CHAPTER 3

MACHINERY MATERIALS AND TESTING METHODS

3.1 INTRODUCTION

This chapter discusses the materials and the methods used in the thesis.

3.2 MACHINERY AND MATERIALS

Rotor spinning was the first commercially implemented method of forming yarn from fiber by the “Open End” principle. The machine used in this study - a Lakshmy Rieter M2 machine- is a third generation machine.

This machine is designed for spinning medium and coarse yarns from short and medium staple fiber. This is reflected in the machine’s gauge, which is designed to accommodate large cans and big yarn packages.

The machine is built on a modular construction, each module containing twenty four rotors. If necessary a module can be removed from the machine and replaced by a spare unit to permit repairs and servicing.

The standard rotor diameter is 54 mm., which is wide enough to process fibers with effective lengths of up to 40 mm. The machine can process any type of cotton grown in India and can handle synthetic fibers and blends whose effective lengths fall within the stated range.

The machine has an electronic control system and considerable thought has gone into the design to permit the machine to work at high efficiency and productivity. A conveyer belt to transport full packages is provided, as is a system for the separate collection of hard waste. The machine can automatically wind a transfer tail to the packages it creates.

The machine can be run at speeds as low as 31,000 RPM. and as high as 60,000 RPM., though the economical range of the machine is 50,000 to 60,000
Table 3.1

TWIST RANGE VS. ROTOR SPEED

<table>
<thead>
<tr>
<th>Rotor RPM</th>
<th>Twist per Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>31,000</td>
<td>222 - 658</td>
</tr>
<tr>
<td>36,000</td>
<td>259 - 777</td>
</tr>
<tr>
<td>40,000</td>
<td>290 - 860</td>
</tr>
<tr>
<td>45,000</td>
<td>323 - 1204</td>
</tr>
<tr>
<td>50,000</td>
<td>363 - 1328</td>
</tr>
<tr>
<td>55,000</td>
<td>403 - 1476</td>
</tr>
<tr>
<td>60,000</td>
<td>448 - 1624</td>
</tr>
</tbody>
</table>

Table 3.2

COTTON FIBER PROPERTIES

2.5% span length ........... 29.84 mm.
50% span length ........... 18.75 mm.
Stelometer tenacity ...... 212.6 mN./Tex
Elongation at break ...... 5.4%.
Micronaire value ........... 4.02
Maturity Coefficient ...... 0.807
RPM. The maximum yarn production rate is 140 metres per minute.

The machine can take as feed stock sliver ranging from 2567 to 4920 Tex and give it a draft ranging from 24 to 246. Thus the machine can produce yarn in a range of 19.7 Tex to 197 Tex.

The use of a five stage twist pulley and a twist change wheel means that the machine can produce yarn with a very wide range of twists. The actual minimum and maximum twists that a yarn can have depends on the rotor speed. Table 3.1 gives the maximum and minimum twist per metre for various rotor speeds.

The opening roller built into each rotor feed system can work at speeds ranging from 5000 to 8000 RPM. This serves as a final trash extractor as well as a fiber individualiser.

The machine can be fitted with fluted take off tubes as well as a false twist device when producing low twist yarns. Another extra fitting permits the yarn to be waxed before it is wound onto the package.

The cotton fibers spun were a mixture of 'Varalakshmi' and 'M.C.U.-5' in the ratio of 20 percent to 80 percent. The properties of the mixing are given in Table 3.2.

The feed material chosen was second passage drawframe sliver. This sliver having a hank of 4217 Tex was feed stock for 19.7 Tex (30 Ne) yarn. This sliver had no measurable trash.

3.3 THE PARAMETERS OF THE STUDY

It was realised quite early that the new machines produced yarns that were fundamentally different in structure from the yarns produced by ringframe. This naturally led to a lot of work towards understanding the structure of these yarns and their properties.
This experiment was designed as a full factorial experiment in which two machine parameters (the rotor speed and the opening roller speed) and two yarn parameters (the count and the twist) were varied at three levels.

It was decided to bracket the commonly used values for all four parameters. Since the tables for setting the yarn parameters were in the English Cotton system, the yarn counts were set at 10s Ne. (59.04 Tex), 20s Ne. (29.52 Tex) and 30s Ne. (19.68 Tex) and the twist factors were set at 4.5 (43.05 tf Tex), 5.5 (52.61 tf Tex) and 6.5 (62.18 tf Tex).

The Rotor speeds were set at 50,000 RPM, 55,000 RPM and 60,000 RPM. The speeds of the opening roller were set at 5000 RPM, 6670 RPM and 8000 RPM, and a smooth take off tube was used.

Since the experiment was a full factorial study, a total of eighty one (3 x 3 x 3 x 3) distinct yams were produced. The production of each yarn was replicated on five rotor heads (each in a different module of the machine), and the four hundred and five packages were tested for the various yarn properties.

3.4 YARN PRODUCTION

Two cans of the sliver were taken and the first can was divided into eight parts and drafted on a Rieter drawframe with a draft of eight reversing it end for end; the second can was divided into five parts and drafted on the same drawframe with the same settings. The drawframe settings were carefully adjusted to ensure that no further periodic variation was introduced by this process. This was verified by spectrograms taken before and after drafting.

The purpose of this was to reduce the linear density of that part of the sliver which would act as the feed stock for the 19.7 & 29.5 Tex yams. The production of 19.7 Tex yarn from 4217 Tex sliver is within the capacity of the machine. However, the draft necessary for such an operation is near the theoretical limit of the machine and probably such a draft would not be used.
during routine production. Therefore it was decided to draft down part of the sliver.

The rotor spinner was set in turn for each yarn (Tables 3.4-3.8). The correct slivers were then fed to the rotors.

Two thousand metres of each yarn was produced at each rotor, the time of each run being adjusted to produce just that much yarn (Table 3.8).

Before each run, the rotors were cleaned. Since the time of a run was for a period ranging from thirteen to forty minutes, no significant accumulation of trash in the rotor could occur. An attempt was made to measure the actual amount of dust accumulated using a hand held vacuum cleaner fitted with a paper filter, but the amount of trash collected was so small that it could not be accurately measured, and this study was discontinued.

The yarn produced was wound onto standard cardboard tubes in the form of cheeses. At the end of each run each tube was marked with the run number, and the number of the head on which it worked and the five tubes were wrapped up in a plastic bag whose mouth was folded and stapled shut. The machine was then set for the next run.

In this manner, the eighty one yarn samples were produced.

3.5 TESTING METHODS

The following measurements were carried out during the course of the experimental work:-

i) Bending properties of the yarns.
ii) Buckling properties of the yarns.
iii) Lateral compression properties of the yarns.
iv) Frictional properties of the yarns.
v) Abrasional properties of the yarns.
vi) Wicking properties of the yarns.
vii) Tensile properties of the yarns.
### Table 3.3

YARN TWIST (TPM)

<table>
<thead>
<tr>
<th>COUNT</th>
<th>43 T.F.</th>
<th>52.6 T.F.</th>
<th>62.2 T.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.0 Tex</td>
<td>558.66</td>
<td>681.89</td>
<td>800.39</td>
</tr>
<tr>
<td>29.5 Tex</td>
<td>796.46</td>
<td>964.57</td>
<td>1144.10</td>
</tr>
<tr>
<td>19.7 Tex</td>
<td>964.57</td>
<td>1179.92</td>
<td>1445.67</td>
</tr>
</tbody>
</table>

### Table 3.4

TWIST SETTINGS FOR 50,000 RPM ROTOR SPEED

<table>
<thead>
<tr>
<th>T.F. = 43</th>
<th>T.F. = 52.6</th>
<th>T.F. = 62.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPM</td>
<td>TW</td>
<td>BP</td>
</tr>
<tr>
<td>562</td>
<td>66</td>
<td>201/226</td>
</tr>
<tr>
<td>789</td>
<td>70</td>
<td>250/202</td>
</tr>
<tr>
<td>978</td>
<td>56</td>
<td>194/153</td>
</tr>
</tbody>
</table>

### Table 3.5

TWIST SETTINGS FOR 55,000 RPM ROTOR SPEED

<table>
<thead>
<tr>
<th>T.F. = 43</th>
<th>T.F. = 52.6</th>
<th>T.F. = 62.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPM</td>
<td>TW</td>
<td>BP</td>
</tr>
<tr>
<td>559</td>
<td>70</td>
<td>201/251</td>
</tr>
<tr>
<td>789</td>
<td>64</td>
<td>250/202</td>
</tr>
<tr>
<td>951</td>
<td>63</td>
<td>273/177</td>
</tr>
</tbody>
</table>

T.F. = Twist Factor  
TPM = Twist Per Meter  
TW = Twist Change Wheel  
BP = Twist pulley setting
Table 3.6
TWIST SETTINGS FOR 60,000 RPM ROTOR SPEED

<table>
<thead>
<tr>
<th>T.F. = 43</th>
<th>T.F. = 52.6</th>
<th>T.F. = 62.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPM TW BP</td>
<td>TPM TW BP</td>
<td>TPM TW BP</td>
</tr>
<tr>
<td>559 64 201/226</td>
<td>682 63 226/226</td>
<td>800 70 226/226</td>
</tr>
<tr>
<td>797 59 250/202</td>
<td>969 58 273/177</td>
<td>1144 68 273/177</td>
</tr>
<tr>
<td>965 72 250/202</td>
<td>1180 70 273/177</td>
<td>1446 67 294/153</td>
</tr>
</tbody>
</table>

Table 3.7
DRAFT SETTINGS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>59 Tex</th>
<th>29.5 Tex</th>
<th>19.7 Tex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliver Hank</td>
<td>3690</td>
<td>2636</td>
<td>2636</td>
</tr>
<tr>
<td>Draft</td>
<td>71.43</td>
<td>82.29</td>
<td>133.93</td>
</tr>
<tr>
<td>Draft Pulley</td>
<td>C / A</td>
<td>C / A</td>
<td>C / B</td>
</tr>
<tr>
<td>Draft Wheel</td>
<td>41</td>
<td>51</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 3.8
RUNNING TIME

<table>
<thead>
<tr>
<th>Yarn Count</th>
<th>T.F.</th>
<th>Time (min) 50,000 RPM</th>
<th>Time (min) 55,000 RPM</th>
<th>Time (min) 60,000 RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.0</td>
<td>43.0</td>
<td>18</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>59.0</td>
<td>52.6</td>
<td>22</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>59.0</td>
<td>62.2</td>
<td>23</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>29.5</td>
<td>43.0</td>
<td>25</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>29.5</td>
<td>52.6</td>
<td>31</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>29.5</td>
<td>62.2</td>
<td>33</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>19.7</td>
<td>43.0</td>
<td>31</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>19.7</td>
<td>52.6</td>
<td>37</td>
<td>31</td>
<td>28</td>
</tr>
<tr>
<td>19.7</td>
<td>62.2</td>
<td>40</td>
<td>36</td>
<td>33</td>
</tr>
</tbody>
</table>
viii) Regularity and imperfections of the yams.

3.5.1 GENERAL CONSIDERATIONS

The parameters of the yams being tested include the usually determined properties like strength, evenness and imperfections as well as the low stress mechanical properties that form the major part of this study.

The testing laboratory has a number of testers that are capable of giving a voltage loop signal representing the instantaneous value of the property being tested.

An analog to digital converter linked to a computer would allow the computer to 'read' and record the change of properties during the duration of the test as well as the final results. This would allow the testers to be used in a much more flexible fashion and permit certain measurements that would otherwise be impossible.

Though commercial analog to digital converters were available that could be fitted to IBM PC compatible computers, at that time the laboratory had only a Tandy Mark IV computer. This computer is an eight bit Z80 based system that uses the CP-M operating system and no commercial unit was available for this.

It was decided therefore to build an analog to digital converter Board that could be attached to this machine. Considerable thought was given to the design of this board, and it was decided early on that an eight bit converter (which would give an accuracy of one part in two hundred and fifty six) would not be sufficiently exact.

The availability of components and financial constraints limited us to a twelve bit converter based on the Intersil 7109 chip. This is an accurate (one part in four thousand and ninety five) but slow (fifteen conversions per second) converter chip.
However since the purpose of the system was to measure mechanical variations, it was felt that the slow speed would be just adequate for its purpose, though a faster converter would give a more precise picture of how the measured parameters were changing.

The nominal range of this chip is -5 volts to +5 volts, and it can only measure the voltage of a single line. The board built around this chip had eight lines multiplexed to the chip under software control. This enabled the computer to select one line, measure the voltage, select another line measure the voltage and so on.

In designing the board it was meant that only two lines would be worked in any one experiment (thus slowing the rate of conversion to seven readings per second for each line).

The reason for eight lines was accuracy. Each line incorporate amplifiers that allowed the zero and maximum voltage of that line to be accurately preset. With the help of an accurate digital voltmeter, the lines were set as such. Thus the maximum voltage (the voltage at which the line would give five volts to the converter chip, causing it to signal full voltage), of lines one and two was one volt, of three and four was two volts, of five and six five volts and seven and eight ten volts.

Now depending on the maximum voltage of the tester to which the converter is to be connected, the appropriate lines could be selected to give the full accuracy of the chip.

The controller software running on the computer was written in Cbasic compiled by the CB-80 compiler. There were two reasons for this choice. Firstly, this compiler is highly optimised, and is probably the fastest high level language available in the CP-M operating system. Further this compiler allows multi line user defined functions whose variables are hidden from any main program that calls them. Thus it was possible to write one set of driver software in such a manner that different data analysis or data recorder programs (different tests on
the same tester or different testers) could call the same functions to actually read the data. A technical description of the board is included in Appendix 1.

With this interface it is possible to obtain the parameters with a far greater accuracy than can be obtained by reading a plotter graph. Also the readings can be obtained far more quickly and since the equipment has no moving parts, is far less likely to go out of order.

3.5.2 MEASUREMENT OF THE BENDING CHARACTERISTICS

To study the bending behavior of yarns, it is clearly necessary to have a means of measuring it. Pure bending testers have only become available fairly recently and such a tester (a KES-FB2-L) was used in this work to obtain the moment curvature relationships for the cotton yarns.

3.5.2.1 SAMPLE PREPARATION

A cardboard 3 cms. by 22 cms. is taken and a piece 1 cm. by 20 cms. is removed from the center to leave a frame (Figure 3.1). Two strips of double sided adhesive tape are stuck onto the top of the long sides.

A special “‘T’” shaped holder (Figure 3.2) with slots cut into the top of the “‘T’” has been constructed for preparing the yarn specimens. This holder fits into the clamp of the blackboard winding machine.

Two cardboard frames are mounted on this holder, one on either side and the holder in turn is placed in the jaws of the blackboard wrapping machine. The plastic layer protecting the top adhesive layer of the tapes is peeled off and the sample yarn is wound over the strips. Two hundred turns are wound onto the holder perpendicular to the long axis of the cardboard strips.

The yarn adheres to the tape, the holder is removed from the winding machine holder and the lengths of yarn extending beyond the strip are trimmed away and the two prepared strips are peeled off the holder.
FIGURE NO. 3.1 SPECIMEN BLANK FOR PREPARING TEST SAMPLE.
FIGURE NO. 3.2 HOLDER FOR PREPARING YARN SPECIMENS
In this manner two samples per cheese (ten per yarn) are prepared from every cheese spun. These specimens are used for the bending tests.

3.5.2.2 TESTING EQUIPMENT

The Kawabata pure bending tester is a special tester designed to measure the bending rigidity and the bending hysteresis of fabrics, nonwovens, papers and other film like materials.

The machine has two jaws (called chucks) that face each other with one cm. of space between them. One chuck (called the back chuck) is fixed to the frame of the machine through a load cell. The other (known as the front chuck) can move in an arc to bend a flat specimen clamped between the two chucks (Figure 3.3).

A computer controls the instrument. When the specimen is mounted onto the chucks, the testing procedure can be started from the computer keyboard.

In this machine the whole sample is bent accurately in an arc of constant curvature (Figure 3.4). The curvature changes at a constant rate. The specimen is bent to the right, brought back to the center, then bent to the left, brought back to the center, again bent to the right and brought back to the center. The bending moment of the sample is constantly monitored, and the relationship between curvature and bending moment is measured accurately digitised and stored in the digital computer.

A typical force versus bending curvature graph given in figure 3.5. This graph shows the procedure for calculating the parameters $B$ (the bending rigidity) and $2HB$ (the bending hysteresis).

$B$ is the average slope of the bending curve at a radius of curvature of 1.5 cm$^{-1}$ to the left and the right. $2HB$ is the average of the difference in force value of the bending and unbending curves at a radius of curvature of 1.0 cm$^{-1}$ to the right and the left.
The percentage of recoverable work is calculated from the formula given by Collier [52]:

\[ \text{RW}\% = \frac{(B)(1\text{cm.}^{-2})}{(B)(1\text{cm.}^{-2}) + 2HB(1\text{cm.}^{-1})} \times 100 \]  

(3.1)

Here the values for \( B \) and \( 2HB \) are the actual values for a single yarn. That is \( B_y \) in gf.cm\(^2\)/cm. and \( 2HB_y \) in gf.cm./cm then the \( 1\text{cm.}^{-2} \) and the \( 1\text{cm.}^{-1} \) factors cancel out numerically.

### 3.5.2.3 TESTING PROCEDURE

The first cardboard frame (along with the yams stuck to it) is taken and placed vertically in the chucks of the tester, so that the space between the chucks contains only the yams (the edges of the cardboard frame and the chucks coincides). The screws of both chucks are tightened fixing the frame in place. Then the cardboard strips at the top and bottom are cut away so that only one set of yams link the two chucks together.

The test is started from the computer. The computer automatically conducts the test recording the results. The values of the parameters \( B \) and \( 2HB \) are calculated automatically according the procedure described above.

These values are displayed along with the experimental curve on the computer screen. Copies of the screen for different yarn samples are shown in figures 4.1 (a) - (c).

At the end of the test the forward chuck returns to the center position. Then the screws of the chucks can be opened and the specimen removed. Then the next specimen can be inserted and the testing can proceed.

### 3.5.3 MEASUREMENT OF THE BUCKLING PARAMETERS

#### 3.5.3.1 SAMPLE PREPARATION

For measuring the buckling behavior of yarn, a technique similar to that
used for measuring bending behavior was employed. However the cardboard 
was only 3 cms. by 11 cms. and the hole in its center was 1 cm. by 9 cms. 
(Figure 3.6). Yarn sheets were prepared using such frames by the procedure 
described in section 3.5.2.1.

3.5.3.2 TESTING EQUIPMENT

To determine the buckling behavior of rotor yarns a special fitting has 
been devised for the Instron Tensile Tester. This consists of a pair of screw 
mounted acrylic jaws long enough to securely clamp the full length of the 
prepared specimens. These jaws are placed in a jig that holds them parallel at 
a distance of one cm. from each other. The remaining equipment consists of a 
special clamp mounted on a long rod which is designed to fit the 10 N load cell 
of the Instron. The clamp can rigidly hold one of the acrylic jaws.

3.5.3.3 TESTING PROCEDURE

The Instron is fitted with the 10 N load cell and the clamp is attached 
to the cell by means of its arm. A standard fabric clamp is fitted to the frame 
of the Instron. The cross-head of the Instron is adjusted so that the clamps are 
three cm from each other. The speed of movement of the cross-head is set to a 
low value of one mm per minute. The load and extension signals of the Instron 
are connected to the ten volt channels of the Instron. The mark IV computer is 
loaded with a special software designed to monitor the Instron.

The screws are released to open the jaws, and the first of the prepared 
specimens is placed between the jaws so that the sides of the specimens are 
gripped by the jaws leaving the yarn in the center free. The jig as a whole is 
lifted and placed between the clamps of the Instron. The clamps are fixed to the 
acrylic jaws, and the jig is removed leaving the jaws with the specimen between 
them clamped in Instron’s clamps. Then the short side of the cardboard is cut 
leaving the yarns fixed between the clamps of the Instron.
The Instron cross head is moved down, axially loading the yams. After a critical load is reached the yams begin to buckle. The changing force/position readings of the Instron are recorded by the computer.

When the cross-head has moved down two millimeters the computer sounds a beeper. The cross-head is then moved up (without stopping) at the same speed. The data is constantly recorded.

When the load registers zero the computer again sounds the beeper. The direction of motion of the cross head is reversed and it is moved down again.

When the cross-head moves down two millimeters the beeper sounds for the third time. The data recording is stopped and the cross head is raised to the starting position. The jaws are removed from the clamp and opened. The cardboard strips holding the yams are removed. The jaws are put back on the jig to permit the next sample to be prepared for testing. In this manner ten samples (each of seventy five threads) per yarn are tested.

Three load/position curves per test are recorded. They are the compression curve, the decompression curve and the recompression curve. A typical set of curves from different yams are shown in figures 5.1 - 5.9.

The computer calculates the energy in each curve by integrating the area under the curve. Then it calculates three buckling parameters. These parameters are 1) the percentage recovery from buckle, 2) the energy loss in a compression cycle and 3) the compressibility of the yam. The energy loss per cycle is a measure of the magnitude of hysteresis in the buckling cycle. The compressibility is the inverse of the initial slope before the yams begin to buckle.

Let the areas under the curves be $\alpha$, $\beta$ and $\gamma$, $N$ the number of yams, $P$ the maximum load and $C$ the compression at maximum load then the following formulas give the required values:

\[ \text{Percentage recovery from Buckling} = \frac{\alpha}{\beta} \times 100 \]  
(3.2) 

\[ \text{Percentage energy lost in Compression cycle} = \frac{(\alpha - \beta)}{\gamma} \times 100 \]  
(3.3)
Compressibility = \frac{C \times N}{10P} \quad (3.4)

3.5.4 MEASUREMENT OF LATERAL COMPRESSION OF THE YARNS

3.5.4.1 TESTING INSTRUMENTS

The Kawabata compression tester is a microprocessor controlled load cell based instrument for determining the stress strain behavior of yarns and fabrics under light compressional loads. It consists of two units, the actual compression unit and a separate control unit, on whose front panel are the switches and read-outs. The two units are connected by cabling. A third optional unit is a digital computer interfaced to the control panel. This unit was not available in the tester on which this study was carried out.

In the compression unit, a horizontal plate with a circular hole cut in the center provides a surface to put the fabric. From the central hole a circular rod 2 sq. cms. in cross-section protrudes a millimeter above the level of the plate. The top of the rod is flat and polished smooth. The bottom of the rod is connected to the load cell. This is the anvil.

The actual compression is done by a plunger that can move down from above the plate to press down onto the anvil. The bottom on the plunger is also a circular rod 2 sq. cm. in area, polished smooth and parallel to the anvil and aligned to descend exactly on top of it. The rest position of this plunger (the gap between plunger and anvil) is adjustable and can be set by a dial on the compression unit.

The position of the plunger is constantly and accurately monitored by the instrument control using a feedback tacho generator. The repeatability of the plunger positioning is of the order of a thousandth of a millimeter.

When a fabric is placed on the plate, the plunger compresses it against the anvil. In such a test the control circuits move the plunger down till the load
cell registers a load of 100 gms. (a pressure of 50 gms./sq. cm.) and then lifts the plunger up again.

During the compression and decompression cycles the load reading and the plunger position are accurately noted. These values are available as voltage signals at a set of terminals on the front panel of the instrument.

An electronic integrator integrates the signals computing the work done during compression and the work recovered during decompression (the areas under the compression & decompression curves) and displays the values on a digital read-out.

For testing yarns the plate in the compressional unit is removed. Below the plate are a set of yarn clamps whose horizontal and vertical positions are adjustable. The bottom of the plunger is exchanged for a unit which has a square cross-section, each side being 4 mm. in length. The maximum pressure felt by the yarn is 250 g per cm. of yarn (100 /0.4).

3.5.4.2 TESTING PROCEDURE

The instrument is adjusted to the yarn testing configuration by removing the top plate and replacing the plunger bottom with the square yarn testing unit. The gap between plunger and anvil is set as 1 millimeter.

The five volt channels of the analog to digital converter are connected to the load and position signal terminals on the front panel of the control unit. Now the Mark IV computer can monitor and record the progress of each test.

The yarn clamps of the tester are raised well above the anvil. A length of yarn is unwound from a cheese of the first yarn and placed between the jaws. One jaw is closed and keeping a light tension on the yarn to keep it taut, so is the other.

Now the jaws are lowered till the length of yarn stretched horizontally between them just touches the top of the anvil. The horizontal position is adjusted so that the yarn is below the plunger.
The test is started. The plunger descends compressing the yarn. As the maximum load is reached, the plunger changes direction and returns to its resting position. The computer records the series of load and position values generated during compression and decompression. Before doing this, the control program converts them to pressure and thickness values.

Then the jaws are removed from their position between plunger and anvil and the yarn sample is changed. The jaws are put back in position and the next test is begun.

In this manner five tests per cheese (twenty five tests per yarn sample are conducted. The test data are fed to a second program which calculates the Kawabata parameters, WC, LC and RC. The program first uses numerical integration to calculate the parameters $\alpha$, the area under the compression curve and $\beta$ the area under the decompression curve.

$$\begin{align*}
\alpha &= \int_{t=t_{\text{min}}}^{t_{t_{\text{max}}}} P_{\text{cmp}} \delta t \\
\beta &= \int_{t=t_{\text{min}}}^{t_{t_{\text{max}}}} P_{\text{dcmp}} \delta t
\end{align*}$$

(3.5) (3.6)

Where $P$ is the pressure and $t$ the thickness. Then the parameters are computed as follows:

$$\begin{align*}
WC &= \alpha \\
RC\% &= \frac{\beta}{\alpha} \times 100 \\
LC &= \frac{2\alpha}{(t_{\text{max}} P_{\text{max}})}
\end{align*}$$

(3.7) (3.8) (3.9)

3.5.5 MEASUREMENT OF FRICTION OF THE YARNS

3.5.5.1 PRINCIPLE OF THE EXPERIMENT

In this study the coefficient of friction ($\mu$) is determined by the capstan method. Here the yarn is wound around the surface of a cylinder (the capstan).
The capstan equation is:

\[ \frac{T_1}{T_2} = e^{\theta} \]  

(3.10)

Here \( T_1 \) and \( T_2 \) are the tensions at the two ends of the yarn, \( e \) is the base for natural logarithms, \( \theta \) is the angle of contact between the yarn and the cylinder measured at the axis of the cylinder. If \( T_1 \) and \( T_2 \) are measured just as the two surfaces are about to slip this method gives the limiting static friction. If the surfaces are already in motion at the time of the measurement, the value of \( \mu \) obtained is for dynamic friction.

A simple fitting on the Instron Tensile Tester permits the instrument to measure the dynamic friction at a yarn to metal interface using a variation of the capstan principle.

### 3.5.5.2 TESTING EQUIPMENT

The testing equipment is extremely simple. It consists of a "L" shaped arm that can be attached to the 10 N load cell of the Instron so that the long horizontal arm of the "L" juts out perpendicular to the frame axis of the Instron and beyond the instrument's base, as well as a capstan (a circular rod 5 mm. in diameter) that can be gripped in the jaws of the fabric clamp (Figure 7.1).

The clamp is turned 90° in its holder so that the capstan also is perpendicular to the frame axis and protrudes beyond the base of the Instron, vertically below the arm of the "L" shape and parallel to it.

The load and cross-head movement signals of the instron are connected to the mark IV computer through the analog to digital converter described above.

### 3.5.5.3 TESTING PROCEDURE

The testing procedure is extremely simple. The cross-head of the Instron is moved down till the arm of the "L" shape is about ten cms. above the capstan.

The end of the yarn to be tested is unwound from the cheese (care being taken that no twist loss occurs) and is tied to the arm of the "L" shape. About
eighty cms. of yarn is unwound from the cheese and the yarn is broken off. The free end of the yarn is attached to a flat acrylic weight (3 cms. by 8 cms. and weighing 10 gms.).

The weight is allowed to hang from the arm. To ensure that the yarn does not untwist, a long glass plate is placed so that a vertical edge of the weight rests against it stopping the weight from rotating.

For this test, the load cell is seated lose in its socket without being bolted to the cross head. So it is free to rotate around its vertical axis. The cell is slowly twisted, sweeping the “L” shape around till the hanging yarn is no longer in contact with the capstan.

The computer program is started, and the cross-head is moved up. The Instron registers the sum of the magnitude of the weight and the frictional drag between the edge of the weight and the glass plate. The cross-head is moved up 50 cms. and returned to the starting position. A total of twenty reading are taken at intervals of 2.5 cms. starting after the cross-head has moved 6.6 cms.

The load cell is rotated in its socket till the hanging yarn is tangential to the capstan surface. Then the yarn is wrapped once around the capstan and the weight is allowed to hang down again (note that the position of the weight now is 1.6 cms. higher than before).

The cross-head is again moved up. This time the readings begin when the cross-head has moved up 5 cms. and again twenty readings are taken at intervals of 2.5 cms.

In the case of the first and second set of measurements each reading is actually the average of ten readings taken quickly in succession. These readings are checked against each other and any reading that differs by more than 0.2 gms. from the others is not included for the purpose of calculating the average. The coefficient of friction is determined from the capstan equation (equation 3.10). Here $T_2$ is the first set of readings and $T_1$ the second set, for this test

\[
\theta = 2 \times \pi = 6.28319 \text{ radians.}
\]

Taking natural logarithms on both sides of
equation (3.10) transforms it to:

\[ \mu = 0.368 \log_e \left( \frac{T_1}{T_2} \right) \]  

(3.11)

In this manner 20 readings per cheese (a 100 readings per yarn sample) are taken and recorded by the computer.

The weight is removed from the yarn and the yarn itself from the arm of the “L” shape. The next cheese is taken, and the test repeated till all the yarns are tested.

3.5.6 MEASUREMENT OF YARN ABRASION CHARACTERISTICS

3.5.6.1 TESTING EQUIPMENT

The abrasion tester consists of a set of metal pins that can oscillate in the vertical plane; these pins can be covered by a layer of abrasive paper of different grades. The device has clamps (one for each pin) that can grip yarns and allow them to hang vertically with a weight at the other end (Figure 7.2). These yarns can be passed around one of the pins so that as the pin moves up and down it will abrade the yarn. The machine has a counter that records the number of oscillations the pin bar makes. The number of oscillations necessary to weaken the yarn so that it breaks under the influence of a twenty gram weight is taken as a measure of its abrasion resistance.

3.5.6.2 TESTING PROCEDURE

The abrasion tester allows ten yarns to be tested simultaneously. For this experiment the pins are covered with emery paper of grade 334W. The yarn is allowed to lap the pin for an angle of 70°. The length of each oscillation is set as 10 cms. The yarn weight is set at 20 gms. for all counts.

Twenty samples per yarn are tested (in two batches). In each batch, two yarn samples per cheese are fitted to the clamps and loaded with the twenty
gram weights. These weights are flat and hang in a narrow slot so that the yarn cannot lose twist by rotating.

All ten clamps are loaded and the recording counter is set to zero. The machine is started. As each yarn breaks, the machine is stopped and the counter reading is noted before restarting the machine. After all the yarns are broken, a fresh set of yarns is loaded and the testing is continued.

3.5.7 MEASUREMENT OF THE WICKING BEHAVIOR OF THE YARNS

3.5.7.1 TESTING EQUIPMENT

The equipment consists of a number of 250 ml. beakers each filled with 100 ml of distilled water in which 0.1 gms. of Direct Blue XGL dye has been added and a number of special frames. These consist of a plastic shape which supports four pegs that form the corners of a rectangle 30 cms. by 5 cms. On the vertical supports two scales are engraved. These have a least count of one mm. The shape of the frame is such that when the yarn is tied into a loop over the pegs each long arm of yarn loop is superimposed on a scale.

3.5.7.2 SAMPLE PREPARATION

The 75 cm of yarn from the cheese is taken and knotted into a loop 70 cm in circumference. In taking the yarn care is taken to discard the outer layer so that the yarn in the loop is not a sample that has suffered twist loss.

Five such loops per yarn are prepared (one per cheese). These were washed in acetone to remove the natural oils and waxes that were present in the cotton. The acetone wash consists of working them in fresh acetone (five loops at a time) for ten minutes and then allowing them to dry in a stream of air.

These loops are conditioned for 24 hours and then each one is fitted onto one of the special frame for the wicking test.
3.5.7.3 TESTING PROCEDURE

The frames are picked up one by one and placed in the beakers. As the first frame is placed in the beaker a stop watch is started. The other frames are immersed at 10 second intervals.

Ten seconds after the last frame is placed in its beaker the yarn in the first beaker is examined and the heights wicked on both arms are recorded. The second beaker’s wicking heights are recorded 10 seconds later and so on. This continues for five minutes. In each sample the height reached by the water at 1, 2, 3, 4 and 5 minutes is recorded.

Then the water level in each beaker is read off from the plastic scales on the frames. The height according to both scales is recorded.

The wicking is allowed to continue. A plastic bag is taped over the beaker and the five beakers are set aside.

Work on dewaxing the second set of yarns is begun. It is possible to dewax condition and test three sets of yarns every day (the samples dewaxed are set to condition and tested the next day).

The fifteen beakers are allowed to stand for twenty four hours and then the height reached in each of the ten yarns is recorded. All the height readings are corrected by subtracting the height of the liquid surface in the beaker from the recorded heights.

The parameter \( k_s \) is computed by fitting a least square regression line to the data taking \( \sqrt{\text{time}} \) as \( X \) and the height as \( Y \). The slope \( m \) of the line \( (Y = mX + C) \) is taken as \( k_s \). The average of the ten readings of maximum height reached is also computed.

This is done for all the yarn samples.
3.5.8 MEASUREMENT OF THE TENSILE PROPERTIES OF THE YARNS

3.5.8.1 TESTING EQUIPMENT

The data on tensile behavior was obtained by breaking the yarns on an Instron Universal Tensile testing machine. For the purposes of these measurements the machine was fitted with a 10 N load cell. The test mode was set to constant rate of extension. The actual extension rate was set to three hundred millimeters per minute.

As the Instron on which these tests were done lacked automatic clamps for use with the 10 N cell a special fitting was designed and manufactured to permit rapid loading of the yarn sample and rapid removal of the broken pieces.

This consisted of two rods of circular cross section. The first rod is "?" shaped and its stem was turned to fit exactly into the holder on the load cell. A hole of the right size was drilled in it at the right height to permit it to be locked into the holder of the load cell with the support pin. In this position the other arm of the rod juts out horizontally. A "V" notch has been cut on the upper side of this arm at a distance of 50 mm from the end.

The second rod is "U" shaped with one arm of the "U" longer than the other. A thread has been cut into the shorter arm and a pair of nuts are used to lock the rod onto a rectangular plate which has a hole of the right size drilled in it ten mm. from one end. The other end of the plate is clamped into the bottom clamp of the Instron. This leaves the longer upper arm of the "U" jutting out horizontally. The position of the plate in the jaw is adjusted so that the rod is directly below the rod fixed to the load cell. A "V" notch has been cut into the underside of the upper arm. The nuts holding the rod to the plate are adjusted so that the notches in the two rods are vertically in line.
3.5.8.2 SAMPLE PREPARATION

The yam samples were conditioned at 20°C and 60% R.H. for twenty four hours prior to the commencement of the tests.

3.5.8.3 TESTING PROCEDURE

Previous single thread tests were done on a Uster Dynamometer with the average of a hundred tests being taken as the representative value. In order to maintain a comparable accuracy it was decided that one hundred tests per yarn would be done. Since each yarn was spun in five replications, a total of twenty tests per cheese were done.

To adjust the special jaws, the crosshead of the Instron is lowered so that the two rods are almost in contact. After the rods are placed vertically in line, the crosshead is raised so that the vertical distance between the horizontal arms of the two rods is five hundred millimeters (the gauge length).

To use this device, yarn is withdrawn from the package and after passing it through the notch on the top rod the free end is quickly wound ten to fifteen times around the rod. More yarn is unwound off the package and taken over the notch in the lower rod and wound onto the rod. During tensile loading, capstan friction prevents slippage. After the yarn breaks pulling the free end at the top quickly unwinds the yarn off that rod and pulling the end leading to the package clears the lower rod as quickly. Then the next length can be unwound from the package and wound onto the rods.

The analog output of the Instron was connected to the ten volt channels of the analog to digital converter (Figure 9.1).

The digitised stress strain curves of the yams were analysed a number of parameters were extracted. These include a) the tenacity, b) the elongation percentage at break, c) the work of rupture d) the work factor and e) the initial modulus.
The tenacity is the breaking load divided by the yarn Tex. The elongation percentage is the ratio of the breaking elongation to the gauge length (500 mm.) expressed as a percentage. The work of rupture is calculated by integrating the area under the load elongation curve. The work factor is the ratio of the work of rupture to the product of breaking load and breaking elongation. The initial modulus is the modulus (slope of the load elongation curve, normalised for yarn count and gauge length) at the start of the test.

Due to the lack of a yield point in this curve the initial modulus and the overall modulus are identical and the work factor is near 0.5.

3.5.9 MEASUREMENT OF YARN IRREGULARITY AND IMPERFECTIONS

3.5.9.1 TESTING INSTRUMENTS

The Uster tester used for this study is a Mark I B type of tester. This model consists of a) the measuring unit, b) the integrator, c) an imperfection indicator, d) a spectrogram and e) a high speed chart recorder.

The measuring unit uses the capacitance principle to measure the linear density of three types of fiber assemblies namely, 'slivers' 'rovings' and 'yarns'. Mounted on the body of the unit is a set of condensers of varying sizes (sometimes referred to as the 'comb').

The condensers of the comb can handle any thickness of textile material from the coarsest sliver to the finest yarn. Immediately below the 'comb' are a pair of spring loaded powered rollers. These rollers are the driving force that pulls the fiber assembly through the appropriate condenser in the comb.

The speed at which the material is moved can be set by a rotary switch on the measuring unit. The machine can test material at speeds of 4, 8, 25, 50, 100 & 200 metres per minute. Slivers are tested at 8 metres per minute, rovings and yarns are tested at 25 metres per minute. The other speeds are meant to be used in connection with the spectrogram module to detect periodic variations of
various wavelengths (generally the longer the wavelength range being examined the faster the scanning speed).

The body of the unit has provision for fitting various interchangeable guides which serve to direct the fiber assembly through the appropriate condenser and on through the driver rollers.

The machine works by sensing the change in the capacitance of the condenser as the varying cross section of the fiber assembly is drawn through it. The condensers used for yarn are 8mm. in length and the U% obtained is equivalent to the coefficient of variation obtained from cutting up the yarn to 8mm. bits and weighing them. An assumption of this mode of testing is that the dielectric constant of the material is constant. Thus when testing blends where a significant inhomogeneity of blending exists, this tester will tend to give a higher value than would be justified by the irregularity of cross sectional thickness.

The measuring unit converts the instantaneous thickness into a frequency modulated signal. This can be passed to a high speed recorder which will give a graphical output of the variation. However, it is more common to use the integrator module to obtain the average variation in the yarn.

Though all the other modules of the Uster use transistors, this unit is valve based. Therefore it is customary for the measuring unit to be switched on 60 to 90 minutes before testing starts to give the valves time to stabilise. The other modules are switched on typically five minutes before testing starts.

The integrator module is fitted with a timer device. When the timer is set the integrator resets itself and begins to integrate the signal from the measuring unit using a electronic hardware based analog integrator. The machine computes the average thickness and the variation in thickness on a real time basis. The machine transmits the instantaneous average to the next module (the Imperfection Indicator). The analog voltmeter mounted on the body of the integrator shows the instantaneous value of the irregularity as the test is proceeding.
Depending on the actual level of irregularity, the combination of measuring unit and integrator can work at one of several levels of sensitivity. Thus the maximum departure from the mean value, the machine can show can be set at 100%, 50%, 25% and 12.5% by means of a rotary switch on the measuring unit and the Integrator. The settings on both modules should be the same if the result is to be meaningful.

The third module of this tester is the imperfection indicator. This module is designed to be used only when yarns are being tested. This unit accepts the instantaneous value signal from the measurement unit and the cumulative value for the average thickness form the integrator. A rotary switch on the instrument is marked in speeds from 25 to 200 metres per minute. This must be set to the current testing speed.

This unit compares the instantaneous thickness against the cumulative average. If the two differ by a preset value, the machine registers the occurrence of an imperfection. Depending of the sign of the difference, this can be a thin place or a thick place. The machine makes a further discrimination between a thick place and a nep. Using the value of the testing speed set by the rotary switch, it times the length of any thickening in the yarn in excess of the preset limit. If the thickening is less than two millimeters in length, it is counted as a nep.

The machine can be set by a timer to test the yarn for an exact length of time. The imperfections observed are displayed on a set of three digital counters (one for thin places, one for thick places and one for neps). Below each counter is a rotary switch that sets the difference between the average and instantaneous values that will cause that counter to be incremented by one unit. These values are usually set at half the average value (50%) for thin places and twice the average value (200%) for thick places and for neps.

Generally the integrator and the imperfection indicator are set to test for five minutes at a test speed of 25 metres per minute. Thus a single test exam-
ines 125 metres of yarn. The values of the three classes of imperfections are multiplied by 8 and reported as imperfections per Kilometer.

The Spectrogram is an electro-mechanical analog computer designed to take the thickness signal from the measuring unit and perform a Fourier transformation on it, outputting the result as a periodic variation diagram on the high speed recorder. The testing speed has to be set on the machine using a rotary switch.

For drawing a spectrogram the recorder must be loaded with a special paper marked with wavelength on a semi-logarithmic chart. On this special chart, the various testing speeds are also marked with an arrow against each speed. While using the spectrogram, the chart paper must be set (by the advance button of the recorder) so that the pen rests on the arrow that corresponds to the testing speed.

Except when the required wavelength range demands a special speed, the spectrogram can be run along with the regular testing. The final module is the High Speed Recorder. This is a fast chart recorder. It can output the length variation curve or loaded with special chart paper output the periodic variation curve. When both outputs are required, there is a provision for a second recorder to be added to the modules of the tester.

3.5.9.2 TESTING PROCEDURE.

The measuring unit is switched on and allowed to warm up, about an hour or two before the testing starts. Once this unit has stabilised the other modules are switched on. The testing speed is set to 25 metres per minute. The sensitivity is set at 50%. The selector switches of the other modules are set accordingly.

The ‘without material’ adjustment knob is used to zero the instrument’s main galvanometer, with the test selector at ‘Adjustment’ position. Then the test selector is set to ‘Inert test’ position. The preset knobs of the Imperfection
Indicator are set to 50% for thin places and 200% & 200% for Thick places and Neps respectively. The three digital counters are set to zero.

The first cheese is taken and placed on the yarn holder vertically. The end is taken up through the eye of the guide through the disk tensioner and through the condenser, before passing it through the nip of the driver rollers. A waste can is placed below the rollers to catch the discarded yarn length.

The machine is started at a slow speed of 8 metres per minute. The needle of the galvanometer will oscillate, reflecting the variations in the yarn. The 'coarse' and 'Fine' amplification knobs are used to make it oscillate around the central position of the galvanometer's scale. Then the speed is increased to 25 metres per minute and the test selector is set to the 'Normal' mode. The Timers of the integrator and the Imperfection Indicators are set for five minutes.

As the timers click to zero the values of the Integrator and the counters of the Imperfection Indicator are recorded. The digital counters are reset to zero. The yarn cheese is replaced with the next sample and the testing resumes.

One test per cheese (five tests per yarn), with a sample length of 125 metres per test was done. In the Initial tests spectrograms were taken. However they uniformly showed no signs of any significant periodic variation and after the ninth yarn spectrograms were taken at random. All were uniformly negative. The only feature of the curves that could be attributed a cause was a small peak with a wave length of about 15 cms. This was probably caused by the yarn assembly point passing below the fiber deposition point.
FIGURE NO. 3.3 TESTING HEAD OF BENDING TESTER
FIGURE NO. 3.4 BENDING PATH OF TESTER
FIGURE 3.5 IDEALISED BENDING GRAPH

BENDING A-FB

B = bending rigidity (gf.cm/cm)

\[ B = \frac{W}{e} \]

2HB = bending moment (gf.cm/cm)

\[ 2HB = m \]

SAMPLE NO. DATE TEMP. Y HUM. %RH

1 Warp Bend

2 WIND BEND

MEAN

2HB = m

SENS 2 x 1

XY = 0.2 cm

X = 0.5 cm

Sample with 20 m

MIXEO