the following factors:

- Degree of fiber straightening
- Degree of fiber parallelism
- Regular arrangement of fiber ends relative to each other
- Binding of the all fiber, if possible both fiber ends, into the yarn structure

D. Fiber Binding system

Yarn is manufactured by binding of fibers, and the binding of fibers is dependent on the spinning system. The general name of fiber binding principle is twist and this twist is inserted to yarn by the different spinning system but all the fibers do not stay in yarn at the same way. According to position of fiber, twist is classified as follows:-

(i) Actual Twist
(ii) Wrapping twist or Surface twist
(iii) False/ Zero twist

(i) Actual Twist:- *Center twist* is a real twist, stays according to axis of yarn is formed by ring and flyer spinning method.
(ii) Wrapping twist or Surface twist:- *Surface twist* is also a twist but not according to axis of yarn and fibers is twisted according to surface of the yarn. Open end rotor and vortex has this type of twist.

(iii) False/ Zero twist:- *False/Zero twist* is not a twist but some outside fiber wrap the core of fiber to make yarn. Air-jet yarn is formed in this way. [6-7]

E) The Over-all Structure of Yarn
It is a visual appearance of yarn, created by the peripheral layer or outer layer of the yarn. The internal and external condition of fiber arrangement in yarn makes the structure of yarn. Yarn structure is variable. The yarn structure is dependent primarily upon the raw material, spinning process, spinning unit, machine, machine setting, twist etc. The structure can be open/close; voluminous/compact; smooth/rough/hairy; soft/hard; round/flat; thin/thick etc.

F) Amount of Twist
In order to obtain strength in the yarn, all length of individual fibers within yarn should be holded together (e.g. bound themselves). In principle, there are two ways of binding fiber with each other. These are (i) adhesives and (ii) twist. By using adhesive, total exploitation of the inherent strength of fiber can be achieved but it has a low demand and also need some extra adhesive ingredient and drying. So twisting is a pioneer way and it can make all or part of the fiber strand together for imparting strength. Normally the degree of exploitation of strength of staple fiber in a spun yarn is between 30-70%.

The strength of spun yarn increases with increasing twist up to a certain limit. Under tensile loading, the load-elongation curve of cotton and polyester spun yarn is shown in Figure 2.1. In the lower portion of the curve, this strength will be due solely to sliding friction, because of under tensile force the fiber slide apart. Cohesive friction arises only in the middle to upper region of the curve. This is caused by the high tension and high pressure and considered that fewer and fewer fiber slide past each other and more are broken. This continues up to a certain maximum, that is, to the optimal exploitation of the strength of the individual fibers, after which strength falls away again. The two curves show the critical twist region (C), is dependent upon the raw material. Normally, yarns are twisted to levels below the critical-twist region (A- knitting, B-warp); only special yarns such as voile(C) and crepe (D) are twisted above the critical region.
2.1.4 Technology of Ring Spinning

2.1.4.1 Principle of Operation

Ring spinning is the processes of twisting and winding of yarn to a suitable package simultaneously. The principle of operation of ring spinning is shown in figure 2.2.

At first, roving are coming from a large bobbin and going into the drafting arrangement by which fiber is attenuated to a definite fineness (count). The drafting arrangement is inclined at 45-60° and it is the most important assemblies on the machine which has strong influences on yarn irregularities. The fine drafted fiber strand is coming from front roller nip and going through lappet and traveller finally wound up at bobbin (as shown in the figure) after twisting. Bobbin is rotated along with the spindle and twist is imparted on fine strand of roving by the rotation of traveller and yarn is manufactured. Twist is inserted in yarn at the rate of one twist per rotation of traveller around the ring.

Actually traveller has no direct drive; it is carried along by the threaded yarn of bobbin by the rotation of spindle. The rotating rate of traveller is lower than that of spindle for the friction between ring and traveller and the resistance of air drag on the yarn balloon formed between thread guide and the traveller. This difference in speed between spindle and traveller enables winding of the yarn on the bobbin.

For making full package the ring rail traverse up and down for fixed length, along with to and fro motion. After each layer of coils the ring rail is raised up by a small amount. In this way the full bobbin is made. The traverse stroke of ring rail is less than the total winding length of bobbin.[1,3]

2.1.4.2 Spinning Geometry

From Roving bobbin to cop, the fibre strand passes through drafting arrangement, thread guide, balloon control rings and traveller. These parts are arranged at various angles and distances relative to each other. The distances and angles together are referred to as the spinning geometry, which is shown in Figure 2.3 has a significant influence on the spinning operation and the resulting yarn. Spinning geometry has influence on the following parameters:-

- yarn tension
- number of ends breaks
- yarn irregularity
- binding-in of the fibres
- Yarn hairiness
- Fiber fly-out [5-7]
2.1.4.3 Design Feature of the Machine

Drafting System

Drafting arrangement is the most important part of the machine, which is shown in Figure 2.4. It influences mainly evenness and strength of the product.

Drafting arrangement influences the economics of the machine, which directly effect on the end break rate and indirectly on the maximum draft possible. If higher drafts can be used with a drafting arrangement, then coarser roving can be used as a feeding material. This result helps to get high production rate at the roving frame and thus reducing the number of roving machine required. Amount of draft have some effects on the quality of the yarn. Within the limit some studies show that increase in draft improves yarn quality. The following draft limits have been established for practical operation for different type of yarn production.

<table>
<thead>
<tr>
<th>Yarn Type</th>
<th>Maximum draft</th>
</tr>
</thead>
<tbody>
<tr>
<td>carded cotton</td>
<td>35</td>
</tr>
<tr>
<td>carded blends</td>
<td>40</td>
</tr>
<tr>
<td>combed cotton and blends (medium counts)</td>
<td>40</td>
</tr>
<tr>
<td>combed cotton and blends(fine counts)</td>
<td>45</td>
</tr>
<tr>
<td>synthetic fibres</td>
<td>50</td>
</tr>
</tbody>
</table>

Lappet and Balloon Control Ring

A lappet is designed to pass the yarn centrally over the spindle axis. A lappet consists of thread guide and pivoted supported arm, which is shown in Figure 2.5. During winding of a cop, the lappet rails perform the same sequence of movement as the ring rail, but with a shorter stroke.

This movement of the guide ensures that differences of the balloon height do not become too large. Different heights of balloon created during winding of bobbin, which make different tension and sometimes that makes end break at different conditions.

The spacing between the thread guide and ring is comparatively large and during formation of twist in yarn it makes a large balloon. This large balloon leads high air drag on the yarn in the balloon. Thus sometimes turn into deformation of balloon and increasing yarn tension leading to yarn breaks.
In order to avoid these problems balloon control ring is used, which makes the balloon into two smaller sub balloons. In this way balloon is stable also with low yarn tension. But it causes roughening of the yarn, loss of fibers for rubbing away (fly), and formation of melt spots in processing of synthetic fiber.

**Spindle**

The spindle consists of two separate parts, namely upper part and the bolster, which is shown in Figure 2.6. The upper part consists of aluminum alloy and is slightly tapered. Most of the times near its upper ends also sometimes lower ends; it has a tube gripping device. At the lower end of the upper part; there is a whorl so that it can be placed over the neck bearing in the bolster. The form of the whorl is very important, because of energy consumption.

The bolster is made of cast iron and is fixed to the ring frame by help of nut. It consists of a fixed neck bearing, spindle blade, a flexible foot bearing, a flexible tube connection, a spiral spring, a spindle damping device all in a lubricating chamber.

The neck bearing can be a journal, ball or roller bearing; but the foot bearing is always a plain bearing. Foot bearing has a slot through which oil can circulate. With the help of spiral spring and lubricating oil minimize the vibration of the foot bearing and finally to damp out the vibration of the blade. Spindles and their drive have a great influence on power consumption and noise level in the machine. The running characteristics of a spindle, especially imbalance and eccentricity relative to the ring flange, also affect yarn quality and of course the number of end breakages. Almost all yarn parameters are affected by poorly running spindles. Hence it should be ensured that the centering of the spindles relative to the rings should be as accurate as possible. Since the ring and spindle form independent units and are able to shift relative to each other during operation, these two parts must be re-centered from time to time. Previously, this used to be done by shifting the spindle relative to the ring, but now it is usually carried out by adjusting the ring.[3]

**Ring and Traveller**

This is the renowned ring, so the frame is named as Ring Spinning Frame. The ring is tough and hard and the range of its surface hardness lies between 800-850 Vickers. The hardness of the running traveller normally lie within 650-700 Vickers, so that wear occur mainly in traveller, which is small, cheap and easy replaceable. The surface smoothness is
also high, but not too high that a lubricating film cannot build up on it, resulting increased friction. Most commonly used material is carbon steel. The surface of ring and traveller are hardened by chrom platiy, carbo-nitridy and flame or induction system.

Traveller is the tiny key parts of ring spinning frame, which travels on ring at maximum of 40m/sec and this rotation impart twist to the yarn. Actually traveller has no drive of its own, it is carried along by the threaded yarn by the rotation of spindle, which is shown in Figure 2.7.

For selection of the ring traveller, the following factors should be considered
- materials of the ring and traveller
- surface characteristics
- the forms of both elements
- wear resistance
- smoothness of running
- running-in conditions
- fibre lubrication

For the rings two dimensions are of primary importance. i) internal diameter ii). flange width. An anti wedge ring exhibits an enlarged flange inner side and is markedly flattened on it upper surface. This type of profile permitted to use traveller with a lower centre of gravity and precisely adapted bow(elliptical traveller), which in turn helped to run the machine with higher spindle speeds. Anti wedge rings and elliptical travellers belong together and can be used in combination. These rings are shown in Figure 2.8.

Low crown profile has the following advantage. Low crown ring has a flattened top surface and this gives space for the passage of the yarn so that the curvature of the traveller can also be reduced and the centre of gravity is lowered. In comparison with anti wedge ring, the low crown ring has the advantage that the space provided for passage of the yarn is somewhat larger and that all current traveller shapes can be applied, with the exception of the elliptical traveller. The low crown ring is the most widely used ring form at present.

A good ring in operation should have the following features:
- best quality raw material
- good, but not too high, surface smoothness
- an even surface
- exact roundness
- good, even surface hardness, higher than that of the traveller
- should have been run in as per ring manufacturers requirement
- long operating life
- correct relationship between ring and bobbin tube diameters
- perfectly horizontal position
- it should be exactly centered relative to the spindle

In reality, the traveller moves on a lubricating film which builds up itself and which consists primarily of cellulose and wax. This material arises from the surface of fibres. If fibre particles are caught between the ring and traveller, then at high traveller speeds and with correspondingly high centrifugal forces, some particles are partially ground and comes out at the form of small particle, which is colorless, transparent and extremely thin layer of paste. This layer of paste is continually being replaced during running of traveller. The position, form and structure of lubricating film depends on

- yarn fineness
- yarn structure
- type of fiber
- traveller mass
- traveller speed
- height of traveller bow

Modern ring and traveller combination with good fibre lubrication enable traveller speed to reach upto 40m/sec. Traveller imparts twist to the yarn. Traveller and spindle together help to wind the yarn on the bobbin. High contact pressure (up to 35 N/mm²) is generated between the ring and the traveller during running, mainly due to centrifugal force. This pressure leads to generation of heat. Low mass of the traveller does not permit dissipation of the generated heat in the short time available. As a result the operating speed of the traveller is limited. When the spindle speed is increased, the frictional work between the ring and the traveller increases. Consequently if the spindle speed is too high, the traveller sustains thermal damage and fails.

This speed restriction is felt particularly when spinning cotton yarns of relatively of high strength. If the traveller speed is raised beyond normal levels, the thermal stress limit of the traveller is exceeded; a drastic change in the wear behavior of the ring and traveller
ensues. Owing to the strongly increased adhesives forces between the ring and the traveller, welding takes place between the two. These seizures inflict massive damage not only to the traveller but to the ring as well. Due to this unstable behavior of the ring and traveller system the wear is at least an order of magnitude higher than during the stable phase. The traveller temperature reaches 300 to 400 degrees Celsius and the danger of the traveller annealing and failing is confirmed.

2.1.4.4 Principle of Twisting and Winding

In Ring spinning system, the process of twisting and winding occur at the same time. Twist is imparted by the rotation of traveller through the circumference of ring and spread the twist through the drafted fiber ribbon which passes from the drafting roller of spinning frame. The newly formed yarn is twisted and at the same time passed through a thread guide and clipped traveller of ring and finally wound onto a bobbin. The bobbin is inserted on spindle and stay in the center of the ring. The spindle is driven by motor through belt and the traveller is dragged around the ring by the pulling of the connected yarn into bobbin. Each revolution of the traveller on the circumference of ring inserts one turn of twist into the length of yarn between the roller nip and traveller. The numbers of twist in the balloon yarn remain constant, yet the newly twisted yarn is passing through the traveller on bobbin surface at a balance rate. Here the important distinct feature is that twist passes the traveller in the same direction of the yarn, but the yarn and twist are moving in the opposite direction across the thread guide, which is shown in Figure 2.10.

\[
TPI = \frac{Spindle\ Speed}{Front\ Roller\ Delivery\ in\ inch/min} \quad \ldots(2.3)
\]

The traveller speed, \( n \), at any instant is given, in thousands of revolutions per minute, by

\[
n = n_0 - \frac{v}{2\pi R_1} \quad \ldots(2.4)
\]

Where, \( n_0 \) is the spindle speed in thousands of revolutions per minute
\( v \) is the yarn delivery speed in cm/sec
\( R_1 \) is the radius, in cm, of the package at the point at which yarn is being wound.
The equation can be written as follows
Actual turns per unit length = Nominal turns per unit length – 1/2πR₁ ............(2.5)

Yarn is continually issuing from the front roller of the drafting system and twisting is done by the revolution of the traveller but the revolution of the traveller is slightly less than spindle, which just sufficient to allow the yarn to be wound onto the bobbin at the same rate as it issues from the drafting roller.

Modern and newly produced ring frame are moving rail type. The ring rail has performed two types of movement; a continuous up and down movement and gradual rising in small steps after each reciprocatory motion. The upward motion of rail is slow makes winding of the yarn on bobbin and downward motion is fast makes cross winding of bobbin.

The spinning condition or the forces acting on traveller is being always changed during the movements of the ring rail. Among all changeable characteristics, balloon size and winding diameter of the bobbin are distinct. These variations directly vary the yarn tension. [1,3,5]

2.1.4.5 Air Drag
In the absence of air drag, neither up twisting nor winding-off would be possible, but tension in the yarn is caused primarily by ring-traveller friction.

Let first consider the magnitude of the air drag forces on an element of yarn. According to aerodynamic theory, the air-drag force per unit length of yarn can be expressed as follows:

\[ \text{Air-drag force} = \frac{1}{2} C₁ \rho u^² d \] ............(2.6)

Where \( \rho \) = the density of air
\( d \) = the diameter of the yarn
\( u \) = the air speed
\( C₁ \) = is a drag co-efficient

But \( C₁ \) is not constant; it is a function of Reynolds Number only. Reynolds Number, \( R_e \) is given by

\[ R_e = \frac{ud}{\eta} \] .................(2.7)

where \( \eta \) is the kinematics viscosity of air.
At normal atmospheric pressure (Temp 21°C and R.H 65%) \( \rho \) is about 0.0122 g/cm\(^3\) and \( \eta \) is about 0.15 cm\(^2\) sec\(^{-1}\).

The effective diameter of cotton yarn can be determined from the measurement of air drag but the diameter of woolen and staple rayon yarn are found to be very similar. At high speed this diameter is decreased but at a low speed it is increased.

In fact

\[
\text{Total air drag} \propto \omega^2 \quad \text{..................(2.8)}
\]

Where, \( \omega \) is the vector sum of the normal velocity and one-half of the tangential velocity of the yarn.[1]

2.1.4.6 Theory of Balloon

Ballon Shape Without Air Drag

In equilibrium at any kind of spinning balloon is formed at a stationary wave system, which is shown in Figure 2.10, by circularly-polarized transverse vibration of string. The whole string rotating in a displaced condition near the equilibrium position and with angular velocity \( \omega = 2\pi \bar{f} \) and the radius of the circle will vary sinusoidal with the distance of the point from the fixed end of the string. The distance \( l \) between adjacent nodes is \( \lambda/2 \).

\[
l = \frac{\lambda}{2} = \frac{1}{2} \sqrt{\frac{T_0}{m}} \pi \frac{T_0}{m} = \frac{\pi}{\omega} \frac{1}{\lambda} \pi P \quad \text{...............(2.9)}
\]

\[
P^2 = \frac{T_0}{m \omega^2} \quad \text{.................................(2.10)}
\]

where \( T_0 = \) tension in string/yarn

\( m = \) mass per unit length in gm/cm

\( \lambda = \) wave length in cm

\( \bar{f} = \) frequency of vibration cycles/sec
If \( T_0 \) is in dynes and \( \omega \) is in radian per sec then \( P \) is in cm

\[
P = 94.6 \sqrt[3]{\frac{T_0}{N_n^2}} \quad \text{(2.11)}
\]

Where,

\[
N \quad \text{is the yarn count in tex}
\]
\[
n \quad \text{is the angular speed of the traveller in the thousands of revolutions per minute.}
\]

It is already proved that when the amplitude of the vibration is small, the balloon profile is a close approximation to a portion of a sin curve of half-wave length \( \pi p \), but the height of such a balloon cannot exceed \( \pi p \) without the formation of node.

Let

- The ring radius = \( R \)
- The axial height of the balloon = \( H \)

If \( R/P = 0.38 \) and \( H/P = 2.2 \), the balloon formed would have a maximum radius, similarly if \( R/P = 0.5 \) and \( H/P = 3.6 \), the balloon would have one node with a maximum radius of \( 0.7P \). With the presence of air drag the balloon of smaller radius is stable. For a given value of \( P \), and a given ring radius and a balloon height, the length of yarn in the balloon adjusts itself and at the same time balloon itself takes up the appropriate shape. There is a limiting minimum value of \( P \) for which a balloon without a node can be formed. The maximum possible value of \( H/P \) is being \( \pi \) for a ring of smallest radius. The maximum possible balloon radius is \( P\sqrt{2} \) when \( \theta_0=90^\circ \). \( \theta_0 \) is the angle of inclination of the yarn at the apex of the balloon to the axis of rotation.

**Ballon Shape Without Air Drag**

The air drag on any element of yarn is proportional to the square of the velocity of that element. The work done per revolution in rotating of an element of yarn is to overcome the resistance of the air. Work done is necessary for the spinning system to keep the traveller and balloon rotating at certain constant speed against resistance of air drag. In general greater the air drag on the yarn in the balloon, the greater the tension in the yarn in the balloon.
For a given value of R/H or \( \beta \), the limiting minimum value of P is reduced by the effect of air drag. Air drag allows stable single balloon to be formed for smaller values of P than would be possible without air drag, i.e. as the air drag increases, stable balloon can be formed with decreasing tension or increasing spindle speed. Again for given values of R and H, the maximum diameter of the limiting balloon decreases as the air drag increases.

Air drag and tangential coriolis forces have the same kind of effect upon the inclination of the yarn in the balloon. An important difference is that, while the air-drag forces are cumulative from top to bottom of the balloon, the sign of the Coriolis force changes at the point of maximum diameter of the balloon. The tangential component of tension in the yarn at the traveller represents the total air drag on the balloon. In spinning, the velocity of the yarn along its length is usually small in comparison with its rotational velocity. Air drag force is significant near the traveller but coriolis force can be significant near the thread guide.

Movement of a string along its length also has the effect of reducing the velocity of propagation of transverse waves along the string. For a stationary string,

\[
C_0 = \sqrt{\frac{T_0}{m}} \quad \text{.........................(2.12)}
\]

When the string is moving with velocity \( \nu \) along its length, when the velocity of wave-propagation relative to fixed axis becomes c, where

\[
c^2 = c_0^2 - \nu^2 \quad \text{.........................(2.13)}
\]

The wave-length of stationary waves of small amplitude, \( \lambda \) is still given by

\[
\frac{\lambda}{2} = \pi P \quad \text{.........................(2.14)}
\]

The velocity of the yarn along its length in ring spinning is small compared with its rotational velocities. When the yarn is moving along its length with velocity \( \nu \), the parameter P becomes

\[
P^2 = \frac{T_0 - m\nu^2}{m\omega^2} \quad \text{.........................(2.15)}
\]
2.1.4.7 Forces Acting on Yarn and Traveller

The following forces acting on yarn and traveller are as following:

\[ \text{Centripetal/Centrifugal} = \frac{\pi \ d^2 \rho_1 r \omega^2}{4} \tag{2.16} \]

\[ \text{Air-drag} = C_1 \rho \ d^2 \omega^2 \tag{2.17} \]

\[ \text{Coriolis} = \frac{\pi \ d^2 \rho_1 v \omega}{2} \tag{2.18} \]

Where \( r \) is the radius of rotation of the element and \( \rho_1 \) is the density of the yarn in gm/cm\(^3\).

All these forces together must be provided by the tension in the yarn in order to continue the rotation by the balloon.

(Coriolis force associated with the radial velocity of a rotating particle acts in the direction of rotation when the element of yarn is moving radially outward.)

The ratios of centrifugal to air-drag and coriolis forces are:

\[ \frac{\text{Centrifugal}}{\text{Air-drag}} = \frac{500d}{r} \tag{2.19} \]

\[ \frac{\text{centrifugal}}{\text{Coriolis}} = \frac{r}{2v} \tag{2.20} \]

So air-drag forces are relatively more important for fine yarn, but in practice for balloon diameter air-drag forces are more important for coarse yarn. Coriolis forces are important only when the velocity of yarn along its length is high (low twist spinning).

The effect of air drag in ring spinning is expressed in term of a non dimensional parameter \( \gamma \), and this is
\[ \gamma = \frac{C_1 \rho dP}{2m} \]  
\[ \text{Air-drag force is proportional to the square of air velocity, but the velocity of air is not constant along its length (}\gamma = 3.0 - 0.3).[1,6,7]\]

2.1.4.8 **Yarn Tension**

The spinning tension is proportional

- to the friction coefficient between ring and traveller
- to the traveller mass
- to the square of the traveller speed
- inversely to the ring diameter and the angle between the connecting line from the traveller-spindle axis to the piece of yarn between the traveller and bobbin.

The yarn strength is affected little only by the spinning tension. On the other hand the elongation diminishes with increasing tension, for every tensile load of the fibre lessens the residual elongation in the fibres and hence in the yarn. Increasing tension leads also to poorer Uster regularity and IPI values. If the spinning tension is more, the spinning triangle becomes smaller. As the spinning triangle gets smaller, there is less hairiness.[1,6,7]

**Yarn Tension in Absent of Air-Drag**

Yarn tension is calculated by considering the conditions of equilibrium of the forces acting on the traveller, which is shown in Figure 2.11.

At the condition of equilibrium the forces are balancing in the following way :

\[ C = T_v \cos \alpha + S \cos \nu - T_r \cos \varepsilon_1 \]  
\[ \mu S + T_r \cos \varepsilon_2 = T_v \sin \alpha \]  
\[ T_r \cos \varepsilon_3 = S \sin \nu + Mg \]

Yarn tension at any point can be calculated from the following equation
\[ T_r = T_0 - \frac{1}{2} m r^2 \omega^2 \] .................................(2.25)

The relation between \( T_r \) and \( T_u \) is given by an equation of the form

\[ T_r = T_u \exp(-\eta, \mu) \] .................................(2.26)

where \( \eta \) is the angle of wrap of the yarn around the traveller

\( \mu \) is the coefficient of friction between yarn and traveller

For convenience, it can write as

\[ T_r = aT_u, \ a > 1 \] .................................(2.27)

From the equation 2.22, 2.23, 2.24 and 2.25

\[ T_r = \frac{a\mu C}{\sin \alpha \cos \nu + \mu \cos \alpha - a(\mu \cos \epsilon_1 + \cos \nu \cos \epsilon_2)} \] .................(2.28)

\[ T_0 = \frac{a\mu MR' \omega^2}{\sin \alpha \cos \nu + \mu \cos \alpha} + \frac{1}{2} m R^2 \omega^2 \] .................(2.29)

**Yarn Tension in The Presence of Air Drag**

Force is necessary on each element of yarn to overcome the resistant of air. At the traveller, the magnitude of this tangential component must be such that its product with the circumference of the ring is equal to the work required, per revolution, to rotate the loop of yarn in the balloon against the resistant of the air.

The rate at which work is done against the resistant of the air in rotating the loop of yarn between the thread-guide and the traveller is

\[ \frac{1}{2} C_r \rho d \omega^3 \int r^3 \cos^2 \phi ds \] .................(2.30)
Where, \( \Phi \) is the inclination to the element of yarn(ds) to the axial plane.

After different calculation it has found that

\[
T_r \approx \frac{a(\mu C + E \cos \nu)}{\sin \alpha \cos \nu + \mu \cos \alpha} \quad \quad \quad \quad \text{(2.31)}
\]

\[
T_w \approx \frac{(\mu C + E \cos \nu)}{\sin \alpha \cos \nu + \mu \cos \alpha} + \frac{1}{2} m\omega^2 (R^2 - R_i) \quad \quad \text{(2.32)}
\]

Air-drag and ring traveller friction play a useful part in ring spinning and these two forces combine make a necessary winding tension for the production of a firm package. There is an interesting thing, an increase in air drag force allow to reduce the ring traveller friction, which is created by using of lighter traveller.

2.1.4.9 Friction of Ring, Traveller and Yarn

Ring Traveller Friction

According to the opinion of Luedicke, the co-efficient of friction between ring and traveller

\[ \mu = 0.65 - 0.05n \quad \text{(2.33)} \]

\( n \) = rotational speed of traveller in thousands of revolutions per minute.

But by Fugiro and Shimotsuma, gave the relation

\[ \mu = 0.55 - 0.023n \quad \text{(2.34)} \]

But the effective value of \( \mu \) is less than the above formula because of those value were calculated under fixed-traveller condition.

The value of \( \mu \) was found between 0.1—0.15 by Escher, Luedicke and Honegger[1]. But later Axson gave another equation

\[ \mu = 0.1 + \frac{0.52}{C} \quad \text{(2.35)} \]

where \( C = MR\omega^2 \) is the centripetal force required to keep the traveller rotating.

\( M \) = mass of the traveller in gm

\( R \) = radius of the ring in cm

\( \omega \) = angular speed of the traveller

\( n \) = traveller speed in thousands of revolutions per minute
Yarn Traveller Friction

Yarn tension is always changeable during passing the yarn through traveller and if the co-efficient of friction between yarn and traveller is $\mu_1$, the angle of wrap of the yarn around traveller is $\eta_1$ then

$$\frac{T_r}{T_u} = \exp(-\eta_1 \mu_1) = a \ldots \ldots \ldots \ldots (2.36)$$

Escher measured the value of $a$ with C-type traveller for a angle of wrap 90º and express in the following way

$$a = \frac{1}{2 - 0.4 \sin \alpha} \ldots \ldots \ldots \ldots (2.37)$$

Practically the value of $\sin \alpha$ varies between 0.5 to 0.95, so that the value of $a$ is from 0.55 to 0.62.

Further investigation by direct measurement of balloon-zone and winding-zone tension, it is found that $a$ varies between 0.6 to 1.0, increasing as the value of P decreases. As P approaches the critical minimum value, $a$ appears to become near to unity.

At the point of balloons collapse, P has approximately its critical minimum value. Under these condition, $a \sim 1.0$

The value of $\mu$ will be assumed to be same given by equation (2.38)

For convenience of calculation of $\mu$ the form of equation is as follows:

$$\mu = 0.1 + \frac{0.41}{\text{Ring radius in inches} \times \text{Traveller weight in gm} \times n^2} \ldots \ldots \ldots \ldots (2.39)$$

where $n$ is the traveller speed in thousand of revolutions per minute.

From the above equation it is clear that co-efficient of friction is very little dependent on spindle speed.[1]
2.1.5 Limitations of Ring Spinning

Ring Size

There are some limitations of ring spinning machine and the first one is ring size. Ring size must be kept limited for certain dimension. Traveller must rotate one time around the circumference of ring only for one twist. The path of traveller is more for large ring than small one for same amount of twist. At normal production speed, the longer path of traveller for larger ring is not scientifically realistic. It decreases the life of traveller. On the other hand, the ring cannot be too small that bobbin can hold only a small amount of yarn. In that case bobbin will be full of yarn within short time, which makes the higher cost of bobbin changing.

It is clear, for a high speed machine that the ring diameter must be smaller and clearly there is a limit, how smaller the ring should be. Because of the volume of yarn on the package is less than

\[ \rho(\pi/4)(d_1^2 - d_2^2)l \]

Where, \( d_1 \) is the outer diameter of package and \( d_2 \) is empty bobbin diameter and \( l \) is bobbin length. The amount of yarn must be kept in mind.

The diameter of full bobbin must be less than the inner diameter of the ring. Currently the ring diameter is varying from 36-53 mm and the inside diameter is less 3-4mm. Smaller ring means not only reducing the amount of produced yarn stored but also insisting the machine more frequently doffed (replace empty bobbin by full bobbin).

Traveller Speed and Temperature

One of the major limitations of ring spinning machine is the traveller speed. With non rotating steel ring and steel traveller the linear speed of traveller is limited to approximately 30m/sec. This limit arises because non lubricated traveller makes micro welds with the surface of the ring, which are immediately broken as the traveller goes on its way. It arises temperature of the Traveller to 300-400°C and al last the traveller breaks and flies out from the ring.

Another speed limit also exists when spinning highly twisted yarn of medium to fine count from cotton and polyester blend fiber. In that case the speed has to reduce to a level that suits the prevailing conditions. The heat dissipation of traveler is approximately
linearly proportional to spindle speed and the traveller has to be able to dissipate the generated heat by conduction, convection or radiation. For insufficient lubrication, the limit of safe temperature for the yarn and the traveler is exceeding at high speed and in that case the polymeric structure of fiber is affected and also the metal structure of traveller is changed, weaken and finally broken. The solution of the problem is to the reduction of spindle speed. But everyone is looking for higher speeds to improve economic performance.

**Production**

Compared to other spinning methods, the production of ring spinning is lower due to low speed of traveller. Figure 2.12 shows the comparison of different spinning methods at different points of views including production.

**Yarn Tension**

Yarn tension is also a limiting factor for ring spinning, because of its negative impact on ends breaks. The probability of end breaks is determined by statistical distributions of yarn strength and tension. A definite specific yarn tension must be needed for arranging parallelization of fiber in yarn axis for a pact yarn. Without a minimum tension it is impossible to make a spun yarn. But this tension is varied during up and down movement of ring rail. The majority of end-breaks occur as the ring rail approaches its topmost position in the traverse, rather than on the down stroke.

**Power Consumption**

Power consumption is also a large problem of ring spinning. In ring spinning system the winding and twisting occurs simultaneously at the same time and for one complete revolution of the package only a few mm of yarn winds-up on package. Always it needs to rotate the yarn package not only for winding but also for twisting. A large amount of power is needed for this laborious work. [1-7]
2.1.6 Modification of Ring Spinning
The original basic principle of the ring spinning is being taken constant but some extra technology is attached to the main frame for modification of yarn structure. The basic modification takes place in the region of spinning triangle. The arrangement of fiber in yarn structure is not similar to one another but all the yarn are twisted by the same principle of conventional technique.

Compact Spinning
In this technique a pair of compacting roller is attached in front of the front roller at the place of out going drafted fiber strand. Spinning triangle of the compact spinning is shorter than conventional. As a result hairiness of the yarn is much lower than conventional.

Solo-Spun Technique
The main element of Solospun is a pair of Solospun rollers fixed on the conventional ring spinning frame. The drafting process of solo spun is similar to the ring spinning but formation of yarn is different. A drafted strand enters the nip of solospun roller which divide the drafted strand into two or three sub strands. A primary twist is individually given to the substrands before leaving the solospun roller and then finally all substrand are twisted together to make a solospun yarn.[22]

Siro-Spun Technique
In this technique two drafted strand are combined after passing from the nip of front roller and twisted at the same principle of conventional technique. Some twisting of the single strands occurs above the convergence point so that a two-fold structure of yarn is obtained. This yarn exhibits also lower hairiness than conventional.[23]

Jet-Ring Spinning
A Jet nozzle is set up between the front roller delivery and the pigtail of ring spinning frame. So the drafted strand first enters into the jet nozzle without pigtail of ring spinning and then is twisted by conventional ring traveller system and the next step is to winding on the bobbin. The newly integrated Jet-Ring spinning system ingeniously combined features of both ring and air-jet spinning technology.[24]
2.1.8 Modern Spinning Systems

For the continued strong limitations, the ring spinning research began at the end of the 1960 with the target of high production at low cost. Research institute, machine builders and several independent inventors have invented a large range of operable and semi-developed different possibilities of spinning system. One common aims of modern spinning systems is to exceed the limitations and improved performance of ring spinning. This is mainly achieved by separating the process of yarn formation named twisting that of yarn winding-on package. This is the way the quality yarn can be manufactured at high speed with low winding cost.

The generic name of new spinning system is open-end spinning. The production rate of this modern machinery is 6-10 times higher than ring spinning machine. In these modern spinning systems twisting and winding of yarn is separated. But fiber binding systems are not similar to ring spinning; they are different e.g. open end twist, false twist and wrapping. Although fibers are binded themselves by wrapping of surface fibers. These binding systems have low ability to bind up the fiber strongly to one another. As a result yarn has low strength but some open-end yarn has good evenness character. Yarn manufacturing process sequences are shorter than ring spinning process, because of two processes (simplex, winding) are overall not necessary for yarn production. Some of the modern spinning systems are:

- Rotor spinning
- Air-jet spinning
- Friction spinning
- Electrostatic spinning
- Wrap spinning
- Composite yarn spinning

After all, these systems can produce only coarse to medium count low strength yarn with high rate.

So till today no one can win over ring spinning system for its capability to spin a large range of yarn count, softness and good strength of yarn[6,7].
2.2 Fundamentals of friction

2.2.1 Friction and Frictional Forces

Friction is the resistance to motion during sliding or rolling, that is experienced when one solid body moves tangentially over another with which it is in contact. The resistive tangential force which acts in a direction directly opposite to the direction of motion is called the frictional force. There are two main types of friction that are commonly named: dry friction and fluid friction. Dry friction is also named “Coulomb” friction. Dry friction describes the tangential component of the contact force that exists when two dry surfaces move or tend to move relative to one another. Fluid friction describes the tangential component of the contact force that exists between adjacent layers in a fluid that are moving at different velocities relative to each other as in a liquid or gas.

If two solids bodies are loaded together and a tangential force \( F \) is applied, then the value of tangential force that is required to initiate motion in one of the bodies is the static frictional force, \( F_{\text{static}} \) or \( F_s \). It may take a while before relative motion is initiated at the interface. The tangential force required to maintain relative motion is known as the kinetic friction force, \( F_{\text{kinetic}} \) or \( F_k \). The static friction force is either higher or equal to the kinetic friction force.

However, the amount of force required to move an object starting from rest is usually greater than the force required to keep it moving at constant velocity once it is started. Therefore two coefficients of frictions are sometimes quoted for a given pair of surfaces (i) a coefficient of static friction (\( \mu_s \)) and (ii) a coefficient of kinetic friction (\( \mu_k \)). In general, the coefficients for static and kinetic friction are different. The static friction coefficient does not characterize static friction in general, but represents the conditions at the threshold of motion only. Nature of static and kinetic friction is shown in Figure 2.13.

When two surfaces are moving with respect to one another, the frictional resistance is almost constant over a wide range of speed. This coefficient is typically less than that of static friction, reflecting the common experience that it is easier to keep something in motion across a horizontal surface than to start it in motion from rest.

If two solids surfaces are clean without chemical films and adsorbents, high friction occurs. Surface contaminants or thin films affect friction. However a small quantity of
liquid present at the interface results in liquid-mediated adhesion, which may result in high friction, especially between two smooth surfaces.

Frictional force can be either desirable or not desirable. Without friction it would be impossible to walk, to roll the automobile tires on a roadway or pick up of objects. Even in some machine applications such as, vehicle brakes and clutches and frictional transmission of power (such as belt drive), friction is maximized. However in most other sliding and rotating components such as bearing and seals, friction is undesirable. Friction causes energy loss and wear of moving surface in contact. In this case friction is minimized.[31,32]

2.2.2 Laws of Sliding Friction

Several famous scientists and engineers contributed to understand the friction. They include Leonardo da Vinci, Guillaume Amontons, John Theophilus Desaguliers, Leonard Euler, and Charles-Augustin de Coulomb. Their findings are codified into these laws:

**First Law:** The force of friction is directly proportional to the applied load and co-efficient of friction (static or kinetic) is independent of the normal load. (Amontons 1st Law)

\[ F = \mu N \]  \hspace{1cm} (2.41)

Where \( \mu \) is a constant known as co-efficient of static friction (\( \mu_s \)) or kinetic friction (\( \mu_k \)), which is independent of the normal load.

Alternatively, it is often convenient to express this law in terms of constant angle of repose or frictional angle \( \theta \) defined by

\[ \mu_s = \tan \theta \]  \hspace{1cm} (2.42)

where, \( \theta \) is the angle of inclination of any body or any weight, placed on a plane inclined at an angle less than 90° from the horizontal, will remain stationary but than if the inclination angle is increased to \( \theta \), the body will start to slide down.
**Second Law:** The co-efficient of friction is independent of the apparent area of contact between the contacting bodies. (Amontons 2nd Law)
Thus two bodies, regardless of their physical size, have the same coefficient of friction.

**Third Law:** Once motion start the coefficient of kinetic friction is independent of the sliding velocity. (Coulomb's Law). There is clear distinction between static friction and kinetic friction. These three laws are entirely empirical.

From the above equations, it can be generally summarized as following:

- The frictional force is proportional to the normal force between the contacting surfaces.
- The frictional force is independent of the velocity of motion
- The frictional force is independent of area of contact

This general description of friction has practical utility; it is by no means a precise description of friction. Friction is in fact a complex phenomenon which cannot be represented by a simple model.

The basic laws of friction are generally obeyed with a little variation which is within a few percentages in many cases. It should be emphasized that coefficient of friction(\(\mu\)) is strictly constant only for a given pair of sliding materials under a given sets of operating conditions (temperature, humidity, normal pressure and sliding velocity). The coefficient of static and kinetic friction in dry and lubricated contacts for many materials shows dependence of normal load, sliding velocity and apparent area.[32]

### 2.2.3 Basic Mechanisms of Sliding Friction

Amontons, Coulomb and other early investigators proposed that metallic friction can be attributed to the mechanical interaction of asperities of the contacting surfaces. According to Coulomb model, the action of the wedge-shaped asperities cause the two surfaces to move apart as they slide from position (a) to position (b) and they again come close to position (c), which is shown in Figure 2.14.

At the first step work is done for raising the asperities from position (a) to (b) (\(\mu=\tan \theta\)) and the normal load does an equal amount of work on the system and most of the potential energy is stored in the first phase of the motion is recovered as surfaces move from position (b) to (c). Only a small fraction of energy is dissipated in sliding down the asperities. This is a mechanism of energy dissipation.
So friction is a dissipative process.

During sliding if there is a negligible interaction between the adhesion and deformation processes, then the total intrinsic frictional force is as follows:

\[ F_i = F_a + F_d \quad (2.43) \]

Here, \( F_a \) = Force needed to shear adhered junction

\( F_d \) = Force needed to supply the energy of deformation

The Co-efficient of friction due to both adhesion and deformation processes, the magnitude of friction is influenced by the physical and chemical properties of the interacting surfaces, the load, the sliding velocity, the temperature, humidity and so on.[32]

2.2.4 Parameters Effect on Friction

A. Surface Roughness

The solid surfaces, irrespective of the method of formation contain irregularities or deviations from the prescribed geometrical form. These irregularities of the surface texture are the roughness of the surface. Another way, it can be explained that surface roughness (nano and micro) is the variations in height of the surface relative to a reference plane. It may be measured either single line profile or along a set of parallel line profiles. Normally it is denoted by \( R_a \). Another measure of surface roughness is an extreme-value height descriptors \( R_t \). The texture of most engineering surfaces are random, either isotropic or anisotropic, and either Gaussian or non-Gaussian and these surface height distribution depends upon the nature of the processing methods. In addition to surface deviation, the solid surface itself consists of several zones having physico-chemical properties peculiar to the bulk material itself.

Always surface contains various form of irregularities ranging from shape deviation to intermolecular distance of irregularities. There is no machining method exist, that can produce a molecular flat surface on conventional materials. Even the smallest surfaces also contain irregularities that the heights of irregularity are more than inter atomic distances. Surface texture includes roughness, waviness, lay and flaws. The texture of solid surface is shown in Figure 2.15. The properties of solid surfaces are also responsible for surface interaction.
Bowden and Tabor [34] proposed that high pressure is developed at individual contact spot during sliding of two metals and that point causes local welding. Later it was argued by them [35,36] that asperities do not have to weld, the interfacial adhesion between asperities is sufficient to account for friction of metals and ceramics. Force is required to overcome the always newly developed adhesion between contacting surfaces and also required to micro scale deformation of surfaces during relative motion.

Surface roughness and the mechanical properties of the mating surfaces are mainly responsible for the elastic or plastic contact of between surfaces. According to surface roughness and the mechanical properties of the contacting surfaces, contacts can either be elastic or plastic. For elastic contacts,

\[ \mu_a \approx \frac{3.2 \tau_a}{E(\sigma_p / R_p)^{1/2}} \]  

Where E = composite or effective elastic modulus
\( \sigma_p \) = composite standard deviation
R_p = composite radius of summit
\( \sigma \) = composite standard deviation of surface height
\( \beta \) = composite correlation length

In case of single asperity contact or constant number of contacts, \( A_r \) is proportional to \((N)^{2/3}\). Therefore at this situations,

\[ \mu_a \propto N^{-1/3} \]  

is not independent of load for these situation

For plastic contact,

\[ \mu_a = \frac{\tau_a}{H} \]  

Where, H is the hardness of the softer of the contacting materials.
\( \mu_a \) is independent of the surface roughness unlike that in elastic contacts.

Typical data for effect of roughness on \( \mu \) for elastic and plastic contact situations are presented in Figures 2.16 and 2.17. In elastic contact situation of a thin-film disk against a ceramic slider, \( \mu \) decreases with an increase in roughness. In the plastic contact situation
of copper against copper, moderate range of roughness, μ is virtually independent of roughness. It tends to be high at very low roughness because of the growth of real area of contact; it also tends to be high at very high roughness because of mechanical interlocking.

B. Asperities

Asperities are referred to as peaks in a profile (two dimension) and summits in a surface map (three dimension). Nano- micro roughness includes those features intrinsic to the production process. These are considered to include traverse feed marks and other irregularities within the limit of roughness sampling length.

When two nominally flat surfaces are placed in contact under load the contact takes place at the tips of the asperities, the load being supported by the deformation of contacting asperities; and discrete contact spots (junctions) are formed. This is shown in Figure 2.18. The sum of the areas of all the contact spots constitutes the real (true) area of the contact \( A_r \) and for most materials under normal load, this is only a small fraction of the apparent (nominal) area of contact \( A_n \). The proximity of the asperities results in adhesive contacts caused by either physical or chemical interaction. When these two surfaces move relative to each other a lateral force is required to shear to the adhesive bonds formed at the interface in the regions of real area of contact. Rupture occurs in the weakest regions, either at the interface or in one of the mating bodies. After shearing off the existing contacts, new contacts are formed. Because adhesion arises from molecular forces between the surfaces, the adhesive force are of the same nature as the forces existing between the molecules themselves. Consequently, the interface may be as strong as the bulk material and during sliding the shearing process may actually tear out fragments of the materials. In that case, the friction force would depend on the bulk shear strength of the materials.

If asperities of one surface are much smaller in lateral dimensions than that of the mating surface and contact stresses are lower than plastic flow stress, sharper asperities climb up and down over broader asperities without creating any interface damage. Energy (or force) is required to climb up the asperity of a given slope and it decreases during climbing down. It is not a totally non-dissipative process (frictionless roller coaster) since the energy expended in ascending is higher than the energy in descending the asperity slopes. In sliding down the asperity, there may be impact and energy may be lost either by
impact deformation or by the generation of phonons. It is reported by Samuels and Wilks [37] that up to 10% of the energy used in ascending the asperities is lost during the descent. This dissipative mechanism is sometimes referred to as the ratchet (ride-over) mechanism.

C. Area of Contact
Courtney-Pratt and Eisner [38] has argued that in most cases with plastic contacts particularly in the case of ductile metals, there is a growth in contact area under the influence of combined normal and tangential stresses and this affects friction. The growth in contact area occurs because plastic yielding of contact is controlled by the combined effect of the normal (p) and tangential (or shear) stresses (τ) according to the form of the asperities of general shape.

In the case of plastic contacts, when the normal load is first applied, the local pressure at asperity tips rapidly approaches the mean contact pressure H under full plasticity, and at a particular location, a contact area $A_r = \frac{N}{H}$

If the normal load remains in constant then the maintenance of plasticity allows the real area of contact to grow. As a first approximation,

$$A_r = (A_r)_0 \left[ 1 + a \left( \frac{F}{N} \right)^2 \right]^{-1/2}$$

(2.48)

where, $(A_r)_0$ is the real area of contact without any shear stresses. Another factor that influences the area of contact is the rise of interface temperature caused by frictional heating. Bhushan [39] has shown that under high load and speed conditions, this could have a substantial effect on the area of contact and consequently friction.

When one sphere comes in contact with the other, the real area of contact starts to grow and becomes maximum when one sphere is directly above the other, the area starts to decrease, as one sphere moves away. The center of the contact moves at approximately half the relative sliding velocity with respect to each asperity. The contacts can be either elastic or plastic. The stresses and contact area in an elastic contact are calculated from the geometrical interference using the Hertz elasticity equations. The stresses and contact area in a plastic contact are calculated using Green’s plane-strain slip-line field analysis. Rabinowicz [40] has argued that the real area of contact is much larger than that given by deformation as a result of applied load because of the work of adhesion.
For interfaces with high $W_{ad}$, the contribution of surface energy to the real area of contact can be large. At that case, the coefficient of friction is

$$\mu = \frac{t_a}{H} \left[ \frac{1}{1 - 2W_{ad}/(rH \sin \theta)} \right] - \frac{t_a}{H} \left( 1 + K \frac{W_{ad}}{H} \right)$$  \hspace{1cm} (2.49)

Suh and Sin [41] has referred K as a geometric factor. In the presence of surface energy $\mu$ is high when $W_{ad}/H$ is large or roughness angle is small, is presented in Figure 2.19. Rabinowicz [40] has shown that the friction is a function of a change in free surface energy for metals.

**D. Shear Strength**

From classical theory of adhesion to a very rough first approximation, the friction force ($F_a$) is defined by Bowden and Tabor [33] as follows. For a dry contact,

$$F_a = A_r \tau_a$$  \hspace{1cm} (2.50)

and for a contact with a partial liquid film,

$$F_a = A_r [ \alpha t_a + (1-\alpha) t_1]$$  \hspace{1cm} (2.51)

and

$$\tau_1 = \frac{\eta_1 V}{h}$$  \hspace{1cm} (2.52)

Where $\tau_a$ and $\tau_1$ are the average shear strengths of the dry contact and of the lubricant film, respectively; $\alpha$ is the fraction of un lubricated area; $\eta_1$ is the dynamic (absolute) viscosity of the lubricant; $V$ is the relative sliding velocity; and $h$ is the liquid film thickness.

If shear occurs in one of the sliding bodies, the shear strength of the relevant body should be used. For a single crystal, the shear stress required to produce slip over the slip plane in the absence of dislocation is on the order of $G/30$, where $G$ is the shear modulus of the material. If dislocations are present, shear strength would be on the order of thousand times less. Interfacial shear strength used for calculating friction should be measured at appropriate strain rate. From Bhushan[42], it is assumed that the depth of a shear zone is equal to the linear dimension of a wear particle. If it is assumed that the average size of a wear particle is 1 $\mu$m for a sliding speed of 1 m/s, the shear-strain rate would be $1 \times 10^6$ s$^{-1}$. The interfacial shear process is unique insofar as it corresponds to vary high rates of
strain which is different from the conventional bulk deformation process. Hence, the correlation between the interface shear process and those in bulk shear is highly approximate. Further it may be noted that shear rate involved in shear are generally in order of magnitude or more higher than that in real area of contact analysis.

E. Adhesion

During sliding of two bodies, one contact body with other and in their contacting points, molecule of the both material want to make bonds between one another and this is called adhesion. When these two surfaces move relative to each other, a lateral force is required to shear the adhesive bonds formed at the interface in the regions of real area of contact. The adhesion strength of the interface depends upon the mechanical properties and the physical and chemical interaction of the contacting bodies. The adhesion strength is reduced by reducing surface interactions at the interface. Presence of contaminants would reduce the adhesion strength. The boundary conditions of two interfaces (presence of humidity or liquid) help to form adhesive bridge and even in some cases dominating overall friction force. Adhesion arises from molecular forces between the surfaces and the adhesive forces are of the same nature as the force existing between the molecules themselves. [43-47]

Adhesion is always present at an interface and it has a less or more contribution to friction.

Thus, the coefficient of adhesional friction (μ_a) is given by

\[ \mu_a = \frac{A_r \tau_a}{N} \quad (2.53) \]

This co-efficient of adhesion friction is also depend on shear strength of the material

The coefficient of adhesional friction for a dry contact is

\[ \mu_a = \frac{\tau_a}{P_r} \quad (2.54) \]

where, P_r is the mean real pressure.

A contribution to friction due to adhesion is always present at an interface. In boundary lubricated condition and/or unlubricated interfaces exposed to humid environments, the
presence of liquid may result in formation of menisci or adhesive bridges and the meniscus/viscus effects may become important, even in some cases dominating the overall friction forces.

F. Ploughing
Two types of interactions can occur during sliding of two surfaces with respect to each other, the microscopic interaction where primarily plastic deformation and displacement of the interlocking surface asperities are required and the macroscopic interaction where the asperities of the harder material either ploughs grooves in the surface of the softer one via plastic deformation or results in fracture, tearing or fragmentation. These interactions are shown in Figure 2.20.

Ploughing of one or both surfaces can also occur by wear particles trapped between them, and truly macroscopic ploughing of the softer material by the harder one with the dimensions of the ploughed groove being orders of magnitude greater than those of the asperities on either surface. Ploughing deals with relatively large volume deformations and small strains, whereas the shearing mechanism and local asperity interactions involve very thin interfacial regions (a fraction of a nanometer thick) and large strains. During any relative motion, adhesion and asperity interactions are always present. The ploughing contribution may or may not be significant; its magnitude depends on the surface roughness and relative hardness of the two surfaces and on the size, shape and hardness of any wear debris and reaction products trapped between them. Before the onset of sliding between two surfaces, the coefficient of static friction plays a vital role. Energy can be dissipated through the deformation of contacting bodies during sliding where no groove (macro-scale deformation) is produced. For adhesional friction Such and Sin [41] has reported that the usual approach to the analysis of the micro-scale deformation of a single asperity is the slip-line field theory of a perfectly rigid material, similar to that used by Green [45]. However, in this analysis, does not depend on adhesion.

G. Chemical
The relative chemical activity of the transition metals (metals with partially filled d shells) as a group can be ascertained from their percentage of the d-bond character. Rigney and Buckley [46-48] argued that the greater the percentage of the d-bond character the less active is the metal and the lower is the friction. The coefficients of
friction for various metals in contact with Ni-Zn ferrite as function of the d-bond character of the transition metal are shown in Figure 2.21. There appears to be good agreement between friction and chemical activity of the transition metals.

This figure also presents the coefficient of friction for various metals in contact with the Ni-Zn ferrite in which both metal and ferrite specimens are exposed to $O_2$ gas. The data reveal that increase in friction with an exposure to $O_2$ gas. The adsorption of oxygen on argon-sputter-cleaned metal forms an oxide surface layer that increases the coefficients of friction for the Ni-Zn ferrite-to-metal interface. The enhanced bond of the metal oxide to ferrite may be due to the formation of complex oxides on establishing contacts.

H. Structural Effect

Hexagonal close-packed (HCP) metals exhibit low coefficient of friction (about 30%) less and much less wear (about a factor of ten ) than face-centered cubic (FCC) metals. One key factor which affects friction and wear is the number of slip planes. Hexagonal metals have a limited number of slip planes. Five slip planes are required so that as two rough surfaces deform at each contact, there is perfect conformance between one surface and the other. Accordingly hexagonal metals like cobalt deform by slippage when pressed against each other leaving many air gaps at each junction, shown in Figure 2.22.

I. Grain Boundary

Strained metal that is metal that contains a high concentration of dislocations is chemically more active on the surface because the presence of defects increases the energy in the material. A grain boundary is a strained condition in that there are many dislocations present to accommodate the misfit or mismatch in adjacent orientations, and there are rows of strained atoms that must help in accommodating the mismatch. Consequently, these regions are high-energy regions at the surface. Bushan [32] reported that the energy is greater at the boundary and the boundary has its own characteristic energy that is separate and distinct from the energy of the grains on either side of the boundary.

J. The Breaking Loose Effect

Fridman, Levesque, [49] suggest that when external vibration is applied to a friction interface, the vibration exerts a force on weld junctions that have formed and breaks some of them decreasing the real area of contact and thus decreasing the frictional force.
According to the adhesion theory of friction, the majority of friction is due to an intermolecular adhesion between two surfaces at the points of contact. The adhesion theory of friction states that geometrically, one may view a material surface as being rough, consisting of asperities of different heights and sizes which will deform under pressure. When two surfaces are brought into contact, initially only three points are in touch, but as the load increases the initial three points become enlarged to small areas and new contact point sits in. These points of contact are called “weld junctions” and total area of these weld junctions is the real of true area of contact \( A_c \). The friction force \( (F_f) \) will then be equal to the real of contact area times the bulk shear strength \( (\tau_y) \). The following equation states that the frictional force is proportional to the real area of contact. Therefore, if some of the weld junctions are broken, decreasing the real area of contact, friction will decrease.

\[
F_f = \tau_y A_c
\]  

(2.55)

K. Operating Condition

Peterson et al., 1960; Bowden and Tabor, 1964; Buckley, 1981; Hutching, 1992; Rabinowich, 1995; Blau, 1996 stated that, the coefficient of friction of metal and alloy is affected by operating condition e.g. surface cleanliness, sliding velocity, contact pressure, temperature, gaseous environment, and relative humidity etc.

The coefficient of friction as a function of load for a steel slider on unlubricated aluminium in air is shown in Figure 2.23(a). The coefficient of friction remains essentially constant although the load is varied by a factor of \( 10^5 \). But the coefficient of friction may not remain constant in the case of materials with surface films which are either deliberately applied or are produced by reaction with environment. Rabinowicz, 1995 states that, this transition is common in other material as well. Again, in many metal pairs, in the high load regime, the coefficient of friction decreases with load, Fig 2.23(b). Increase surface roughening and a large quantity of wear debris are believed to be responsible for decrease of friction.

Rabinowicz, 1995; shows that coefficient of friction for wooden sliders on an unlubricated steel surface as a function of apparent area of contact in air is approximately constant and is not dependent on apparent area of contact.

Rabinowicz, 1995, shows that coefficient of friction a little bit depends on sliding velocity and this result carries out titanium sliding on titanium at a normal load of 3
Newton. Figure 2.24 shows that the coefficient of friction changes by only a few percentage for a change in velocity of an order of magnitude. Bhushan, 1981; states that, high normal pressure and high sliding velocity can result in high interface temperature that can significantly reduce the strength of most material and in some cases, localized surface melting reduces shear strength and friction drops to a low value.

K. **Vibration**

Experiments were conducted by Godfrey [50] to determine the effect of vibration on friction and found that for both at the lubricated and the un-lubricated conditions apparent kinetic friction decreased rapidly after the acceleration of vibration was increased and exceeded that due to gravity. The friction tracing without vibration is shown in Figure 2.25b.

Thus with vibration, the frictional value of copper sliding on steel would have been reported as an average of 0.16 and without (or at least with less) vibration, the value becomes 0.19, shown in Figure 2.25. This result shows that in cases like this the highest friction value should be reported because it is the value for the least vibration. The data indicated that the vibration periodically reduced metal to metal contact due to reduced load. Vibration reduces load momentarily which results in reduced metal contact. Thus an apparent reduction of the coefficient of friction was observed. Microscopic observation of the un-lubricated wear tracks on the plate showed absence of galling, brown film formation and marked plastic deformation during sliding with vibration.

The effect of vibration on the coefficient of friction for lubricated surface was measured by Godfrey [50]. In Figure 2.26, the friction data are plotted against the acceleration of the plate at frequencies of 100, 500 and 1000 cycles/sec. Under the test conditions, as shown by Godfrey, [50] sliding velocity had no effect on the relationship of vibration and friction which is contradictory with the observation presented by Bhushan and Jahsman [51].

Preliminary runs showed that the kinetic friction was reduced by vibration with un-lubricated steel on steel. Therefore the basic cause appeared to be independent of the pressure of oil; and all further experiments to determine the mechanism were conducted un-lubricated surface. In Figure 2.26 three frequencies were used and the slowest speed of 0.02 cm/sec is shown. Vibration reduced kinetic friction for un-lubricated sliding. The
curves are similar in shape to the curves of lubricated runs; but the friction was higher and slightly greater accelerations were required to reduce friction to 0.1. Godfrey [50] observed that at very high vibrational frequencies, friction could be reduced to values that appeared to approach zero, but the system became unstable. Figure.2.27 also showed that friction remains constant up to approximately 762 cm/s\(^2\) and decreases with increasing acceleration beyond that value. These data suggest that there is reduction in load between the rider and the plate when the plate is pulled down faster than the rider assembly can fall due to gravity (acceleration due to gravity is 980 cm/s\(^2\)). Therefore in the gravity-loaded system, the following experimental observations were made.

1. Vibration reduced the apparent friction during lubricated and un-lubricated sliding. During un-lubricated sliding, vibration eliminated scuffing and increased plastic deformation.

2. Friction was apparently reduced when the acceleration of the vibrating plate approached and exceeded the value of acceleration due to gravity.

The effect of induced vibration on friction is important both in the case of static and kinetic friction. A distinct effect of induced vibrations on friction for low sliding speed has been observed by Lenkiewicz [52] which results in a decrease in the frictional force values of up to 15% of the original value. Broniec and Lenkiewicz[53] reported that sinusoidal vibration in the contact area caused a decrease in the coefficient of static friction of about 60% which is important especially in design of machine connections where vibration occurs. The friction induced vibration has been studied separately by several investigators including Hess and Soom,[54] Lin and Bryant [55], Ko and Brockley[56]. Different types of vibration induced by friction have been reported in the literature depending on the normal load, sliding speed and the nature of the contact surfaces. It is apparent that there exist several distinct mechanisms that can excite different types of oscillations. B.V. Budanov et al, [57] explained the mechanism of oscillations of the rigid slider when it moves over a relatively compliant body. This process has been shown to reduce the frictional coefficient of the pair and this is particularly noticeable with an increase in sliding speed leading to greater amplitude of the normal oscillations of the slider. The existence of a particular base frequency of contact micro-oscillations is responsible for the existence of a resonance effect for the
friction coefficient depending on the frequency of the forced oscillations applied to the system.

It is an established fact that friction generates vibration in various forms, while vibration in turns affects friction. Two forms of this relationship exist, (i) the possibility of self excited frictional oscillations in the course of friction and (ii) the possibility of reducing friction through forced oscillations of the friction pair.

A concept in an analysis of friction-vibration interaction is extremely important; oscillations are coupled in complex elastic systems whatever the friction-assembly structures used in practice. This means that the normal, tangential, longitudinal and tangential-transverse vibrations of a slider cannot take place independently. When one of them appears, so do the others as a rule. The coupling pattern depends on the closeness of the natural frequencies of the corresponding vibrations and on the nature of the coupling.

The friction contact between rubbing surfaces is formed under the influence of normal and tangential loads. In first approximation the slider may be compared to an ideally rigid body resting on a system of micro-springs that model the elastic properties of the surface irregularities. Thus, the slider is capable of executing free oscillations in the normal and tangential direction. Since the amplitudes are small, their fundamental frequency will be close to the natural frequencies of the linear oscillations which is

\[
\omega_{\text{os}} = \sqrt{\frac{k_n}{m}} \quad (2.56)
\]

\[
\omega_{\text{ot}} = \sqrt{\frac{k_t}{m}} \quad (2.57)
\]

The slider oscillations normal to the surface of sliding (contact vibration) are nonlinear and asymmetric, since the slider descends, new smaller asperities come in contact and the contact stiffness is not constant. The stiffness increases as the slider descends and reduces to zero as the slider rises. An increase in the amplitude of the normal slider oscillations increase its average level above the opposing body and leads to a reduction in the average number of asperities making contact in a given time and to decrease in their total area; as a result the force of static friction diminishes.

At instants at which the vibrational displacement causes a decrease in the initial contact deformation slippage begins with a shearing force that is less than the static friction force. This corresponds to a decrease in the normal load by inertial forces. If in the absence of
free contact vibrations the slider commences to slip only when the shearing force $\sigma_s$, exceeds the static friction force $F_s$, then when such oscillations are excited slippage will begin, provided the following condition is satisfied.

$$\sigma_s F_s - \Delta T - f_0 m a_n \omega^2 \quad (2.58)$$

During the sliding process the free contact oscillations of the slider are maintained continuously owing to collisions of the micro-asperities of slider and opposing body. By virtue of the complex roughness profile it is natural that the force oscillations excited by friction will be polyharmonic, which is clear from Figure. 2.28.

Excitations of the free tangential oscillations of the slider reduce the limiting value of the friction force owing to the appearance of additional inertial forces. In this case slippage commences if

$$F_T - ma_n \omega^2 \quad (2.59)$$

Thus the force of sliding kinetic friction is always reduced somewhat by contact oscillations excited by the friction itself, while the static friction force is also reduced somewhat by free oscillations of the slider both along the normal and in a tangential direction. These oscillations excited by the microseisms that always occur with amplitude ranging from tenths of micrometer to hundreds of micrometers.

The causes of reduction of frictional coefficient due to vibration as explained by D. M. Tolstoi et al., 1971 [58] are as follows;

1. A steel ball falling on the slide at rest causes an elastic deflection and rebound as a train of damped oscillations. The first rebound takes the slide out of contact if the tangential external force is less than the boundary frictional force, observed by Tolstoi [59].

2. Tangential self-exciting oscillations (jerky sliding) cause each jump to occur when the tangential external force reaches the boundary force (static force) which generates a train of normal free vibration. Tolstoi and Kaplan [60] stated that these reduce $F$ and this is the cause of the jerky sliding, because the damping of the normal vibrations completely eliminates the difference between the forces of static and dynamic friction. These normal vibrations arise in a very simple way, as they are excited by the normal components of the shocks arising from collision of opposing projections. These shocks increase in magnitude with the speed and hence $\Delta F/F$ increases in the small way. This accounts for the falling velocity characteristic of the friction in the absence of lubrication and hence to
the instability of a slide with an elastic drive. The instability involves first a rise and then a fall in the amplitude of the normal vibrations and this involves a fall in F followed by a gradual recovery to the static value. The entire process takes about 1 millisecond.

3. Grigorva and Tolstoi [61] argued that an indirect effect from the normal vibrations is the markedly resonant response of friction force to forced normal vibration. But since many different effects occur at vibration assistance and the significance of the different effects varies with surface pressure, amplitude, material, frequency, surface roughness etc., Skare and Stahl [62] has concluded that no clear correlation has, as yet, been determined.

The measurements of static and dynamic frictional forces by Skare and Stahl [62] under the influence of external vibrations indicate three different or opposite trends and these trends are:

(i) The frictional force is increased by vibrational assistance.
(ii) The frictional force is not changed or slightly changed by vibrational assistance.
(iii) The frictional force is reduced by vibrational assistance.

These trends are observed when the parameters involved in the process i.e. normal force, amplitude, frequency, material and surface are changed. Thus the frictional force may be increased or decreased as a result of an adequate choice of parameters. The investigation by Skare and Stahl [62] shows that either an increase or a decrease in the frictional forces can be obtained when one of the parameters like, surface pressure, frequency or amplitude is changed. The above results indicate the domain of specific behaviors i.e. certain mechanisms cause a friction to increase while others to decrease. In some cases, the mechanisms are balanced and will not affect the friction. The frictional force can be weakened mainly through a separation of the surfaces or strengthened by welding phenomena in the contact surfaces.

A decrease in frictional force can be obtained through

- resonance between the natural frequency of the contacting asperities and that of the external vibration,
- reversal of the friction vector,
• superposition between static and dynamic load, which means that a lower tangential force is needed to initiate the sliding of materials in the friction surface or

• local transformation of vibration energy into heat energy in the friction surface, so that the yield point of the material is lowered.

An increase in the frictional force can be obtained

• viscous damping of the friction surface,

• increased adhesion or micro welding (pick-ups) between the materials or

• deformation and material hardening of the material

The complexity of friction makes it different to identify the basic mechanisms responsible for these results. However, a separation of interactive friction and wear mechanisms has been made by Vingsbo [63], where interactive mechanisms are common phenomena such as heating, plastic deformation, phase transformation, recrystallization and recovery, diffusion and oxidation. Again wear mechanisms are also phenomena due to shearing of asperities, micro-cutting, surface fatigue and impact. Some important mechanisms which could explain the results obtained.

Bryggman, Sodeberg and Thomas [64, 65] state that the amplitude of sliding vibration is low, when the contacting asperities are elastic. Above its certain amplitude the elasticity of the contacting asperities changes into a dynamic frictional force.

The tangential force is equal to the dynamic force until the point where the relative motion between the materials stops. When the motion between materials stops, the contacting asperities will once again be elastic. This can be compared with one stick-slip motion for each cycle of external vibrations. In a study of stick-slip phenomenon in a friction surface by Sakamoto [66] it is found that the distance between the friction surfaces increases at slip and decreases at stick and that frictional force is proportional to the contact area between the materials. In the above investigation, the tendency to stick-slip motion decrease when the friction surface is affected by an external vibration. Figure 2.29 shows that both the phenomena of stick-slip and the tangential force decrease. In this case, it is the result of a decreased contact surface area between the materials. In the above investigation, the stick-slip has also decreased as the tangential force increased, which is the result of a larger contact surface between the materials.
Wertheim, Hess and others [67, 68] reported that vibration affects friction to a noticeable degree only if several conditions are met. Vibration having amplitude, which is smaller than the RMS of the surface profile, is unlikely to reduce friction. Smooth motion is guaranteed only if the amplitude of the vibration is uniform along the sliding path. The frictional force between the mass and the disc is measured by Wertheim and Bucher [67] by means of a stain-gauge-based force-gauge. Measurements is taken under vibrating and non-vibrating conditions. During measurement the most dramatic decrease in friction is observed. It is interesting to note that in that case the amplitude had an average value, but the acceleration was the largest (200g), friction in that case was reduced nearly to zero. The frictional force was influenced from the local behavior of the vibrating disc and demonstrates that the non-uniformity of the mode shape gives rise to different friction force under the same global vibration parameters.

Under the condition where the amplitude of vibration was smaller than the surface roughness \( (R_a) \) the reduction in friction force is minor but it could be seen that the “stick-slip” phenomenon is decreased. Smooth motion can be obtained under appropriate vibrating conditions. Reduction in friction cannot be obtained when vibrations are blindly activated as both amplitude and acceleration are important. The mode shapes of the vibrating bodies need to be chosen to allow uniform (as possible) amplitude along the motion path. Vibration in small amplitudes does not have a great influence on the mean friction, but still a significant reduction in “stick-slip” motion can be obtained for large accelerations. The vibration consisted of standing waves thus uniform amplitudes were not obtained. Wertheim and Bucher [67] proposed that future work will study the effect of uniform amplitude and frequency. In conclusion it is possible to state that mechanical process can be considerably improved and torque/force rating could be decreased when a suitable vibration pattern is created. The mean frictional force is greatly influenced by the mode shape therefore the dynamics of the sliding elements must be thoroughly understood before reduction in friction can be successfully applied.
3 Experimental Design and Methodology

3.1 Introduction
The objective of this thesis work is to find out the effect of vibration on the twisting rate of ring spinning frame for the production of yarn. To satisfy the demand of this work, a laboratory type ring spinning frame available at the spinning laboratory of Bangladesh University of Textiles and is decided to use this for the purpose.

3.2 Miniature Ring Spinning Frame
SDL-15 Shirley Miniature Ring Spinning Frame shown in Figure 3.1 is an eight spindle, single sided machine. It has Casablanca type 4 over 4 apron drafting system, able to process a staple fiber up to 64 mm at draft range 50 - 400. The top rollers of the drafting system are spring loaded and carried by a quick release overarm system. Revolving front under clearers and revolving top clearers are also present to collect loose fiber from drafting rollers. The spindles are driven by tapes from pulleys, with two spindles per tape. As per machine catalog the recommended maximum spindle speed is 12000 r.p.m but the normal spindle speed is 9000-10000 r.p.m.. Maximum speed of traveller that can be raised is 28.25m/sec with 45mm of ring diameter. The ring rail is carried on pockers and lifted by chains from a shaft actuated by a standard cop type builder mechanism. Traverse length is a fixed length and for this machine the length is 38 mm. As a laboratory type machine, the size of the bobbin is medium. Length and diameter of the empty bobbin are 180 cm and 2cm respectively. It has roller bearing spindle, made of aluminum. There are three clips on the outer surface of the spindle, which makes conformity of the bobbin to stay fit on the spindle.

The condition of the machine is not sufficient to serve the requirement of the study to achieve full objective. Therefore we created facilities by introducing some new attachments for this machine. These attachments and modifications of the ring spinning are as following:-

- Connection of a speed controller for variable speed of the motor of the machine.
- A new ring base is designed, fabricated and placed at the normal position of conventional ring to create some facility for experimental purpose.
- A new spindle with corrugated surface (fluted) is designed, fabricated and placed at the normal position of conventional spindle to create vibration to the ring.
Three extra arrangements are designed, fabricated and placed for generation and transfer vibration to the ring in three different ways.

All the existing tin cylinder except one are removed to attain high speed.

### 3.3 Attachment and Modification of Ring Spinning Machine for Vibration Generation.

#### 3.3.1 General Discussion

From different previous research work it was observed that during sliding motion of one surface relative to other, frictional coefficient between the surfaces decrease with the application of vibration to these surface. It was also observed that higher the frequency and the amplitude of vibration the higher the rate of reduction of frictional co-efficient. So it was decided to impart vibration to the ring of the setup. Considering the facilities with the machine it was decided that the frequency and amplitude of the vibration to be generated are 200-800 Hz and 0.1-0.2mm respectively.

To generate vibration two methods were designed. They are as following:

1) Using unbalance rotating mass
2) Using to and fro motion of a shaft. This to and fro motion was applied to the ring in radial and transverse direction.

#### 3.3.2 Speed Controller

It is an electronic device known as variable frequency drive(inverter). This speed controller is connected with the motor of the spinning machine, which facilities to select different speed of the motor for doing the necessary experimental work.

#### 3.3.3 Ring Base

The base of the ring is shown in figures 3.2 and 3.3. The size and shape of the base is selected according to the ring holder and ring rail of the miniature frame. There are some facilities created to fix the normal conventional ring on the base. The ring base with ring can be placed in the existing position of the ring rail. Three small spring loaded balls are attached at the lower part of the base, which allow the ring to vibrate the ring at its position. A threaded hole is also located at the base for inserting a vibration transferring arm.
3.3.4 Fluted Spindle
A corrugated surface fluted spindle is designed and fabricated, which is shown in figures 3.4 and 3.5. There is also another component, which is shown in Figures 3.6 and 3.7 to fix the fluted spindle in ring rail at definite position. The corrugated surface of fluted spindle helps to generate desired vibration. To fit the fluted spindle at its proper position and also to keep the spindle at its own axis during rotating a rotating pivot is fixed on the frame of the machine. The photographic view of rotating pivot is shown in Figure 3.8.

3.3.5 Step Pulley Arrangement
A step pulley arrangement shown in Figure 3.9 is designed and fabricated to create facility for different speed of fluted spindle. A one horse power motor is mounted vertically on a separate base having rubber damper. The separate base is arranged to reduce the effect of self vibration of the motor on the main structure. Power is transferred through belt from the motor of the step pulley arrangement.

3.4 Necessary Arrangement for Vibration Generation and Transmission to Ring Base
Three different required arrangements are designed and fabricated for three ways of vibration generation and transfer to the ring. Three arrangements are discussed below:

Arrangement A: This arrangement helps to generate vibration by using unbalance rotating mass, which is shown in Figures 3.10 and 3.11.

Arrangement B: This arrangement helps to generate vibration by using to and fro motion of a small shaft at radial direction of the ring, which is shown in Figures 3.12 and 3.13.

Arrangement C: This arrangement helps to generate vibration by using transverse motion of a small shaft at radial direction of the ring, which is shown in Figures 3.14 and 3.15.
4. EXPERIMENTAL PROCEDURE

4.1 Selection of Variables

4.1.1 Variable for Experimental Work

To verify the effect of vibration on ring traveller friction, the following parameters are selected to generate vibration:

Table 4.1: Frequency and amplitude of vibration

<table>
<thead>
<tr>
<th>Way of Force vibration Generation motion</th>
<th>Frequency of vibration(Hz)</th>
<th>Amplitude of vibration(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbalance rotating mass (All direction)</td>
<td>100- 260</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Radial direction</td>
<td>200-800</td>
<td>0.2 – 1.0</td>
</tr>
<tr>
<td>Transverse direction</td>
<td>200- 800</td>
<td>0.2 – 1.0</td>
</tr>
</tbody>
</table>

4.1.2. Spinning Parameter Selection

SDL 15- Shirley Miniature Ring spinning is being worked with the following parameters to verify the effect of vibration on yarn tension, ring temperature as well as ring traveller friction.

Table 4.2: Parameters for experiment

<table>
<thead>
<tr>
<th>Sc. No.</th>
<th>Name of the Parameter</th>
<th>Selected Parameter for experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Input material</td>
<td>Polyester multifilament and cotton fiber</td>
</tr>
<tr>
<td>2</td>
<td>Yarn count</td>
<td>10 and 20 Ne</td>
</tr>
<tr>
<td>3</td>
<td>Twist per inch</td>
<td>15, 18</td>
</tr>
<tr>
<td>4</td>
<td>Spindle speed</td>
<td>3200 - 16500</td>
</tr>
<tr>
<td>5</td>
<td>Ring diameter</td>
<td>45 mm</td>
</tr>
<tr>
<td>6</td>
<td>Traveller No</td>
<td>1/0 - 2/0</td>
</tr>
<tr>
<td>7</td>
<td>Traveller weight</td>
<td>0.045- 0.049 gm</td>
</tr>
<tr>
<td>8</td>
<td>Diameter of empty bobbin</td>
<td>18mm</td>
</tr>
<tr>
<td>9</td>
<td>Length of empty bobbin</td>
<td>180 mm</td>
</tr>
<tr>
<td>10</td>
<td>Tension measuring position</td>
<td>In front of pigtail</td>
</tr>
<tr>
<td>11</td>
<td>Yarn winding position</td>
<td>Between 70-120 mm high from the bottom of the bobbin</td>
</tr>
</tbody>
</table>
### 4.1.3 Measuring and Testing Equipment

The following calibrated measuring and testing instrument are used for this experimental works

#### Table 4.3: Measurement and measuring instrument

<table>
<thead>
<tr>
<th>Name of the Measuring Instrument</th>
<th>Manufacturer and model of the instrument</th>
<th>Parameters measured/Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration Measuring Meter</td>
<td>METRIX Instrument Co</td>
<td>Velocity displacement of vibration</td>
</tr>
<tr>
<td>Temperature Measuring Meter</td>
<td></td>
<td>Ring Temperature</td>
</tr>
<tr>
<td>Yarn Tension Measuring Meter</td>
<td>(0-200) cN Meter SCHMIDT, Germany</td>
<td>Yarn Tension Min, Max and Peak value</td>
</tr>
<tr>
<td>Tachometer</td>
<td></td>
<td>Spindle speed</td>
</tr>
<tr>
<td>Wet and dry bulb hygrometer</td>
<td>James and Heal Co. Ltd</td>
<td>Temperature and humidity of environment</td>
</tr>
</tbody>
</table>

#### Table 4.4: Test and Testing instrument

<table>
<thead>
<tr>
<th>Testing instrument</th>
<th>Manufacturer and model of the instrument</th>
<th>Parameters measured/Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>High volume instrument</td>
<td>Premier 7000</td>
<td>Fiber properties:- Fiber length, strength, fineness, maturity</td>
</tr>
<tr>
<td>Wrap reel and balance</td>
<td>James and Heal co. Ltd</td>
<td>Yarn count</td>
</tr>
<tr>
<td>Yarn twist tester</td>
<td>Shirley SDL</td>
<td>Yarn twist</td>
</tr>
<tr>
<td>Universal strength tester</td>
<td>James and Heal co. Ltd</td>
<td>Yarn strength and elongation</td>
</tr>
<tr>
<td>Evenness tester</td>
<td>Premier 9000</td>
<td>Evenness, thick, thin, neps and hairiness</td>
</tr>
</tbody>
</table>
4.2 Twisting of Polyester Multifilament at Vibrating Status

Polyester multifilament is chosen for twisting in this spinning machine and this filament is very convenient to processing at any environmental condition. It is also suitable to measure yarn tension accurately. Environmental condition is a great factor for smooth running of ring spinning machine, but synthetic filament is not normally affected by environmental condition. In spite of this filament is less affected by air drag force instead of cotton, [1] because of absence of yarn hairiness. Considering all things, filament is used for the optimization of this research work. Filament is twisted and measurements (yarn tension) are taken with the following three ways of vibration.

4.2.1 Vibration Generation at Ring by Unbalanced Rotating Mass

(Arrangement A)

Introduction: The set-up is designed, fabricated and placed on ring rail of ring spinning frame to generate vibration at ring by using unbalance rotating mass, which is given through all direction. This set-up is shown in Figures 4.1 and 4.2.

A small variable speed motor(4) is selected to help the generation of force vibration. A small shaft(5) with a variable weight(6) is attached with the motor. The weight of the screw is variable. Spinning ring(8) with ring holder(9) and base(10) placed on a L-shaped plate. Motor(4) is placed at the vertical portion of L-plate. All together, the frame with ring and motor are placed on ring rail of the machine. One set of flat bar and two long screws(3) helps the arrangement to be fitted tightly on the ring rail.

The ring base is 60% lighter than the ring base designed to use for generating vibration with to and fro motion.

During running the motor, the unbalance weight (6) rotates uniformly with the shaft of the motor and generates vibration with simple harmonic motion. At the condition of vibration, Miniature ring spinning machine starts by motor (14) and the spindle rotates at the same time multifilament comes forward through the nip-point of front drafting roller and travels through lappet, traveller and finally connects at bobbin. During traveling, multifilament rotates with traveller for rotation of spindle and inserts twist. Yarn tension is measured in front of lappet at the same time of twisting and winding during application of vibration.
4.2.2 Vibration Generation at Ring by Radial Motion (Arrangement B)

Introduction: A set-up is designed, fabricated and placed on ring rail of ring spinning frame to generate vibration at the ring base by positive displacement of motion, along the radial direction, which is shown in Figures 4.3 and 4.4. The construction and working principle of the set-up is given below.

Construction and working principle: A fluted spindle with corrugated surface (shown in Figures 3.4 and 3.5) is designed and fabricated in such a way that it can be placed at the normal position of the spindle with existing facilities. To rotate this fluted spindle, power is transferred through the belt from step pulley arrangement of a one horse-power motor. In addition to step pulley, a variable frequency drive (an electronic speed control unit) is used to vary the speed of the motor as required. To fit the fluted spindle at its proper position and also to keep the spindle at its own axis during rotation a rotating pivot is fixed on the frame of the machine (Figure 3.8).

Spinning ring is placed tightly on the base by the ring holder with screw. A vibration transferring arm stays between fluted spindle and ring base. One end of this arm is inserted into the hole of the ring base and other end is on the contact with the corrugated surface of the fluted spindle.

This vibration transferring arm is placed also through a helical compression spring. One end of the spring is allowed to the frame and other end with the arm. Both arm and spring fitted inside a frame, which is placed tightly at ring rail by four sets of screw and nut.

When fluted spindle rotates it push, the end of the vibration transferring arm toward the center of the ring base and a little bit later when the fluted spindle rotates further the tip of the arm releases pressure and compression spring pull the arm toward the original position. By the continuous rotation of the fluted spindle the inward and outward motion of the arm, which finally becomes a vibrating motion of the ring base? The arm transfers vibration to the ring through the base. By rotation of the fluted spindle, vibration is generated and transferred to the ring base through the arm. Different frequencies of vibration are generated by changing number of flutes and r.p.m of the fluted spindle. The amplitude of vibration is controlled by the penetration depth of the front end of vibration transferring arm to the fluted spindle.

The Spindle of the ring spinning machine rotates from the power of main drive through belt (spindle tape). A variable frequency drive is also connected with this main motor,
which helps to rotate the spindle at variable speed. Yarn tension is measured the same way, which is done according to arrangement A

4.2.3 Vibration Generation at Ring by Transverse Motion (Arrangement C)

**Introduction:** Another set-up is designed and fabricated to generated vibration at ring of ring spinning machine by the positive displacement motion, which is given through transverse direction. The construction and working principle of the set-up with Figure 4.5 and 4.6 is given below.

**Construction and working principle:** The design, set-up and rotating principle of fluted spindle is the same as the arrangement A. In this case a long screw is placed vertically at the ring holder. The vibration transferring arm is connected from ring holder to fluted spindle. The middle of the arm is pivoted on a platform. The two springs with small disk are set tangentially on the front part of the platform. One end of the vibration transferring arm is inserted at the screw of ring holder and other end is placed on the surface of the fluted spindle, which is also pressurized tangentially by two springs with disk. By adjusting the pressure of two springs the arm is forced to stay on the contact of the fluted spindle. The arrangement with platform placed on the ring rail and fitted tightly by four sets of screw.

During rotating of the fluted spindle, front end of vibration transferring arm is become transverse motion for its contact pressure by flutes and return to its original position by spring deflection. Tangentially placed two spring forced the arm to return to original position. This tangentially originated to and fro motion generated vibration and transfer through arm to the ring holder as well as the ring. In this way generation of vibration is easier than set-up no. I. Vibration is generated by applying small amount of force. Different frequencies of vibration are generated by changing number of flutes and r.p.m of the fluted spindle. The amplitude of vibration is controlled by the penetration depth of the front end of vibration transferring arm to fluted spindle. Yarn tension is measured the same way, which is done according to arrangement A
4.3 Production of Cotton Yarn

Combed sliver is selected for production of cotton yarn. Fineness of the sliver was 0.14 Ne. Fiber properties of sliver is given below:

<table>
<thead>
<tr>
<th>Fiber length</th>
<th>Fiber strength</th>
<th>Fiber Fineness</th>
<th>Fiber maturity</th>
<th>Fiber neps</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mm</td>
<td>26 gm/tex</td>
<td>3.6 micronaire</td>
<td>0.9 %</td>
<td>140 nep/gm</td>
</tr>
</tbody>
</table>

Two cotton yarns are manufactured from the above sliver with the following parameters, which are being tested to examine the effect of vibration.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Yarn - I</th>
<th>Yarn - II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yarn count (Ne)</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Twist per inch</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>Traveller No.</td>
<td>1/0</td>
<td>2/0</td>
</tr>
<tr>
<td>Spindle speed</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>Frequency of vibration (Hz)</td>
<td>375</td>
<td>375</td>
</tr>
<tr>
<td>Amplitude of vibration (mm)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

4.4 Measurement of Ring Temperature

Temperature of the ring is measured by k-type thermocouple system, which is a digital meter. The point of thermocouple is kept as close as near the contact surface of the ring and the traveller, which is shown in Figure 5.15. During manufacturing of cotton yarn the temperature of the ring is measured digitally.
6. Conclusion

6.1 Conclusions
The prime target of this research work to find out the effect of forced vibration on the ring traveller friction. After application of three different ways of forced vibration at ring, it concludes

- Vibration reduces friction between the ring and the traveller of ring spinning machine.
- The amount of reduction depends on the spindle speed, amplitude and frequency of vibration.
- High frequency of vibration reduce high amount of friction.
- The way of application of forced vibration is also an important factor, which makes to generate effective vibration at the ring.
- Forced vibration with transverse direction motion generates more effective vibration than the others two.
- Reduction of yarn tension as well as co-efficient of friction reduces to the maximum of 25%.
- Friction generated temperature is reduced with application of vibration.
- Reduction of friction generated temperature is maximum 16%.
- The total quality of yarn is not detoriated with the effect of vibration.
- The strength of yarn increases by 2-8% and sometimes elongation properties of yarn are also increased.
- Evenness and hairiness value of yarn remain unchanged with the effect of vibration.
- Speed of traveller is also increased to the maximum of 5%. As a result twisting rate also becomes higher at the same rate.

Ring spinning is an important spinning system for making spun yarn from different short to medium staple fibers in the textile industry. But low productivity is one of the remarkable problems of this system. The limited speed of traveller is mainly responsible for the low production rate. It is well known that traveller speed is limited for generation of high frictional force between the ring and the traveller. Based on the analysis of ring traveller friction, three systems were developed for the reduction of friction. In Ring spinning frictional force is developed between the ring and the traveller due to the centrifugal force of the traveller for high rotational speed. This frictional force is also
dependent on the contact area of the ring and the traveller. In the new system an opposing force is generated within the traveller. So that the newly generated force is the counter balance of the centrifugal force and influenced the traveller to rotate through the ring but not always in the ring contact surface. Now it is proved that the running contact time is less than 15-25% of total contact time needed during rotation. Consequently less contact time has reduced the generation of frictional heat between the ring and the traveller and also reduced the yarn tension.

6.2 Recommendations for Future Study
This work opens a new dimension to the reduction of ring traveller friction. In the present study, the effects of spindle speed, frequency and amplitude of vibration on ring-traveller combination are investigated. The generated vibration is transferred to the ring base not directly to ring. The future study can be carried out

- Individually vibration generation at every single ring, which does not allow to transfer to ring rail or other machine parts.
- Effect of vibration on balloon characteristics can be investigated.
- Effect of vibration on fiber migration of yarn can also be investigated.
- Optimum frequency and amplitude of vibration need to investigate for practical application.
Fig. 5.1: Average value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.2: Percentage reduction of average value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)
Fig. 5.3: Minimum value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.4: Percentage reduction of minimum value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)
Fig. 5.5: Maximum value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.6: Percentage reduction of maximum value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)
Fig. 5.7: Peak value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.8: Percentage reduction of peak value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)
Fig. 5.9: Comparison of reduction percentage of yarn tension (average, minimum, maximum and peak value) at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.10: Yarn Tension at different amplitude of unbalance rotating mass vibration at ring. (spindle speed 16000 r.p.m., frequency 150 Hz)
Fig. 5.11: Yarn Tension at different frequency of unbalance rotating mass vibration at ring.(spindle speed 16000 r.p.m., amplitude 0.075mm )

Figure 5.12. Measurement of ring temperature by K type thermocouple system.
Figure 5.13. Temperature of ring at different spindle speed with and without application of vibration.

Figure 5.14. Percentage reduction of ring temperature at different spindle speed with application of vibration.
Figure 5.15. Load-elongation curves of 10 Ne cotton yarn, (a) without vibration condition (b) Forced vibration with unbalance rotating mass condition.

Figure 5.16. Load-elongation curves of 20 Ne cotton yarn, (a) without vibration condition (b) Forced vibration with unbalance rotating mass condition.
Fig. 5.17: Average value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction)

Fig. 5.18: Percentage reduction of average value of yarn tension at different spindle speed with effect of vibration. (Radial direction)
Fig. 5.19: Trend of average value of yarn tension at different spindle speed with effect of vibration. (Radial direction)

Figure 5.20: Maximum value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction)
Fig. 5.21: Percentage reduction of maximum value of yarn tension at different spindle speed with effect of vibration. (Radial direction)

Fig. 5.22: Trend of maximum value of yarn tension at different spindle speed with effect of vibration. (Radial direction)
Figure 5.23: Minimum value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction)

Fig. 5.24: Percentage reduction of minimum value of yarn tension at different spindle speed with effect of vibration. (Radial direction)
Fig. 5.25: Trend of minimum value of yarn tension at different spindle speed with effect of vibration. (Radial direction)

Figure 5.26: Peak value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction)
Fig. 5.27: Percentage reduction of Peak value of yarn tension at different spindle speed with effect of vibration. (Radial direction)

Fig. 5.28: Trend of Peak value of yarn tension at different spindle speed with effect of vibration. (Radial direction)
Fig. 5.29: Yarn Tension at different frequency of force vibration at ring with radial direction motion. (spindle speed 8000 r.p.m., amplitude 0.5mm)

Fig. 5.30: Yarn Tension at different frequency of force vibration at ring with radial direction motion. (spindle speed 10000 r.p.m., amplitude 0.5mm)
Fig. 5.31: Yarn Tension at different frequency of force vibration at ring with radial direction motion. (spindle speed 12000 r.p.m., Amplitude 0.5mm)

Fig. 5.32: Yarn Tension at different amplitude of force vibration at ring with radial direction motion. (spindle speed 8000 r.p.m., frequency 400 Hz)
Fig. 5.33: Yarn Tension at different amplitude of force vibration at ring with radial direction motion. (spindle speed 10000 r.p.m., frequency 400 Hz)

Fig. 5.34: Yarn Tension at different amplitude of force vibration at ring with radial direction motion. (spindle speed 12000 r.p.m., Frequency 400 Hz)
Figure 5.35. Temperature of ring at different spindle speed with and without application of vibration.

Figure 5.36. Percentage reduction of ring temperature at different spindle speed with application of vibration.
Figure: 5.37. Load-elongation curves of 10 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at radial direction condition

Figure: 5.38. Load-elongation curves of 20 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at radial direction condition
Fig. 5.39: Average value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction)

Fig. 5.40: Percentage reduction of average value of yarn tension at different spindle speed with effect of vibration. (Transverse direction)
Fig. 5.41: Minimum value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction)

Fig. 5.42: Percentage reduction of minimum value of yarn tension at different spindle speed with effect of vibration. (Transverse direction)
Fig. 5.43: Maximum value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction)

Fig. 5.44: Percentage reduction of maximum value of yarn tension at different spindle speed with effect of vibration. (Transverse direction)
Fig. 5.45: Peak value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction)

Fig. 5.46: Percentage reduction of peak value of yarn tension at different spindle speed with effect of vibration. (Transverse direction)
Fig 5.47. Yarn Tension at different frequency of vibration (Transverse direction).

Fig 5.48. Yarn Tension at different amplitude of vibration (Transverse direction).
Figure 5.49. Temperature rise of ring at different spindle speed with and without application of vibration.

Figure 5.50. Percentage reduction of ring temperature at different spindle speed with application of vibration.
Figure: 5.51. Load-elongation curves of 10 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at transverse direction condition.

Figure: 5.52. Load-elongation curves of 20 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at transverse direction condition.
Figure 3.1: Photographic view of miniature ring spinning machine.
Figure 3.2: Newly designed ring base.

Figure 3.3: Photographic view of newly designed ring base.
Figure 3.4: Fluted Spindle.

Figure 3.5: Photographic view of newly designed fluted spindle.
Figure 3.6: Fitting part of fluted spindle.

Figure 3.7: Photographic view of the bottom fitting part of fluted spindle.
Figure 3.8: Photographic view of the top rotating pivot.

Figure 3.9: Photographic view of the step pulley arrangement.
Figure 3.10: Arrangement A
Figure 3.11: Photographic view of the Arrangement A
Figure 3.12: Arrangement B
Figure 3.13: Photographic view of the Arrangement B
Figure 3.14: Arrangement C
Figure 3.15: Photographic view of the Arrangement C
Fig. 2.1. Relation between twist and strength of cotton (Co) and polyester (PES) spun yarn [3].

Fig. 2.2. Principle of operation of ring spinning machine [1].
Fig. 2.3. General geometry of ring spinning machine[6].

- a  Bottom roller
- b  Top roller
- c  Pressure arm

Fig. 2.4. Drafting arrangement[2].
Fig. 2.5. Lappet and balloon control ring[2].

1 Lapet
2 Balloon control ring
3 Ring
4 Spindle
5 Wharve
6 Spindle break
7 Bolster
8 Bearing

Fig. 2.6 Spindle[2].
Fig. 2.7 Running in condition of Traveller on the rail of Ring (a) enlarge without ring cop (b) with ring cop[2].

Fig. 2.8. a. Antiwedge ring b. low crown ring c. SU-ring ring[2].
Fig. 2.9. Flow of twist during yarn formation[1]

Fig. 2.10 Stationary wave system of balloon formation[1].
Here $C = M R \omega^2$ is the centripetal force required to keep the traveller rotating.

$R$ = is the radius of rotation of the center of gravity of the traveller

$M$ = mass of the traveller

$S$ = the normal reaction between ring and traveller

$T_p$ = yarn tension at traveller in the balloon side

$T_u$ = yarn tension at traveller in the package side

$\mu$ = the co-efficient of friction between ring and traveler

$\alpha$ = the winding angle

Fig 2.11. Forces acting on traveler[1].

<table>
<thead>
<tr>
<th>Productivity</th>
<th>Ring spinning</th>
<th>Rotor spinning</th>
<th>New Spinning Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yarn quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universality</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig 2.12. Compare the productivity and yarn quality of different spinning method[4].
Figure No. 2.13. Static friction and Kinetic friction[31]

Fig. 2.14 Schematic illustrations depicting the principles of the coulomb model for sliding friction[32].
Fig. 2.15 Pictorial display of surface texture (Anonymous)[32].
Fig. No. 2.16. Coefficient of friction as a function of surface roughness for a thin film magnetic rigid disk with sputtered diamond like carbon overcoat against an Mn-Zn ferrite slider[31].

Fig. 2.17. Coefficient of friction as a function of surface roughness for a copper against copper[40].
Fig. 2.18: Schematic (a) two rough surface in sliding contact (b) a corresponding free body diagram[40].

Fig. 2.19: Coefficient of friction as a function of $W_{ad}/H$ for a self mated clean metals[36].
Fig. 2.20: Schematic of interactions (a) asperity of interaction and (b) microscopic interaction of two sliding surface[32].

Fig. 2.21: Coefficient of friction as a function of percent of d-bond character of various transition metals in sliding contact with Ni-Zn ferrite[32].
Fig. 2.22. Schematic diagram of plastic flow for hexagonal metals[40].

Fig 2.23 (a) Effect of normal load on coefficient of friction (a) steel sliding on aluminium in air (b) copper on copper in air[32].
Fig 2.24: (a) The effect on apparent area of contact on sliding velocity. (b) Coefficient of friction as a function of sliding velocity for titanium sliding on titanium at a normal load of 3 N[32].

Figure No. 2.25: Friction tracing with (a) without disk vibration (b) in a pin on rotating disc apparatus[58].
Figure No. 2.26: Effect of acceleration of vibration on coefficient of kinetic friction; lubricated steel sliding on steel[58].

Figure No. 2.27: Effect of acceleration of vibration on coefficient of kinetic friction; un lubricate steel sliding on steel[58].
Figure No. 2.28: Oscillogram of free contact oscillations appearing in stages of tangential jumps of slider in course of self-excited friction oscillations[62].

Figure No. 2.29: Both the tendency of stick-slip and, in this case, the tangential force decrease when the friction surface is affected by an external vibration. (f=400Hz, δ=35µm, p=0.4mm⁻¹ F_N =150N): (a) an experiment without external vibration; (b) experiment with external vibration[62].
The thesis titled “Effect of Vibration on the Twisting Rate of Ring Spinning for the Production of Yarn” submitted by Hosne Ara Begum Roll No: P10061001P Session: October 2006 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Mechanical Engineering.

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DEDICATED TO MY AUTISTIC CHILD

Arefin Siddique
## CONTENTS

<table>
<thead>
<tr>
<th>List of Tables</th>
<th>vii</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures</td>
<td>viii</td>
</tr>
<tr>
<td>List of Abbreviations of Symbols and Terms</td>
<td>xv</td>
</tr>
<tr>
<td>Acknowledgement</td>
<td>xviii</td>
</tr>
<tr>
<td>Abstract</td>
<td>xiv</td>
</tr>
</tbody>
</table>

1. **INTRODUCTION**
   1.1 Background  
   1.2 Present state of the problem  
   1.3 Problem solving technique  
   1.4 Objectives

2. **LITERATURE REVIEW**
   2.1 Fundamentals of Spinning
      2.1.1 Early stage of spinning  
      2.1.2 Invention of ring spinning  
      2.1.3 Yarn formation  
      2.1.4 Technology of ring spinning
         2.1.4.1 Principle of operation  
         2.1.4.2 Spinning geometry  
         2.1.4.3 Design feature of the machine  
         2.1.4.4 Principle of twisting and winding  
         2.1.4.5 Air drag  
         2.1.4.6 Theory of balloon  
         2.1.4.7 Forces acting on yarn and Traveller  
         2.1.4.8 Yarn Tension  
         2.1.4.9 Friction of ring, traveller and yarn  
      2.1.5 Limitations of ring spinning  
      2.1.6 Modification of ring spinning  
      2.1.7 Modern spinning systems
2.2 Fundamentals of Friction 34
2.2.1 Friction and frictional forces 34
2.2.2 Laws of sliding friction 35
2.2.3 Basic mechanisms of sliding friction 36
2.2.4 Parameters effect on friction 37

3 EXPERIMENTAL DESIGN AND METHODOLOGY 68
3.1 Introduction 68
3.2 Miniature ring spinning frame 68
3.3 Attachment and modification of ring spinning machine for vibration generation. 69
3.3.1 General discussion 69
3.3.2 Speed controller 69
3.3.3 Ring base 69
3.3.4 Fluted spindle 70
3.3.5 Step pulley arrangement 70
3.4 Necessary arrangement for vibration generation and transmission to ring base 70

4 EXPERIMENTAL PROCEDURE 82
4.1 Selection of Variables 82
4.1.1 Variable for Experimental work 82
4.1.2 Spinning Parameter Selection 82
4.1.3 Measuring and Testing Equipment 83
4.2 Twisting of polyester multifilament at vibrating status 84
4.2.1 Vibration generation at ring by unbalanced rotating mass (Arrangement A) 84
4.2.2 Vibration Generation at ring by radial motion (Arrangement B) 85
4.2.3 Vibration generation at ring by transverse motion (Arrangement C) 86
4.3 Production of cotton yarn 87
4.4 Measurement of Ring Temperature 87
5 RESULTS AND DISCUSSION

5.1 Introduction

5.2 Friction with Unbalance Rotating Mass Vibration

5.2.1 Yarn tension at different spindle speeds

5.2.2 Effect of amplitude of unbalanced rotating mass vibration on yarn tension

5.2.3 Effect of frequency of unbalanced rotating mass vibration on yarn tension

5.2.4 Effect of unbalanced rotating mass vibration on ring temperature at different spindle speeds

5.2.5 Effect of unbalanced rotating mass vibration on yarn properties

5.3 Friction with Radial Vibration

5.3.1 Effect of vibration at different spindle speeds on yarn tension.

5.3.2 Effect of frequency of radial vibration on yarn tension

5.3.3 Effect of amplitude of radial vibration on yarn tension

5.3.4 Effect of radial vibration at different spindle speeds on ring temperature.

5.3.5 Effect of radial vibration on spun cotton yarn properties.

5.4 Friction with Transverse Vibration.

5.4.1 Effect of vibration at different spindle speeds on yarn tension.

5.4.2 Effect of different frequencies of transverse vibration on yarn tension

5.4.3 Effect of different amplitudes of transverse vibration on yarn tension

5.4.4 Effect of transverse vibration at different spindle speeds on ring temperature.

5.4.5 Effect of transverse vibration on yarn properties.

5.5 Effect of vibration on yarn twist.

5.6 Analysis of experimental result

6 CONCLUSION

6.1 Conclusions

6.2 Recommendations for Future Study
LIST OF TABLES

Table 2.1: Minimum no. of fiber in yarn cross-section 12
Table 2.2: Maximum draft of ring spinning machine for different yarn production 16
Table 4.1: Frequency and amplitude of vibration 82
Table 4.2: Parameters for experiment 82
Table 4.3: Measurement and measuring instruments 83
Table 4.4: Test and testing instrument 83
Table 4.5: Properties of cotton fiber 87
Table 4.6: Parameters for the production of cotton yarn 87
Table 5.1: Parameters of cotton yarn sample 99
Table 5.2: Compare the properties of 10Ne and 20Ne cotton yarn(U.R.M) 100
Table 5.3: Compare the properties of 10Ne and 20Ne cotton yarn(R.V) 108
Table 5.4: Compare the properties of 10 and 20Ne cotton(T.V) 113
Table 5.5: Twist per inch of yarn with and without application of vibration 115
**List of Figure**

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Figure Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig 1.1:</td>
<td>Ring and Traveller of a Ring Spinning Frame.</td>
<td>4</td>
</tr>
<tr>
<td>Fig 1.2:</td>
<td>Flow diagram of the ring spinning methods problem.</td>
<td>5</td>
</tr>
<tr>
<td>Fig 1.3:</td>
<td>A way to reduce friction between ring and traveller of a ring spinning.</td>
<td>7</td>
</tr>
<tr>
<td>Fig. 2.1:</td>
<td>Relation between twist and strength of cotton spun yarn.</td>
<td>53</td>
</tr>
<tr>
<td>Fig. 2.2:</td>
<td>Relation between twist and strength of cotton spun yarn.</td>
<td>53</td>
</tr>
<tr>
<td>Fig. 2.3:</td>
<td>General geometry of ring spinning machine.</td>
<td>54</td>
</tr>
<tr>
<td>Fig. 2.4:</td>
<td>Drafting arrangement.</td>
<td>54</td>
</tr>
<tr>
<td>Fig. 2.5:</td>
<td>Lappet and balloon control ring.</td>
<td>55</td>
</tr>
<tr>
<td>Fig. 2.6:</td>
<td>Spindle.</td>
<td>55</td>
</tr>
<tr>
<td>Fig 2.7:</td>
<td>Running in condition of traveller on the rail of ring (a) enlarge without ring cop (b) with ring cop.</td>
<td>56</td>
</tr>
<tr>
<td>Fig 2.8:</td>
<td>Antiwedge ring b. low crown ring c. SU-ring ring.</td>
<td>56</td>
</tr>
<tr>
<td>Fig. 2.9:</td>
<td>Flow of twist during yarn formation.</td>
<td>57</td>
</tr>
<tr>
<td>Fig. 2.10:</td>
<td>Stationary wave system of balloon formation.</td>
<td>57</td>
</tr>
<tr>
<td>Fig. 2.11:</td>
<td>Forces acting on traveler.</td>
<td>58</td>
</tr>
<tr>
<td>Fig. 2.12:</td>
<td>Compare the productivity and yarn quality of different spinning method.</td>
<td>58</td>
</tr>
<tr>
<td>Fig. 2.13:</td>
<td>Static friction and kinetic friction.</td>
<td>59</td>
</tr>
<tr>
<td>Fig. 2.14:</td>
<td>Schematic illustrations depicting the principles of the coulomb model for sliding friction.</td>
<td>59</td>
</tr>
<tr>
<td>Fig. 2.15:</td>
<td>Pictorial display of surface texture (Anonymous).</td>
<td>60</td>
</tr>
<tr>
<td>Fig. 2.16:</td>
<td>Coefficient of friction as a function of surface roughness for a thin film magnetic rigid disk with sputtered diamond like carbon overcoat against an Mn-Zn ferrite slider.</td>
<td>61</td>
</tr>
<tr>
<td>Fig. 2.17:</td>
<td>Coefficient of friction as a function of surface roughness for a copper against copper.</td>
<td>61</td>
</tr>
<tr>
<td>Fig. 2.18:</td>
<td>Schematic (a) two rough surface in sliding contact (b) a corresponding free body diagram.</td>
<td>62</td>
</tr>
<tr>
<td>Fig. 2.19:</td>
<td>coefficient of friction as a function of W\text{ad}/H for a self mated clean metals.</td>
<td>62</td>
</tr>
</tbody>
</table>
Fig. 2.20: Schematic of interactions (a) asperity of interaction and (b) microscopic interaction of two sliding surface.

Fig. 2.21: Coefficient of friction as a function of percent of d-bond character of various transition metals in sliding contact with Ni-Zn ferrite.

Fig. 2.22: Schematic diagram of plastic flow for hexagonal metals.

Fig. 2.23: Effect of normal load on coefficient of friction (a) steel sliding on aluminium in air (b) copper on copper in air.

Fig. 2.24: The effect on apparent area of contact on sliding velocity. (b) Coefficient of friction as a function of sliding velocity for titanium sliding on titanium at a normal load of 3 N.

Fig. 2.25: Friction tracing with (a) without disk vibration (b) in a pin on rotating disc apparatus.

Fig. 2.26: Effect of acceleration of vibration on coefficient of kinetic friction; lubricated steel sliding on steel.

Fig. 2.27: Effect of acceleration of vibration on coefficient of kinetic friction; un lubricate steel sliding on steel.

Fig. 2.28: Oscillogram of free contact oscillations appearing in stages of tangential jumps of slider in course of self-excited friction oscillations.

Fig. 2.29: Both the tendency of stick-slip and, in this case, the tangential force decrease when the friction surface is affected by an external vibration. (f=400Hz, δ=35µm, p=0.4mm⁻¹ F_N =150N): (a) an experiment without external vibration; (b) experiment with external vibration.

Fig. 3.1: Photographic view of miniature ring spinning machine.

Fig. 3.2: Newly designed ring base.

Fig. 3.3: Photographic view of newly designed ring base.

Fig. 3.4: Fluted Spindle.

Fig. 3.5: Photographic view of newly designed fluted spindle.

Fig. 3.6: Fitting part of fluted spindle.

Fig. 3.7: Photographic view of the bottom fitting part of fluted spindle.

Fig. 3.8: Photographic view of the top rotating pivot.
Fig. 3.9: Photographic view of the step pulley arrangement.

Fig. 3.10: Arrangement A

Fig. 3.11: Photographic view of the Arrangement A

Fig. 3.12: Arrangement B

Fig. 3.13: Photographic view of the Arrangement B

Fig. 3.14: Arrangement C

Fig. 3.15: Photographic view of the Arrangement C

Fig. 4.1: Photographic view of vibration generation at ring by unbalanced rotating.

Fig. 4.2: Schematic diagram of the experimental set-up (Vibration is generated by unbalance rotating mass).

Fig. 4.3: Photographic view of vibration generation at ring by radial direction motion.

Fig. 4.4: Schematic diagram of the experimental set-up (Vibration is generated by the radial direction motion)

Fig. 4.5: Photographic view of vibration generation at ring by transverse direction motion.

Fig. 4.6: A Schematic diagram of the experimental set-up. (Force vibration generation at transverse direction motion)

Fig. 5.1: Average value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.2: Percentage reduction of average value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.3: Minimum value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.4: Percentage reduction of minimum value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)

Fig. 5.5: Maximum value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)
vibration)

**Fig. 5.6:** Percentage reduction of maximum value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)

**Fig. 5.7:** Peak value of yarn tension at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

**Fig. 5.8:** Percentage reduction of peak value of yarn tension at different spindle speed with effect of vibration. (Unbalance rotating mass vibration)

**Fig. 5.9:** Comparisons of reduction percentage of yarn tension (average, minimum, maximum and peak value) at different spindle speed with and without effect of vibration. (Unbalance rotating mass vibration)

**Fig. 5.10:** Yarn Tension at different amplitude of unbalance rotating mass vibration at ring. (spindle speed 16000 r.p.m., frequency 150 Hz)

**Fig. 5.11:** Yarn Tension at different frequency of unbalance rotating mass vibration at ring. (spindle speed 16000 r.p.m., amplitude 0.075mm)

**Fig. 5.12:** Measurement of ring temperature by K type thermocouple system.

**Fig. 5.13:** Temperature of ring at different spindle speed with and without application of vibration.

**Fig. 5.14:** Percentage reduction of ring temperature at different spindle speed with application of vibration.

**Fig. 5.15:** Load-elongation curves of 10 Ne cotton yarn, (a) without vibration condition (b) Forced vibration with unbalance rotating mass condition.

**Fig. 5.16:** Load-elongation curves of 20 Ne cotton yarn, (a) without vibration condition (b) Forced vibration with unbalance rotating mass condition.

**Fig. 5.17:** Average value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction)

**Fig. 5.18:** Percentage reduction of average value of yarn tension at
different spindle speed with effect of vibration. (Radial direction)

**Fig. 5.19:** Trend of average value of yarn tension at different spindle speed with effect of vibration. (Radial direction) 126

**Fig. 5.20:** Maximum value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction) 126

**Fig. 5.21:** Percentage reduction of maximum value of yarn tension at different spindle speed with effect of vibration. (Radial direction) 127

**Fig. 5.22:** Trend of maximum value of yarn tension at different spindle speed with effect of vibration. (Radial direction) 127

**Fig. 5.23:** Minimum value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction) 128

**Fig. 5.24:** Percentage reduction of minimum value of yarn tension at different spindle speed with effect of vibration. (Radial direction) 128

**Fig. 5.25:** Trend of minimum value of yarn tension at different spindle speed with effect of vibration. (Radial direction) 129

**Fig. 5.26:** Peak value of yarn tension at different spindle speed with and without effect of vibration. (Radial direction) 129

**Fig. 5.27:** Percentage reduction of Peak value of yarn tension at different spindle speed with effect of vibration. (Radial direction) 130

**Fig. 5.28:** Trend of Peak value of yarn tension at different spindle speed with effect of vibration. (Radial direction) 130

**Fig. 5.29:** Yarn Tension at different frequency of force vibration at ring with radial direction motion. (spindle speed 8000 r.p.m., amplitude 0.5mm) 131

**Fig. 5.30:** Yarn Tension at different frequency of force vibration at ring with radial direction motion. (spindle speed 10000 r.p.m., amplitude 0.5mm) 131

**Fig. 5.31:** Yarn Tension at different frequency of force vibration at ring with radial direction motion. (spindle speed 12000 r.p.m., Amplitude 0.5mm) 132
Fig. 5.32: Yarn Tension at different amplitude of force vibration at ring with radial direction motion. (spindle speed 8000 r.p.m., frequency 400 Hz)

Fig. 5.33: Yarn Tension at different amplitude of force vibration at ring with radial direction motion. (spindle speed 10000 r.p.m., frequency 400 Hz)

Fig. 5.34: Yarn Tension at different amplitude of force vibration at ring with radial direction motion. (spindle speed 12000 r.p.m., Frequency 400Hz)

Fig. 5.35: Temperature of ring at different spindle speed with and without application of vibration.

Fig. 5.36: Percentage reduction of ring temperature at different spindle speed with application of vibration.

Fig. 5.37: Load-elongation curves of 10 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at radial direction condition

Fig. 5.38: Load-elongation curves of 20 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at radial direction condition

Fig. 5.39: Average value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction)

Fig. 5.40: Percentage reduction of average value of yarn tension at different spindle speed with effect of vibration. (Transverse direction)

Fig. 5.41: Minimum value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction)

Fig. 5.42: Percentage reduction of minimum value of yarn tension at different spindle speed with effect of vibration. (Transverse direction)

Fig. 5.43: Maximum value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction)

Fig. 5.44: Percentage reduction of maximum value of yarn tension at different spindle speed with effect of vibration. (Transverse direction)
direction)

**Fig. 5.45:** Peak value of yarn tension at different spindle speed with and without effect of vibration. (Transverse direction) 139

**Fig. 5.46:** Percentage reduction of peak value of yarn tension at different spindle speed with effect of vibration. (Transverse direction) 139

**Fig. 5.47:** Yarn Tension at different frequency of vibration (Transverse direction). 140

**Fig. 5.48:** Yarn Tension at different amplitude of vibration (Transverse direction). 140

**Fig. 5.49:** Temperature rise of ring at different spindle speed with and without application of vibration. 141

**Fig. 5.50:** Percentage reduction of ring temperature at different spindle speed with application of vibration. 141

**Fig. 5.51:** Load-elongation curves of 10 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at transverse direction condition. 142

**Fig. 5.52:** Load-elongation curves of 20 Ne cotton yarn, which are produced by (a) without vibration condition (b) Forced vibration at transverse direction condition. 142

**Fig. 5.53:** Result for the effect of vibration on ring traveller combination. 118

---

**List of Abbreviations of Symbols and Terms**

- $C$: centrifugal force on a traveler
- $C_I$: air-drag coefficient
- $E$: coefficient in balloon theory
\[ H \] axial balloon height \\
\[ H_1, H_2 \] axial balloon height with control rings \\
\[ M \] mass \\
\[ M_1 \] minimum traveller mass \\
\[ N \] mass per unit length of yarn (in tex) \\
\[ N_e \] yarn count in english system \\
\[ P, P_{\text{max}}, P_{\text{min}} \] length used to simplify balloon-theory calculations (\( p^2 = \frac{T_0}{m w^2} \)) \\
\[ P_{\text{f}}, P_{\text{a}} \] component of length \( p \) contributed by friction and air drag, respectively \\
\[ R \] radius of ring \\
\[ R_1 \] radius of package \\
\[ R_e \] Reynolds number \\
\[ R \] \( \frac{r}{p} \) \\
\[ R_{\text{max}} \] \( \frac{r_{\text{max}}}{p} \) \\
\[ S \] normal reaction between ring and traveler \\
\[ T \] tension \\
\[ T_0 \] tension at the thread-guide \\
\[ T_v \] vertical component of tension \\
\[ T_{\text{f}}, T_{\text{a}} \] yarn tension at traveller on balloon side and package side, respectively (a second suffix t, r, or p denotes the component of these tensions in the Tangential; radial, or perpendicular plane) \\
\[ T_{\text{w}}, T_{\text{aw}} \] winding tensions \\
\[ X \] Cartesian axis in balloon theory \\
\[ X \] \( x/p \) position co-ordinate in balloon theory \\
\[ \gamma \] Cartesian axis in balloon theory \\
\[ Y \] \( y/p \) position co-ordinate in balloon theory \\
\[ Z \] Cartesian axis in balloon theory \\
\[ Z \] \( z/p \) position co-ordinate in balloon theory \\
\[ a \] yarn-tension ratio across traveller \\
\[ b \] maximum value of \( H/P \) in balloon theory \\
\[ c \] velocity of wave motion relative to fixed axes \\
\[ c_0 \] velocity of wave motion relative to string \\
\[ d \] diameter of yarn \\
\[ f \] frequency \\
\[ g \] acceleration due to gravity \\
\[ l \] half wave-length \\
\[ l_1 \] direction cosine of \( u_1 \) \\
\[ m \] mass per unit length \\
\[ m_1 \] direction cosine of \( u_1 \) \\
\[ n \] angular velocity in thousands of revolutions per minute \\
\[ n_0 \] spindle speed in thousands of revolutions per minute \\
\[ p \] additional twist required in balloon zone \\
\[ q \] a number- \( q \)th neck of a balloon \\
\[ r_s, r_{\text{max}} \] radius of rotation \\
\[ s \] displacement along the yarn \\
\[ t \] time \\
\[ u \] air speed \\
\[ u_1 \] component of yarn velocity \\
\[ v \] yarn-delivery speed
\( v_1, v_2 \) radial and tangential components of yarn-delivery speed
\( \omega \) air velocity vector; also rate of change of balloon length
\( x \) position co-ordinate in balloon theory
\( y \) position co-ordinate in balloon theory
\( z \) position co-ordinate in balloon theory
\( \alpha \) angle of lead (winding angle)
\( \beta \) angle in balloon theory
\( \gamma \) air-drag parameter
\( \gamma \) Angle of tilt of traveller in tangential plane
\( \varepsilon_1, \varepsilon_2, \varepsilon_3 \) angles of inclination of yarn at traveller
\( \eta \) kinematic viscosity of air
\( \theta, \theta_0 \) inclination of element of yarn
\( \lambda \) wave-length
\( \mu \) coefficient of friction between traveller and ring
\( \nu \) angle between normal reaction and radius vector
\( \rho \) density of air
\( \rho \) Density of yarn
\( \tau \) twist in turns per unit length
\( \Phi \) inclination of yarn in axial plane
\( \omega \) angular velocity in radians/sec
\( \omega_0 \) Angular velocity of package in radians/sec
\( F_k \) Kinetic friction force
\( F_s \) Static friction force
\( \mu \) Coefficient of friction
\( N \text{ or } W \) Normal force
\( \mu_s \) Coefficient of static friction
\( \mu_k \) Coefficient of kinetic friction
\( \theta \) Frictional angle
\( F_i \) Total intrinsic frictional force
\( F_a \) Force needed to shear adhered junctions
\( F_d \) Force needed to supply the energy of deformation
\( \sigma_p \) Composite standard deviation
\( E \) Composite or effective elastic modulus
\( R_p \) Composite radius of summits
\( T_a \) Interfacial shear strength
\( B \) Composite correlation length
\( H \) Hardness of the softer of the contacting materials
\( K \) Bulk shear strength
\( S \) Local friction force
\( R_{p1} \text{ or } R_{p2} \) Sphere of radius
\( A_r \) Real (true) area of the contact
\( A_a \) Apparent (nominal) area of the contact
\( V \) Relative sliding velocity
\( P_r \) Mean real pressure
\( G \) Shear modulus of the materials
\( P \) Normal stresses
\( T \) Tangential (or shear) stresses
\( P_m \) the contact pressure for full plasticity in normal compression
\( K \) Geometric factor
\( W_{ad} \) Work of adhesion
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tan \delta$</td>
<td>Tangent modulus or damping factor</td>
</tr>
<tr>
<td>$V_s$</td>
<td>Sliding velocity</td>
</tr>
<tr>
<td>$f$</td>
<td>Frequency of vibration</td>
</tr>
<tr>
<td>$A$</td>
<td>Amplitude of vibration</td>
</tr>
<tr>
<td>$R_{rms}$</td>
<td>RMS roughness</td>
</tr>
<tr>
<td>$R$</td>
<td>Relative humidity</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENT

I am too much grateful to Dr. Md. Maksud Helali, Professor Department of Mechanical Engineering, BUET for his guidance, supervision, constructive suggestions and comments during my study. He always give me courage to overcome different difficulties during this work, are made me indebted.

I am grateful to all staffs of the Yarn Manufacturing and Textile Testing Laboratory of Bangladesh University of Textiles for their help to install the experimental setup and test the sample of yarn. I am also grateful all the staffs of the different workshop of Bangladesh University of Engineering and Technology for their effort to prepare all the necessary parts for my experimental work. Thanks to all of them for their assistance at different times during working of this investigation. Special thanks to my husband Dr. Abu Bakr Siddique for his good cooperation.

ABSTRACT
This work presents the effect of vibration on yarn tension as well as friction between ring and traveller and their temperature rise during spinning. It also examines how friction force is affected by amplitude and frequency of vibration at different methods of vibration applied at ring.

Three external vibration generating facilities are designed and placed in a miniature ring spinning frame to generate and apply vibration to the ring. The miniature ring spinning frame has the facility to vary twist and count of yarn and was modified to vary the spindle speed in the range 6500 –13000 revolution per minute approximately. During this study, the amplitude and frequency of vibration were varied between 0.1 to 1mm and 100 to 800 Hz, respectively. During this work, it is found that ring-traveller friction is influenced by the application of vibration and the properties of cotton yarn are also influenced with the effect of vibration. Results are compared with and without vibration status.

It was found that friction between ring and traveller was reduced 3-24% depending on the speed of the traveller and the way of vibration application to ring along with amplitude and frequency of vibration. The strength, elongation and evenness of the cotton yarn showed improved quality.

Therefore it can be concluded that application of vibration may be a way of reducing friction between ring and traveler and thus the mechanical process of twisting and winding can be done at high speed for higher productivity of ring spinning system which is a limiting factor of this system.

With the application of vibration the variation of yarn qualities such as its strength, elongation, evenness and hairiness properties are explained and compared to without application of vibration product.
References


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[7]. Lord, P R, 2003, Yarn Production (Science Technology and economics), The Textile Institute.


[16]. Chowdhury, M. A. and Helali, M. M., “The Effect of Frequency of Vibration and Humidity on Wear Rate”,


C


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F
Table A1: Values of Yarn Tension (cN) at different Spindle Speed (without vibration)

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Average Tension</th>
<th>Minimum Tension</th>
<th>Maximum Tension</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>8000</td>
<td>38.1</td>
<td>33.1</td>
<td>41.1</td>
<td>42</td>
</tr>
<tr>
<td>10000</td>
<td>52.5</td>
<td>47.2</td>
<td>53.1</td>
<td>54</td>
</tr>
<tr>
<td>12000</td>
<td>66.7</td>
<td>58.9</td>
<td>68.5</td>
<td>69.3</td>
</tr>
<tr>
<td>14000</td>
<td>81.2</td>
<td>76.1</td>
<td>88.5</td>
<td>90.3</td>
</tr>
<tr>
<td>16000</td>
<td>108.7</td>
<td>102.9</td>
<td>115.6</td>
<td>119.4</td>
</tr>
</tbody>
</table>

Table A2: Values of Yarn Tension (cN) at different Spindle Speed (Unbalance rotating mass vibration)

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Average value</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>8000</td>
<td>38</td>
<td>33</td>
<td>41</td>
<td>41.8</td>
</tr>
<tr>
<td>10000</td>
<td>52.4</td>
<td>47</td>
<td>53</td>
<td>53.7</td>
</tr>
<tr>
<td>12000</td>
<td>66</td>
<td>58.1</td>
<td>67.8</td>
<td>69</td>
</tr>
<tr>
<td>14000</td>
<td>79.2</td>
<td>74.1</td>
<td>87.1</td>
<td>89</td>
</tr>
<tr>
<td>16000</td>
<td>102.5</td>
<td>96.9</td>
<td>109.1</td>
<td>113.2</td>
</tr>
</tbody>
</table>

[Amplitude 0.05mm, Frequency 150Hz]

Table A3: Percent reduction of yarn tension at different spindle speed with effect of unbalanced rotating mass vibration.

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Average value</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>8000</td>
<td>0.262467</td>
<td>0.302115</td>
<td>0.243309</td>
<td>0.47619</td>
</tr>
<tr>
<td>10000</td>
<td>0.190476</td>
<td>0.423729</td>
<td>0.188324</td>
<td>0.555556</td>
</tr>
<tr>
<td>12000</td>
<td>1.049475</td>
<td>1.358234</td>
<td>1.021898</td>
<td>0.4329</td>
</tr>
<tr>
<td>14000</td>
<td>2.463054</td>
<td>2.628121</td>
<td>1.581921</td>
<td>1.439646</td>
</tr>
<tr>
<td>16000</td>
<td>5.703772</td>
<td>5.830904</td>
<td>5.622837</td>
<td>5.19263</td>
</tr>
</tbody>
</table>

[Amplitude 0.05mm, Frequency 150Hz]
Table A4: Yarn Tension(cN) at different Amplitude of unbalance rotating mass vibration at ring.

<table>
<thead>
<tr>
<th>Amplitude (mm)</th>
<th>Average value</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>106.5</td>
<td>102.9</td>
<td>115.5</td>
<td>119.4</td>
</tr>
<tr>
<td>0.025</td>
<td>111.3</td>
<td>105.7</td>
<td>118.6</td>
<td>121.8</td>
</tr>
<tr>
<td>0.05</td>
<td>110.2</td>
<td>105</td>
<td>112.9</td>
<td>115.9</td>
</tr>
<tr>
<td>0.075</td>
<td>104.2</td>
<td>97.4</td>
<td>107.8</td>
<td>114.8</td>
</tr>
<tr>
<td>0.1</td>
<td>102.4</td>
<td>98.1</td>
<td>106.8</td>
<td>113.3</td>
</tr>
</tbody>
</table>

[spindle speed 16000 r.p.m., frequency 150 Hz]

Table A5: Yarn Tension(cN) at different Frequency of unbalance rotating mass vibration at ring.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Average value</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>106.5</td>
<td>102.9</td>
<td>115.5</td>
<td>119.4</td>
</tr>
<tr>
<td>50</td>
<td>105.3</td>
<td>102.4</td>
<td>113.6</td>
<td>117.8</td>
</tr>
<tr>
<td>100</td>
<td>104.2</td>
<td>102.2</td>
<td>110.4</td>
<td>115.2</td>
</tr>
<tr>
<td>150</td>
<td>101.5</td>
<td>98.7</td>
<td>108.1</td>
<td>110.3</td>
</tr>
<tr>
<td>200</td>
<td>97.2</td>
<td>95.3</td>
<td>105.2</td>
<td>107.5</td>
</tr>
</tbody>
</table>

[spindle speed 16000 r.p.m., Amplitude 0.05mm]
### Table A6: Temperature of Ring at different spindle speed with and without effect of unbalance rotating mass vibration.

<table>
<thead>
<tr>
<th>Vibration status</th>
<th>Spindle speed r.p.m</th>
<th>Before start</th>
<th>After 2 minute</th>
<th>After 4 minute</th>
<th>After 6 minute</th>
<th>After 8 minute</th>
<th>After 10 minute</th>
<th>After 12 minute</th>
<th>After 14 minute</th>
<th>After 16 minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>without V</td>
<td>12000</td>
<td>30.2</td>
<td>43.6</td>
<td>47.5</td>
<td>52.8</td>
<td>53.2</td>
<td>53.8</td>
<td>53.7</td>
<td>53.9</td>
<td>54.2</td>
</tr>
<tr>
<td>with V</td>
<td>12000</td>
<td>30</td>
<td>43.5</td>
<td>47.4</td>
<td>52.6</td>
<td>53</td>
<td>53.6</td>
<td>53.6</td>
<td>53.6</td>
<td>53.8</td>
</tr>
<tr>
<td>Without V</td>
<td>14000</td>
<td>29.8</td>
<td>46.3</td>
<td>55.1</td>
<td>64.5</td>
<td>66.3</td>
<td>67</td>
<td>67.2</td>
<td>67.4</td>
<td>67.5</td>
</tr>
<tr>
<td>with V</td>
<td>14000</td>
<td>29.9</td>
<td>45.1</td>
<td>54</td>
<td>63.2</td>
<td>65</td>
<td>65.7</td>
<td>65.7</td>
<td>65.7</td>
<td>66</td>
</tr>
<tr>
<td>without V</td>
<td>16000</td>
<td>29.7</td>
<td>52.6</td>
<td>60.8</td>
<td>70.1</td>
<td>73.2</td>
<td>73.5</td>
<td>73.9</td>
<td>73.8</td>
<td>74</td>
</tr>
<tr>
<td>with V</td>
<td>16000</td>
<td>29.9</td>
<td>51.5</td>
<td>58.2</td>
<td>68.2</td>
<td>70.8</td>
<td>70.5</td>
<td>70.3</td>
<td>70.2</td>
<td>70</td>
</tr>
</tbody>
</table>

[Amplitude 0.05mm, Frequency 150Hz]

### Table A7: Percent reduction of Ring Temperature at different spindle speed with effect of unbalance rotating mass vibration.

<table>
<thead>
<tr>
<th>Spindle speed r.p.m</th>
<th>After 6 minute</th>
<th>After 8 minute</th>
<th>After 10 minute</th>
<th>After 12 minute</th>
<th>After 14 minute</th>
<th>After 16 minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>12000</td>
<td>0.380228</td>
<td>0.377358</td>
<td>0.373134</td>
<td>0.186567</td>
<td>0.559701</td>
<td>0.380228</td>
</tr>
<tr>
<td>14000</td>
<td>2.056962</td>
<td>2</td>
<td>1.978691</td>
<td>2.283105</td>
<td>2.743902</td>
<td>2.056962</td>
</tr>
<tr>
<td>16000</td>
<td>2.785924</td>
<td>3.389831</td>
<td>4.255319</td>
<td>5.12091</td>
<td>5.128205</td>
<td>2.785924</td>
</tr>
</tbody>
</table>

[Amplitude 0.05mm, Frequency 150Hz]
Table A8: Measurement of Yarn Tension (cN) at different Spindle Speed

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Average value</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>13125</td>
<td>78.8</td>
<td>72</td>
<td>80.4</td>
<td>82.6</td>
</tr>
<tr>
<td>11518</td>
<td>64.5</td>
<td>57</td>
<td>66</td>
<td>67</td>
</tr>
<tr>
<td>9920</td>
<td>52.8</td>
<td>47.2</td>
<td>53.1</td>
<td>54</td>
</tr>
<tr>
<td>8410</td>
<td>38</td>
<td>34</td>
<td>41.4</td>
<td>42</td>
</tr>
<tr>
<td>6540</td>
<td>35</td>
<td>32</td>
<td>39</td>
<td>40</td>
</tr>
</tbody>
</table>

[without vibration]

Table A9: Measurement of Yarn Tension (cN) at different Spindle Speed with vibration at radial direction.

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Average Tension</th>
<th>Minimum Tension</th>
<th>Maximum Tension</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>13125</td>
<td>71.1</td>
<td>70</td>
<td>72</td>
<td>74.7</td>
</tr>
<tr>
<td>11518</td>
<td>58.6</td>
<td>54</td>
<td>61.5</td>
<td>62.5</td>
</tr>
<tr>
<td>9920</td>
<td>47.5</td>
<td>42.9</td>
<td>48.6</td>
<td>49.4</td>
</tr>
<tr>
<td>8410</td>
<td>35.2</td>
<td>32</td>
<td>38.5</td>
<td>38.4</td>
</tr>
<tr>
<td>6540</td>
<td>33</td>
<td>30</td>
<td>36</td>
<td>37.5</td>
</tr>
</tbody>
</table>

[Amplitude = 0.5mm, Frequency = 450]

Table A10: Percent reduction of yarn tension at different spindle speed with vibration at radial direction.

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Percent reduction of Average yarn tension</th>
<th>Percent reduction of Minimum Tension</th>
<th>Percent reduction of Maximum Tension</th>
<th>Percent reduction of Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>13125</td>
<td>9.77</td>
<td>2.78</td>
<td>10.45</td>
<td>9.56</td>
</tr>
<tr>
<td>11518</td>
<td>9.15</td>
<td>5.26</td>
<td>8.07</td>
<td>8.09</td>
</tr>
<tr>
<td>9920</td>
<td>10.04</td>
<td>9.11</td>
<td>8.47</td>
<td>8.52</td>
</tr>
<tr>
<td>8410</td>
<td>7.37</td>
<td>5.88</td>
<td>7.00</td>
<td>8.57</td>
</tr>
<tr>
<td>6540</td>
<td>5.71</td>
<td>6.25</td>
<td>7.69</td>
<td>6.25</td>
</tr>
</tbody>
</table>
Table A11: Yarn Tension (cN) at different Frequency of vibration at radial direction.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>40.6</td>
<td>38.8</td>
<td>41.9</td>
<td>42.3</td>
</tr>
<tr>
<td>200</td>
<td>38.6</td>
<td>37.2</td>
<td>39</td>
<td>40.2</td>
</tr>
<tr>
<td>400</td>
<td>36.8</td>
<td>35.1</td>
<td>37.2</td>
<td>38.5</td>
</tr>
<tr>
<td>600</td>
<td>34.5</td>
<td>32.3</td>
<td>35.6</td>
<td>36.9</td>
</tr>
<tr>
<td>800</td>
<td>32.3</td>
<td>30.7</td>
<td>33.9</td>
<td>35</td>
</tr>
</tbody>
</table>

Table A12: Yarn Tension (cN) at different Frequency of vibration at radial direction.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>65.5</td>
<td>59</td>
<td>70.2</td>
<td>72</td>
</tr>
<tr>
<td>200</td>
<td>63.2</td>
<td>56.8</td>
<td>67</td>
<td>70</td>
</tr>
<tr>
<td>400</td>
<td>61.1</td>
<td>55.5</td>
<td>64.2</td>
<td>68.2</td>
</tr>
<tr>
<td>600</td>
<td>57.5</td>
<td>54.5</td>
<td>62.1</td>
<td>66.5</td>
</tr>
<tr>
<td>800</td>
<td>56.1</td>
<td>53.5</td>
<td>59.5</td>
<td>63.2</td>
</tr>
</tbody>
</table>

Table A13: Yarn Tension (cN) at different Frequency of vibration at radial direction.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>66.2</td>
<td>64.1</td>
<td>68.5</td>
<td>70.2</td>
</tr>
<tr>
<td>200</td>
<td>64.4</td>
<td>62.8</td>
<td>66.4</td>
<td>68.1</td>
</tr>
<tr>
<td>400</td>
<td>62.1</td>
<td>60.5</td>
<td>64.2</td>
<td>66.3</td>
</tr>
<tr>
<td>600</td>
<td>59.6</td>
<td>58.8</td>
<td>62.1</td>
<td>64.1</td>
</tr>
<tr>
<td>800</td>
<td>57.2</td>
<td>56.7</td>
<td>59.6</td>
<td>61.8</td>
</tr>
</tbody>
</table>

[Spindle speed = 8000 rpm, Amplitude = 0.5mm]
Table A14: Yarn Tension (cN) at different amplitude with vibration at radial direction.

<table>
<thead>
<tr>
<th>Amplitude (mm)</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>40.6</td>
<td>38.8</td>
<td>41.9</td>
<td>42.3</td>
</tr>
<tr>
<td>0.25</td>
<td>38.4</td>
<td>36.6</td>
<td>40.4</td>
<td>41.7</td>
</tr>
<tr>
<td>0.5</td>
<td>35.8</td>
<td>34.2</td>
<td>36.2</td>
<td>37.5</td>
</tr>
<tr>
<td>0.75</td>
<td>38.9</td>
<td>37.4</td>
<td>40.9</td>
<td>42</td>
</tr>
<tr>
<td>1</td>
<td>42.1</td>
<td>39.7</td>
<td>43.4</td>
<td>44.7</td>
</tr>
<tr>
<td>1.25</td>
<td>44.5</td>
<td>41.5</td>
<td>45.7</td>
<td>47</td>
</tr>
</tbody>
</table>

[Spindle speed = 8000 rpm, Frequency = 400 Hz]

Table A15: Yarn Tension (cN) at different amplitude with vibration at radial direction.

<table>
<thead>
<tr>
<th>Amplitude (mm)</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>50.2</td>
<td>46.2</td>
<td>52.1</td>
<td>54</td>
</tr>
<tr>
<td>0.25</td>
<td>47.6</td>
<td>45.1</td>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td>0.5</td>
<td>44</td>
<td>41.5</td>
<td>47.8</td>
<td>50</td>
</tr>
<tr>
<td>0.75</td>
<td>43.4</td>
<td>42.4</td>
<td>46.8</td>
<td>49</td>
</tr>
<tr>
<td>1</td>
<td>52.1</td>
<td>48.8</td>
<td>53.5</td>
<td>54.6</td>
</tr>
<tr>
<td>1.25</td>
<td>55.3</td>
<td>52.1</td>
<td>57.2</td>
<td>58.2</td>
</tr>
</tbody>
</table>

[Spindle speed = 10000 rpm, Frequency = 400 Hz]

Table A16: Yarn Tension (cN) at different amplitude with vibration at radial direction.

<table>
<thead>
<tr>
<th>Amplitude (mm)</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>66.2</td>
<td>64.1</td>
<td>68.5</td>
<td>70.2</td>
</tr>
<tr>
<td>0.25</td>
<td>62.6</td>
<td>60.8</td>
<td>64.1</td>
<td>65.2</td>
</tr>
<tr>
<td>0.5</td>
<td>59.4</td>
<td>58.6</td>
<td>61.8</td>
<td>63.1</td>
</tr>
<tr>
<td>0.75</td>
<td>64.9</td>
<td>64.1</td>
<td>66.3</td>
<td>69.6</td>
</tr>
<tr>
<td>1</td>
<td>67.8</td>
<td>66.2</td>
<td>69.3</td>
<td>71.5</td>
</tr>
<tr>
<td>1.25</td>
<td>69.9</td>
<td>68.2</td>
<td>72.3</td>
<td>72.9</td>
</tr>
</tbody>
</table>

[Spindle speed = 12000 rpm, Frequency = 400 Hz]
Table A17: Temperature of Ring at different spindle speed with and without effect of vibration at radial direction.

<table>
<thead>
<tr>
<th>Vibration status</th>
<th>Spindle speed r.p.m</th>
<th>Before start</th>
<th>After 2 minute</th>
<th>After 4 minute</th>
<th>After 6 minute</th>
<th>After 8 minute</th>
<th>After 10 minute</th>
<th>After 12 minute</th>
<th>After 14 minute</th>
<th>After 16 minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>without V</td>
<td>13125</td>
<td>29.8</td>
<td>46.3</td>
<td>55.1</td>
<td>59.5</td>
<td>63.7</td>
<td>65</td>
<td>65.2</td>
<td>64.8</td>
<td>65</td>
</tr>
<tr>
<td>with V</td>
<td>13125</td>
<td>29</td>
<td>43.2</td>
<td>53.5</td>
<td>55.2</td>
<td>58.8</td>
<td>59.2</td>
<td>59.1</td>
<td>58.9</td>
<td>59.6</td>
</tr>
<tr>
<td>Without V</td>
<td>11518</td>
<td>30.2</td>
<td>44.6</td>
<td>48.8</td>
<td>51.2</td>
<td>53.1</td>
<td>54.4</td>
<td>54</td>
<td>54.6</td>
<td>55.2</td>
</tr>
<tr>
<td>with V</td>
<td>11518</td>
<td>29</td>
<td>42</td>
<td>44.5</td>
<td>50.1</td>
<td>48.8</td>
<td>51.5</td>
<td>52</td>
<td>51.8</td>
<td>52</td>
</tr>
<tr>
<td>without V</td>
<td>9920</td>
<td>29.4</td>
<td>43</td>
<td>48</td>
<td>48.5</td>
<td>49</td>
<td>48.7</td>
<td>50.1</td>
<td>50</td>
<td>50.2</td>
</tr>
<tr>
<td>with V</td>
<td>9920</td>
<td>30</td>
<td>41.5</td>
<td>44</td>
<td>45.8</td>
<td>46.5</td>
<td>47.2</td>
<td>47.5</td>
<td>47</td>
<td>47.2</td>
</tr>
<tr>
<td>without V</td>
<td>8410</td>
<td>29.6</td>
<td>35.2</td>
<td>38.7</td>
<td>42.4</td>
<td>44</td>
<td>44.1</td>
<td>44.2</td>
<td>44.4</td>
<td>44.5</td>
</tr>
<tr>
<td>with V</td>
<td>8410</td>
<td>29.7</td>
<td>33.7</td>
<td>37.2</td>
<td>40.1</td>
<td>41.5</td>
<td>42.1</td>
<td>42</td>
<td>42.1</td>
<td>42</td>
</tr>
<tr>
<td>without V</td>
<td>6540</td>
<td>29.9</td>
<td>32.8</td>
<td>35.3</td>
<td>37.8</td>
<td>37.9</td>
<td>38.5</td>
<td>39.8</td>
<td>40</td>
<td>40.2</td>
</tr>
<tr>
<td>with V</td>
<td>6540</td>
<td>29.8</td>
<td>32.5</td>
<td>34.8</td>
<td>37.1</td>
<td>37.1</td>
<td>37.7</td>
<td>38</td>
<td>38.1</td>
<td>38.6</td>
</tr>
</tbody>
</table>

[Amplitude 0.5mm, Frequency 400Hz]

Table A18: Percent reduction of Ring Temperature at different spindle speed with effect of vibration at radial direction.

<table>
<thead>
<tr>
<th>Spindle speed r.p.m</th>
<th>After 6 minute</th>
<th>After 8 minute</th>
<th>After 10 minute</th>
<th>After 12 minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>13125</td>
<td>8.83</td>
<td>8.91</td>
<td>9.3</td>
<td>9.1</td>
</tr>
<tr>
<td>11518</td>
<td>6.7</td>
<td>7.63</td>
<td>7.68</td>
<td>9.07</td>
</tr>
<tr>
<td>9920</td>
<td>7.2</td>
<td>8.02</td>
<td>8.9</td>
<td>9.3</td>
</tr>
<tr>
<td>8410</td>
<td>5.8</td>
<td>5.1</td>
<td>5.3</td>
<td>5.9</td>
</tr>
<tr>
<td>6540</td>
<td>5.8</td>
<td>5.68</td>
<td>4.6</td>
<td>5.1</td>
</tr>
</tbody>
</table>

[Amplitude 0.5mm, Frequency 400Hz]
Table A19: Yarn Tension (cN) at different Spindle Speed

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Average value</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3200</td>
<td>13.5</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>5200</td>
<td>28.8</td>
<td>27.1</td>
<td>30.1</td>
<td>31.5</td>
</tr>
<tr>
<td>7500</td>
<td>37.6</td>
<td>33.1</td>
<td>39.2</td>
<td>39.2</td>
</tr>
<tr>
<td>9500</td>
<td>48.3</td>
<td>45.3</td>
<td>50.2</td>
<td>50.2</td>
</tr>
<tr>
<td>11500</td>
<td>58.9</td>
<td>56.1</td>
<td>60.2</td>
<td>66.2</td>
</tr>
</tbody>
</table>

[without vibration]

Table A20: Yarn Tension (cN) at different Spindle Speed with vibration at transverse direction.

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Average value</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3200</td>
<td>11.4</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>5200</td>
<td>24.2</td>
<td>20.2</td>
<td>26.2</td>
<td>26.8</td>
</tr>
<tr>
<td>7500</td>
<td>30.5</td>
<td>25.3</td>
<td>32.7</td>
<td>33.9</td>
</tr>
<tr>
<td>9500</td>
<td>38.3</td>
<td>36.7</td>
<td>40.1</td>
<td>42.1</td>
</tr>
<tr>
<td>11500</td>
<td>47.8</td>
<td>42.4</td>
<td>52.1</td>
<td>58.1</td>
</tr>
</tbody>
</table>

[Amplitude = 0.5mm, Frequency = 400]

Table A21: Percent reduction of yarn tension at different spindle speed with vibration at transverse direction.

<table>
<thead>
<tr>
<th>Spindle Speed (r.p.m)</th>
<th>Percent reduction of Average yarn tension</th>
<th>Percent reduction of Minimum Tension</th>
<th>Percent reduction of Maximum Tension</th>
<th>Percent reduction of Peak Tension</th>
</tr>
</thead>
<tbody>
<tr>
<td>3200</td>
<td>15.56</td>
<td>8.33</td>
<td>14.29</td>
<td>18.75</td>
</tr>
<tr>
<td>5200</td>
<td>15.97</td>
<td>25.46</td>
<td>12.96</td>
<td>14.92</td>
</tr>
<tr>
<td>7500</td>
<td>18.8</td>
<td>23.56</td>
<td>16.58</td>
<td>13.52</td>
</tr>
<tr>
<td>9500</td>
<td>20.7</td>
<td>18.98</td>
<td>20.12</td>
<td>16.14</td>
</tr>
<tr>
<td>11500</td>
<td>18.85</td>
<td>24.42</td>
<td>13.46</td>
<td>12.24</td>
</tr>
</tbody>
</table>
Table A22: Yarn Tension (cN) at different Frequency of vibration at transverse direction.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>50.2</td>
<td>46.8</td>
<td>52.7</td>
<td>53</td>
</tr>
<tr>
<td>200</td>
<td>48.3</td>
<td>45.3</td>
<td>50.2</td>
<td>51.2</td>
</tr>
<tr>
<td>400</td>
<td>46.7</td>
<td>43.5</td>
<td>48.1</td>
<td>50</td>
</tr>
<tr>
<td>600</td>
<td>44.5</td>
<td>41.2</td>
<td>46.2</td>
<td>48.1</td>
</tr>
<tr>
<td>800</td>
<td>42</td>
<td>40</td>
<td>44</td>
<td>46</td>
</tr>
</tbody>
</table>

[Spindle speed = 10000 rpm, Amplitude = 0.5mm]

Table A23: Yarn Tension (cN) at different amplitude of vibration at transverse direction.

<table>
<thead>
<tr>
<th>Amplitude(mm)</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Vibration</td>
<td>54.5</td>
<td>50.2</td>
<td>55.6</td>
<td>57.8</td>
</tr>
<tr>
<td>0.25</td>
<td>48.4</td>
<td>44.2</td>
<td>50.1</td>
<td>51.1</td>
</tr>
<tr>
<td>0.5</td>
<td>46.2</td>
<td>42</td>
<td>48.2</td>
<td>50.2</td>
</tr>
<tr>
<td>0.75</td>
<td>56.7</td>
<td>52.2</td>
<td>58.4</td>
<td>60.1</td>
</tr>
<tr>
<td>1</td>
<td>60.2</td>
<td>58.8</td>
<td>63.1</td>
<td>64.8</td>
</tr>
</tbody>
</table>

[Spindle speed = 10000 rpm, Frequency = 400 Hz]
Table A24: Temperature of Ring at different spindle speed with and without effect of vibration at transverse direction.

<table>
<thead>
<tr>
<th>Vibration status</th>
<th>Spindle speed r.p.m</th>
<th>Before start</th>
<th>After 2 minute</th>
<th>After 4 minute</th>
<th>After 6 minute</th>
<th>After 8 minute</th>
<th>After 10 minute</th>
<th>After 12 minute</th>
<th>After 14 minute</th>
<th>After 16 minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>without V</td>
<td>3200</td>
<td>29.8</td>
<td>30.6</td>
<td>31.9</td>
<td>33.7</td>
<td>34.2</td>
<td>34.5</td>
<td>34.9</td>
<td>35</td>
<td>35.2</td>
</tr>
<tr>
<td>with V</td>
<td>3200</td>
<td>29.9</td>
<td>30.4</td>
<td>31.5</td>
<td>33.4</td>
<td>33.8</td>
<td>33.7</td>
<td>33.9</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>without V</td>
<td>5200</td>
<td>29.4</td>
<td>32.2</td>
<td>33.5</td>
<td>34.1</td>
<td>35.2</td>
<td>37.5</td>
<td>37.7</td>
<td>37.4</td>
<td>37.5</td>
</tr>
<tr>
<td>with V</td>
<td>5200</td>
<td>29.6</td>
<td>30.2</td>
<td>30.6</td>
<td>31</td>
<td>33.2</td>
<td>35.5</td>
<td>35.7</td>
<td>35.6</td>
<td>35.7</td>
</tr>
<tr>
<td>without V</td>
<td>7500</td>
<td>29.6</td>
<td>33.2</td>
<td>35.7</td>
<td>40.4</td>
<td>41.5</td>
<td>42.1</td>
<td>42.2</td>
<td>42.4</td>
<td>42.5</td>
</tr>
<tr>
<td>with V</td>
<td>7500</td>
<td>29.7</td>
<td>31.7</td>
<td>32.2</td>
<td>35.2</td>
<td>36.4</td>
<td>37.5</td>
<td>37.6</td>
<td>38</td>
<td>38.1</td>
</tr>
<tr>
<td>without V</td>
<td>9500</td>
<td>29.4</td>
<td>37.5</td>
<td>41.7</td>
<td>44.3</td>
<td>46.1</td>
<td>46.6</td>
<td>46.8</td>
<td>47</td>
<td>47.1</td>
</tr>
<tr>
<td>with V</td>
<td>9500</td>
<td>30</td>
<td>33.5</td>
<td>37.3</td>
<td>40.1</td>
<td>41.1</td>
<td>41.5</td>
<td>41.7</td>
<td>42.1</td>
<td>42.2</td>
</tr>
<tr>
<td>without V</td>
<td>11500</td>
<td>30.2</td>
<td>43.6</td>
<td>47.5</td>
<td>50.2</td>
<td>51.5</td>
<td>52.2</td>
<td>52.8</td>
<td>52.4</td>
<td>52.8</td>
</tr>
<tr>
<td>with V</td>
<td>11500</td>
<td>29</td>
<td>37.3</td>
<td>42.2</td>
<td>45</td>
<td>45.5</td>
<td>46</td>
<td>46.1</td>
<td>46</td>
<td>46.1</td>
</tr>
</tbody>
</table>

[Amplitude 0.5mm, Frequency 400Hz]

Table A25: Percent reduction of Ring Temperature at different spindle speed with effect of vibration at transverse direction.

<table>
<thead>
<tr>
<th>Spindle speed r.p.m</th>
<th>After 6 minute</th>
<th>After 8 minute</th>
<th>After 10 minute</th>
<th>After 12 minute</th>
<th>After 14 minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>3200</td>
<td>9.1</td>
<td>11.36</td>
<td>10.81</td>
<td>10.4</td>
<td>10.1</td>
</tr>
<tr>
<td>5200</td>
<td>12.84</td>
<td>12.89</td>
<td>10.82</td>
<td>10.9</td>
<td>10.37</td>
</tr>
<tr>
<td>7500</td>
<td>9.7</td>
<td>10.86</td>
<td>10.94</td>
<td>10.89</td>
<td>10.4</td>
</tr>
<tr>
<td>9500</td>
<td>10.4</td>
<td>9.8</td>
<td>11.92</td>
<td>12.87</td>
<td>12.68</td>
</tr>
<tr>
<td>11500</td>
<td>12.37</td>
<td>13.76</td>
<td>13.23</td>
<td>13.87</td>
<td>13.23</td>
</tr>
</tbody>
</table>

[Amplitude 0.5mm, Frequency 400Hz]