A STUDY OF
THE EFFECTS OF HIGH SPEED DRAWING ON
THE PROPERTIES OF YARN

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By
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A STUDY OF

THE EFFECTS OF HIGH SPEED DRAWING ON

THE PROPERTIES OF YARN

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ABSTRACT

The textile industry of this country today is faced with stiff competition not only at home but also with very fierce competition from abroad. And in order for mills to remain financially solvent, ways and means of reducing costs must be continually sought and applied. There are many ways in which costs can be reduced. If the production of a machine can be materially increased without a material increase in cost, then the cost of the end product can be reduced accordingly. Toward this end was the object of this study. The problem was to determine if the speed of the rolls on the drawing frame could be greatly increased (thereby increasing production) without producing an inferior yarn.

In the experimental portion of this study, Viscose rayon staple was processed conventionally from bale to yarn with the exception of the drawing process. At the drawing frame, roll speeds were increased for each of 20 lots in increments of 25 feet per minute from a starting speed of 105 feet per minute to a final speed of 680 feet per minute inclusive. The resultant yarn was then tested for tensile strength, elongation at break, and uniformity. There were found to be some variations in these parameters of yarn quality between lots whose slivers had been

processed at different speeds. However, a complete Analysis of Variance was made which showed that the variations noted were due solely to experimental error and that the mean universe value of each parameter was equal for each lot.

From the above it follows quite logically that the speed of the rolls of the drawing frame has no effect on the tensile strength, elongation at break, or uniformity of the resultant yarn.

It is strongly recommended, however, that work be done toward the development of a mechanically improved drawing frame that can be run efficiently at high speeds.

CHAPTER I

INTRODUCTION

Historical Sketch.--The fact that man has been interested in textiles from the most remote ages of time is substantiated by a fairly recent discovery of a true cotton fabric in the Sindh valley of India dating from the third millenium B.C. (1) About this same time (2640 B.C.), silk had its origin in China under the reign of the Chinese Emperor, Huang-ti, and it was his wife, Empress Si-ling-chi, (to this day worshipped as the Goddess of Silk) who paid particular attention to the cultivation of silk, its application to textiles and even invented a type of loom for weaving it (2). According to historians, in ancient times a nation's attainment of civilization and culture was attested by her peoples' skill in weaving and ornamenting fabrics. With such an extremely long background and history of practice, it is ironical indeed to note that no other art of comparable background has been so unprogressive as has the art of spinning fibers into yarn. Even admitting that much of the art was lost with buried civilizations, the lack of progress still weighs heavily in the scales of time.

It wasn't until the 18th century that man began to unfold his inventive genius toward the development of textile processing machinery. In the primitive era, yarn was spun directly from the raw stock onto a wooden spindle, a procedure far removed from present day practice. The first real step in the transition to the mechanical age occurred in 1738 with the invention by Lewis Paul (some historians credit John Wyatt) of the drawing process which embodied the principle of drafting or attenuating the rope or sliver by means of rollers (3). Specifically, Paul's patent application states:

> The wooll or cotton being thus prepared, one end of the mass, rope, thread or sliver, is put betwixt a pair of rowlers, cillinders or cones or some such movements, which being turned round by their motion, draws in the raw mass of wooll or cotton to be spun, in proportion to the velocity given to such rowlers, cillinders or cones; as the prepared mass passes regularly through or betwixt those rowlers, cillinders or cones, a succession of other rowlers, cillinders or cones moving proportionately faster than the first, draw the rope, thread or sliver into any degree of fineness which may be required.

From this time on and in successive stages, the textile industry has become more and more complex and intricuate in nature. Its economic influence and implications affect no less an area than the entire world. To survive the fierce present day competition in the industry, mill men everywhere must maintain their operation at the lowest possible cost level commensurate with their product and its end-use requirements. Toward this end then, of minimizing costs, is the practical application of this study.

Statement of the Problem.--The problem at hand was to determine what effect increasing the roll speed on the drawing frame had on the various physical characteristics of the resultant yarn. If high speed drawing and its implied greater production is not detrimental in light of the various parameters of yarn quality, the practical implication is quite clear. The number of drawing frames required, other factors remaining equal, would vary inversely with the increase in speed, resulting in a lower first cost, less maintenance and the concomitant saving because of less floor space required.

The amount of work done along this line or at least that which has been published, is almost negligible. In 1938 Peacock (4) conducted a series of experiments to determine the effect of roll speed in the drawing process on the tensile strength of spun yarn. He utilized long draft as well as regular draft making both warp and filling cotton yarn. He also utilized one and two process drawing as well as metallic and cork covered rolls. In general, Peacock found that the tensile strength increased with an increase in roll speed, particularly that which had been processed on one-and-three-eights inches metallic rolls. The outstanding shortcoming of his experiment was the narrow range of speeds used; the maximum range was from 65 feet per minute through 140 feet per minute. Although today this is hardly considered "high speed", it must be remembered that in those days, conventional speeds were in the vicinity of only 100 feet per minute.

The United States Department of Agriculture (5) conducted some experiments with high speed drawing and their general conclusion was that drawing roll speeds up to 240 feet per minute did not lower yarn strength or increase the coefficient of variation of weight per unit length of the yarn.

It is known that some other few laboratories have worked with high speed drawing but as yet their results have not been published.

Theoretical Considerations.--It might be well at this time to examine some of the theories of drafting. Many theories have been presented but a close examination reveals that the greater portion of them falls under a few main headings. Grishin (6) very aptly classifies the existing theories under four general categories:

1. Descriptive of Qualitative Approach--may or may not be substantiated by mathematical considerations. Basically an attempt to arrive at the crux of drafting by common sense considerations of the reasons for irregularity in the drafted sliver.

2. Mechanical Approach--an attempt to determine the speed of the fibers during drafting or their number per cross section at any given time under more or less practical conditions.

3. Statistical Approach--most of these have as their basis the Law of Great Numbers. In actual fact most of these do not deal with drafting but concern themselves with "ideal irregularity" as a function of the number of fibers per cross section.

4. Combined Approach--more or less a combination of categories 2 and 3 above, and considering not only the physical characteristics of the fibers but also the operating characteristics of the machines involved.

Most of the theories of drafting revolve around the irregularities of the drawing sliver giving descriptions of the irregularities, their causes, and developing formulas to be used as tools by the textile technologist to minimize these sliver irregularities. In general, they help him to establish roll settings and to divide the total draft properly among the sectional drafts. The essence of the problem is that while the doublings behind the drawing frame reduce the irregularities of the combined sliver, this good is offset by the irregularities introduced during drafting and it seems that the latter outweighs the former. This was substantiated by a long series of experiments conducted by the Wool Industries Research Association of Leeds, England (7) wherein they found that it was more desirable to reduce the number of doublings than to increase the draft as the bad effect of increasing the draft was not compensated for by the good accomplished by the doublings.

The benefits derived from doublings is developed from certain formulas of the Theory of Probability relative to the dispersion of a sum of independent quantities and Grishin (8) shows this to be substantially as follows:

The Law of Doubling is:

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \cdots + \sigma_n^2 \tag{1}$$

or the dispersion, σ^2 , of a resultant single sliver is equal to the sum of the dispersion of the component slivers. The problem is simplified in that the hank numbers of the component slivers are equal. It follows then that the standard deviation of the slivers

$$\sigma_1 = \sigma_2 = \cdots = \sigma_n$$

Then formula (1) becomes

$$\sigma^2 = n\sigma_1^2$$

or

$$\sigma = \sigma_1\sqrt{n} \tag{2}$$

The above then means that the standard deviation of a resultant single sliver is $\sqrt{n}$ times greater than the standard deviation of the component slivers, where n is the number of doublings. The evening effect of the doublings can therefore be readily seen since the mass of the resultant sliver is greater not by $\sqrt{n}$ but by n times. It must be cautioned however that this is the irregularity before drafting; the Law of Doublings provides no information about the irregularity once the drafting process has been used.

It is accepted generally that there are two factors which account for the irregularity of the drafted sliver. First, when fibers are arranged in a random way in a sliver there is an irregularity of thickness inseparable from this irregular assemblage. As slivers become thinner, this irregularity increases; in fact, the coefficient of variation of thickness on this score is inversely proportional to the square root of the thickness. The second factor is the inability of the drafting rollers to exercise a positive control on the movement of short fibers which lie somewhere between them. Since the rolls must be set far enough apart not to break or "crack" the longest fibers, the vast majority of the fibers are shorter than the roll settings. These uncontrolled fibers are called "floating fibers" and the manner of their removal from the drafting zone in clots has given rise to the term "drafting wave" to describe the quasi-periodic thickness variations in the drafter sliver produced. It was these "floating fibers" that Fernando Casablancas (9) had in mind when he developed his system of drafting aprons.

It was also this problem of "floating fibers" that Vasilief (10) attempted to interpret mathematically. The development of his theory is far beyond the scope of this paper but primarily he used the term "shear" (distance between the front ends of two adjacent fibers in an idealized system) as a measurement of sliver irregularity and he showed how it was proportional to the draft employed. Vasilief also applied the Theory of Probability to the problem of dividing total drafts into sectional drafts.

The irregularities of the drafting wave mentioned earlier has long been a fertile ground for textile theorists. Foster (11) has developed a moving boundary hypothesis which assumes that the floating fibers continue to move at the speed of the back rolls until crossing the boundary, at which time their speed changes to that of the front rolls. The distance of this boundary from the front rolls depends on the number and distribution of the fast moving fibers along the sliver. He shows that when the speed of the boundary exceeds that of the back rolls, the drafting action ceases and a gap devoid of fiber mid-points is formed in the sliver. When the tips of the slow moving fibers reach the front rolls, drafting is again resumed and the boundary moves back. It may be seen that drafting proceeds as a succession of "breaks" in the sliver. He also discusses the type of break, e.g., if the gaps which are devoid of fiber ends are longer than the fiber length, the breaks are complete but if they are shorter, some fibers bridge the gap and the breaks are only partial. Breaks are not regular, however, owing to the variations in the entering sliver, but it is also complicated by the fact that the phase of the wave is not the same all the way across the sliver, different longitudinal strips almost behaving independently. Because of this, even complete breaks do not cause the sliver to fall to pieces.

There have been many arguments, pro and con, concerning two- and three-process drawing. Martindale (12) developed an interesting theory concerning the weakness of tandem drawing unless the slivers are reversed between drawings. A series of many observations showed that the drafted sliver contains many individual fibers whose back ends are curled. Unless these slivers are reversed before the next drafting, the tendency toward more curling is greater and the result is an even more irregular sliver.

The role played by inherent defects in the processing machinery should not be overlooked when considering drawing sliver irregularity. Foster (13) feels that irregularity due to imperfect machinery does depend on the draft and that the other irregularity due to roll speed variations is similar in that the wavelength is equal to the roll circumference but is not sensitive to draft. He concludes that if yarn irregularities are caused by drafting waves, then high drafts of fewer machines need not cause abnormal variations, but if the irregularities are caused by imperfect machinery, they are almost certain to be accentuated by high draft.

The preceding pages represent an attempt to bring to light some of the more interesting and widely known theories concerning the drawing process. That they were covered briefly is readily admitted but this was intentional; sufficient references have been given so that anyone desiring to explore them more fully may readily do so. As was implied earlier, there have been many more theories presented than were covered here, and omission of any one theory does not connote that they are unacceptable or untenable.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

The raw stock selected for this study was bright Fibro Viscose Rayon staple, one-and-nine-sixteenths inches staple length, and one-and-one-half denier. This raw stock was selected primarily for two reasons. First, the individual fibers are of a more uniform length than would be cotton fibers, thereby eliminating a variable which might prove cumbersome, and secondly, the staple length more nearly approximated the operating characteristics of the drawing frame available for this particular study.

In selecting the processing machinery to be used, every effort was made to choose that machinery that would normally be found in today's average mill. The opening equipment consisted of a Whitin Combination One Process Picker Model T, 1949, with a feed hopper in tandem with a blending hopper, Model K-6, 1949. The picker laps were processed on a Saco Lowell Roller Top Card, Model 1, 1948.

The Medley single delivery drawing frame was unique in two respects. It was initially (1945) constructed for experimental purposes only, and its original drive was altered to accommodate a Reeves Variable Speed Transmission (size 1, Class F No. 44099).

The next machine in the process was a Whitin Super Draft roving frame, Woonsocket Model G 8 C, 1948, and the final piece of processing equipment was a Saco Lowell Long Draft Z type spinning frame.

Table 1. Operating Data for Whitin Model T Picker

Type of beater	Kirschner
Beater speed (RPM)	850
Beater to feed roll	.875"
Beater pulley diameter	4"
Feed roll diameter	2.5"
Draft gear	24
Sturtevant No. 4 Fan speed (RPM)	1725
Production pulley diameter	4"

Table 2. Operating Data for Saco Lowell Model 1 Roller Top Card

Feed plate to lickerin	.017"
Mote knife to lickerin (top)	.022"
Mote knife to lickerin (bottom)	.034"
Lickerin to cylinder	.017"
Back knife plate (top and bottom)	.017"
Front knife plate (top)	.017"
Front knife plate (bottom)	.029"
Doffer to cylinder	.007"
Doffer comb to doffer	.017"
Lickerin screen to lickerin (back)	.187"
Lickerin screen to lickerin (front)	.029"
Cylinder screen to cylinder (front)	.187"
Cylinder screen to cylinder (middle)	.058"
Cylinder screen to cylinder (back)	.029"
Worker to cylinder	.010"
Doffer speed (RPM)	10
Lickerin speed (RPM)	180

Table 3. Operating Data for Medley Single Delivery Drawing Frame

Roll No.	Roll Diameter	Roll Pitch	Type Roll
1	1.375"	32	Metallic
2	1.375"	32	Metallic
3	1.5"	24	Metallic
4	1.5"	16	Metallic

Roll Settings (center to center)			Draft
Calendar to front roll	---		.92
First to second	1.78"		2.38
Second to third	2.0"		1.63
Third to fourth	2.25"		1.41
		Total	5.04

Weights	80 pounds per top roll
Speed of front roll	105 to 680 feet per minute*

*A 12" pulley was keyed to the output shaft of the Reeves Variable Speed Transmission and this drove through a V-belt, first a 16" pulley and for the higher speeds a 7.5" pulley keyed to the countershaft of the drawing frame to obtain the desired range of speeds.

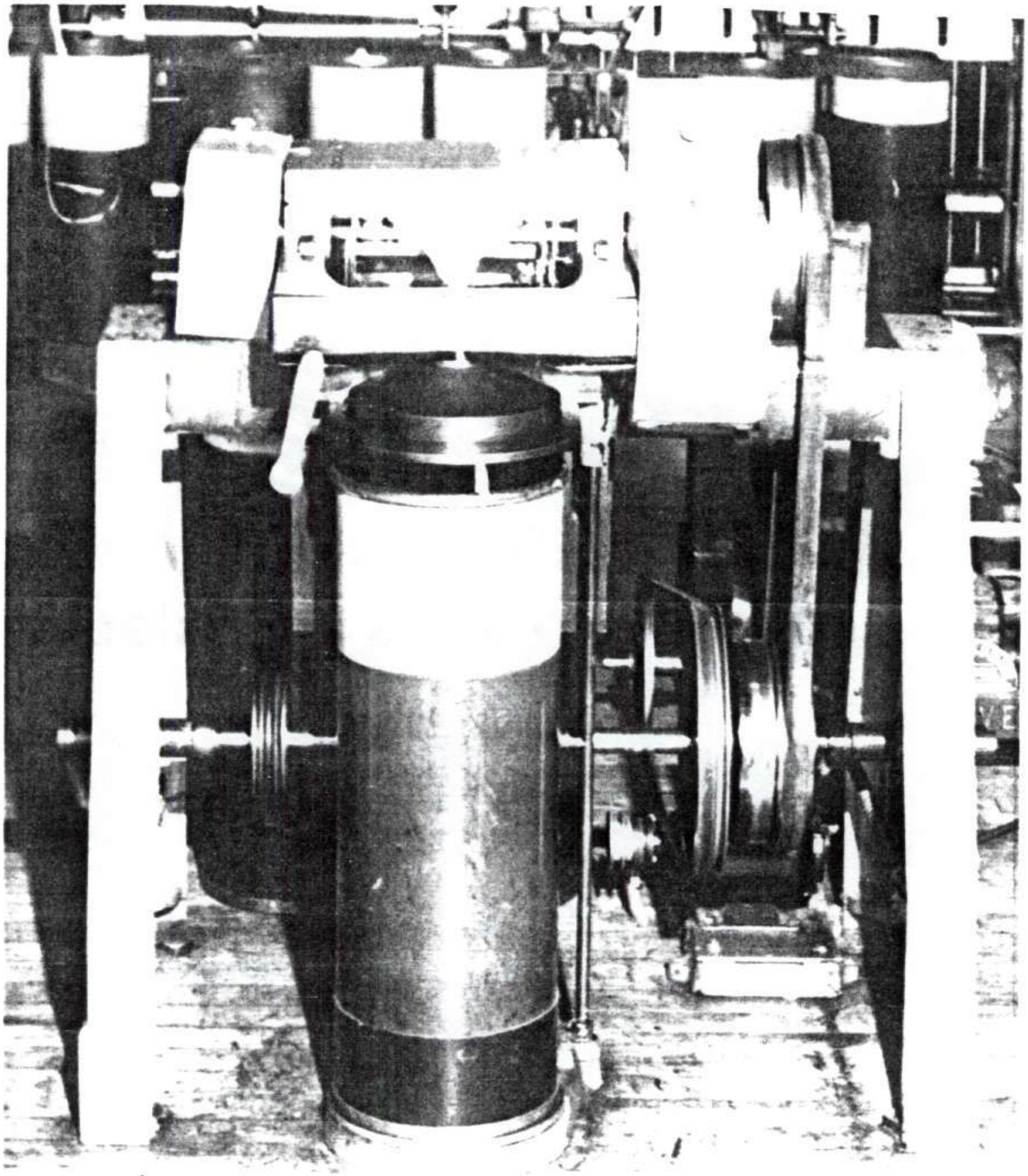


Fig. 1. Medley Single Delivery Drawing Frame

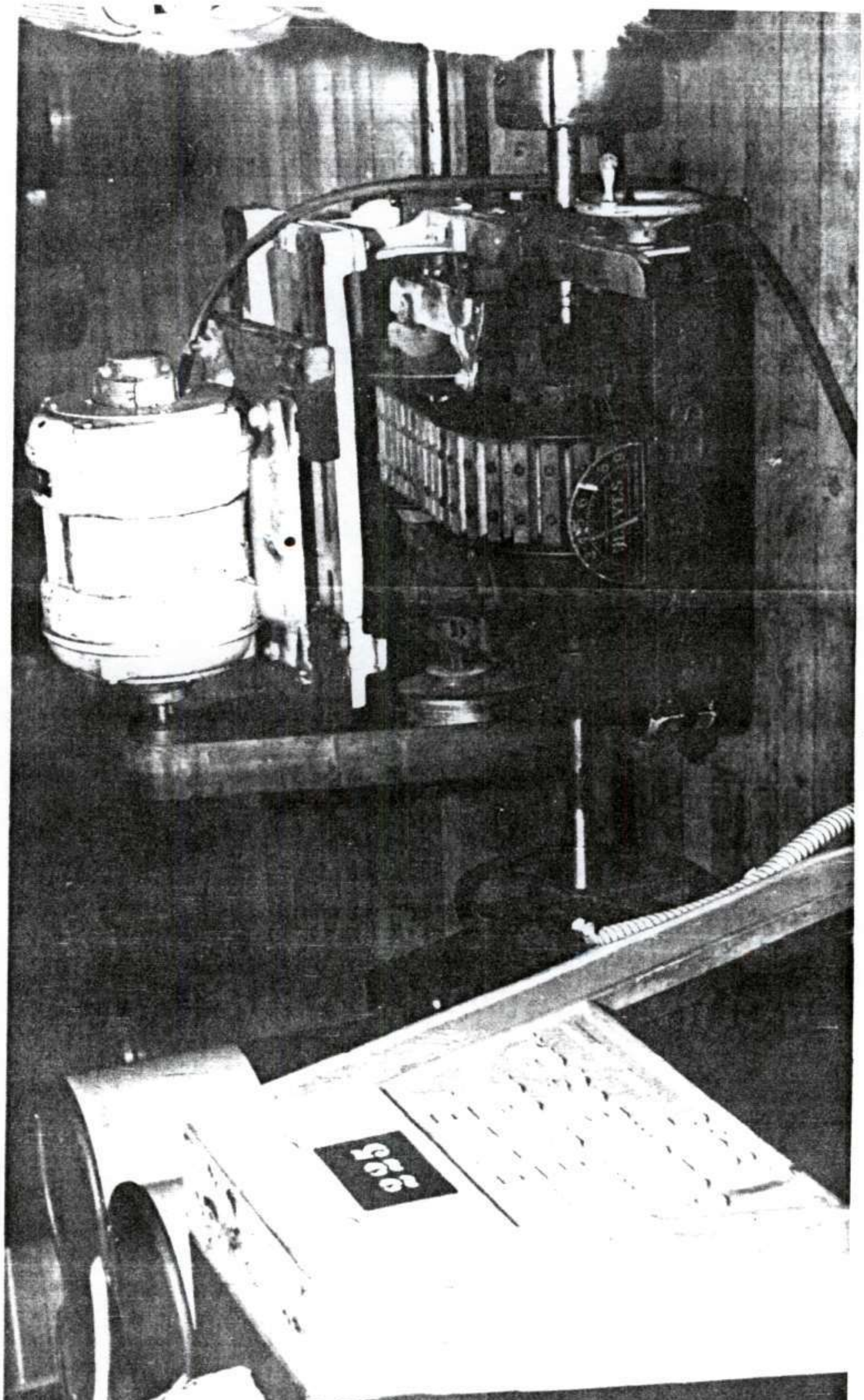


Fig. 2. Reeves Variable Speed Transmission

Table 4. Operating Data for Whitin Super Draft, Woonsocket Model G 8 C, 1948

Roll No.	Roll Diameter	Roll Setting (center to center)	
1	1.125"	First to second	2.75"*
2	1.062"	Second to third	Fixed
3	1.0"	Third to fourth	1.9375"
4	1.0"		

*Closest possible setting

Front roll speed (RPM)	110
Spindle speed (RPM)	1200
Twist gear	36
Tension gear	38
Lay gear	30

Table 5. Operating Data for Saco Lowell Long Draft Z Type Spinning Frame

Roll diameters		
Front	1.0"	
Control roll	0.5"	
Back	1.0"	
Front roll to back roll (center to center)		3.5"
Front roll speed (RPM at 21.8 turns per inch)		105
Spindle Speed (RPM)		5425

Thus far this chapter has been restricted solely to that machinery actually used in the manufacturing process. The remainder of the chapter concerns itself with the instruments and equipment used for conducting the various measurements and tests of the laps, slivers, roving and yarn utilized in this study.

Of the four laps made on the Whitin Model T Picker, three were used for manufacturing purposes and one was used for a weight uniformity run on a Saco Lowell Lap Meter, Model No. 4, 1951.

All weighings of sliver, roving, and yarn were made on a Christian Becker Chainomatic Analytical grain balance. Also for sizing, standard lengths of roving and yarn were obtained by use of Browne and Sharpe Company roving and yarn reels.

All speeds were measured by use of a Compteur Hassler tachometer manufactured in Berne, Switzerland, and distributed by C. H. Boulin Company, New York.

Sliver and yarn uniformity was determined by use of a Uster Model B Tester with Linear Integrator.

> This instrument is designed to obtain electronically a value of yarn uniformity known as 'linear un-evenness per cent' which is the statistical equivalent of Average Per Cent Variation along the linear length of the yarn. (14)

In statistical work the Average Per Cent Variation is determined by dividing the Mean Deviation by the arithmetical average of the distribution and expressing the quotient as a per cent.

The single strand breaks were made on an Auto-dynamographe, an autographic instrument of Italian design and manufacture. Seven bobbins are creeled in on this instrument and it automatically makes ten breaks per bobbin for a total of seventy breaks, recording both tensile strength and elongation at break on specially prepared charts and, upon the completion of the breaks, furnishing an average value for both tensile strength and elongation.

The instrument consists of two units mounted on a common base and made of a light alloy. The unit on the left (Fig. 3) contains the perpendicular arm which activates the three pens (elongation, tensile strength, and average value). The unit on the right (Fig. 4) contains the mechanism which gives motion to the instrument. On the back of this second unit there is a "transporter" which consists of two arms which carry the clamps that hold the yarn during the break. This unit also contains an indicator which controls the speed of the two jaws. Between these two units there is a distributor which functions in a way to present successively the ends of the yarns to the clamps on the transporter.

The gauge of the breaks is 500 mm, measuring up to a 20 per cent elongation. It is run by a 50W motor and its dimensions are: length 1400 mm, width 350 mm, and height 600 mm.

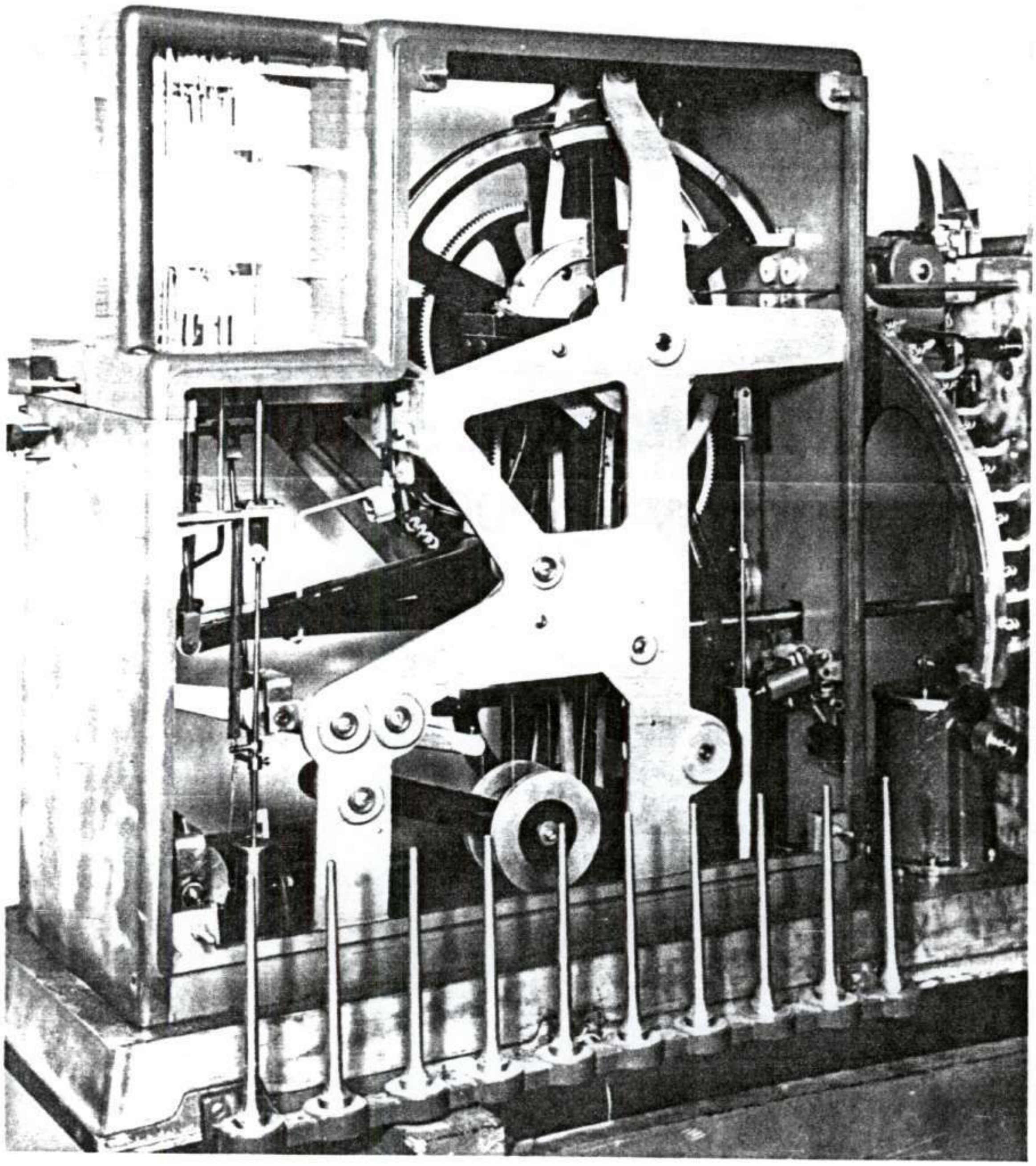


Fig. 3. Autodynamographe (recording unit)

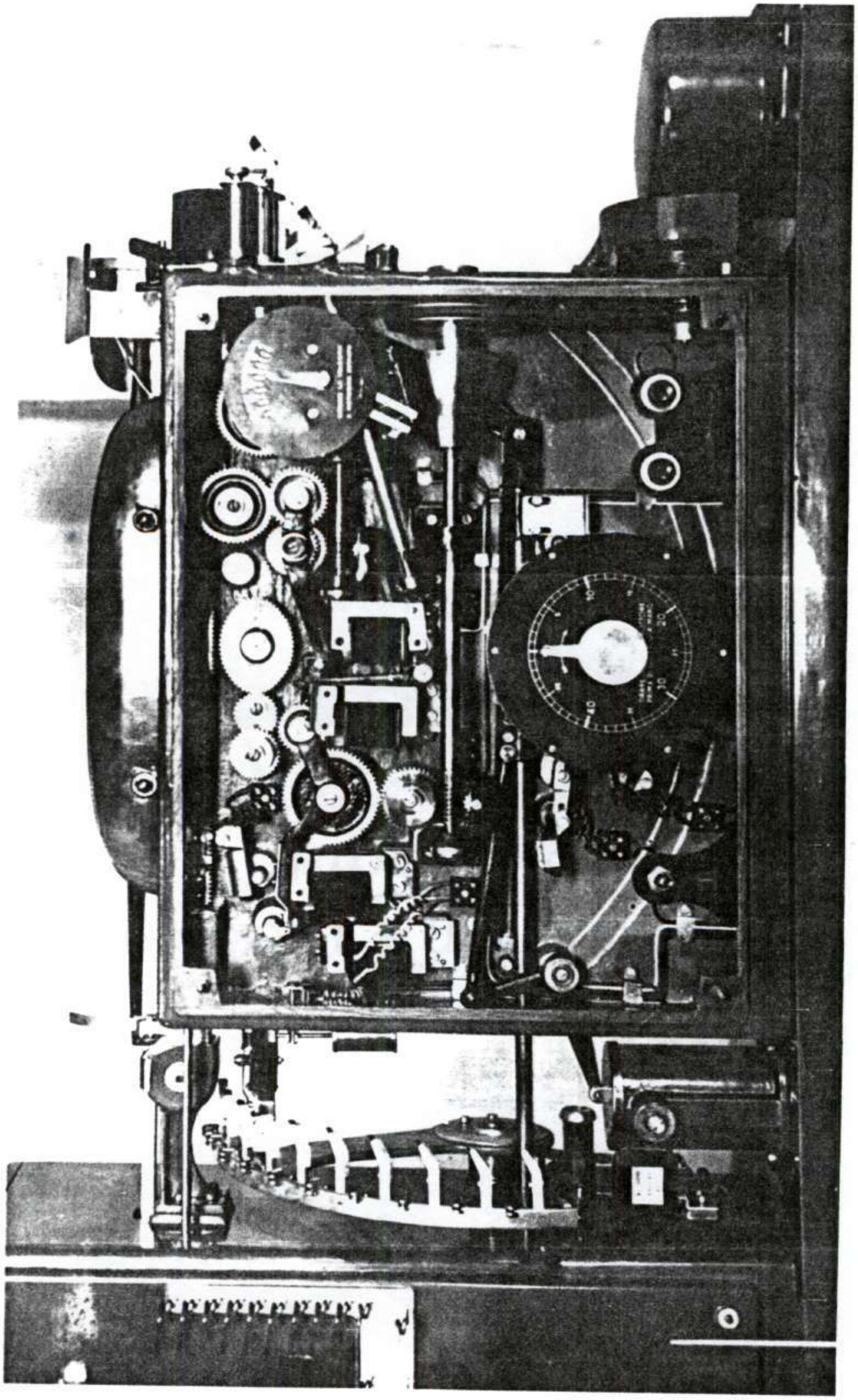


Fig. 4. Autodynamographe (breaking unit)

CHAPTER III

PROCEDURE

As was mentioned earlier, every endeavor was made in this study to simulate as closely as possible actual mill processing procedures by using standard equipment and normal processing sequence. All production and testing were carried out under standard atmospheric conditions of 65 per cent relative humidity at 70 degrees Fahrenheit. Each can of card sliver, drawing sliver and bobbin of roving was free from piecings; only the bobbin on the spinning frame contained piecings and even here, if the number of piecings exceeded two, the bobbin was rejected. This should not be considered a departure from mill procedure but merely a refinement completely desirable in research work. Before proceeding further, it is deemed advisable to present the organization of weights and drafts as established for this study.

Table 6. Organization of Weights and Drafts

Machine	Draft	Doublings	Size
Picker	4	4	12.5 oz.
Card	106	1	50.0 gr.
Drawing frame	6	6	50.0 gr.
Roving frame	21	1	3.50 HR.
Spinning frame	14.5	2	25 s.
Twist multiplier	4.35 (Z twist)		

To carry out this study, twenty lots of yarn were to be made, each lot being processed identically from the picker through the spinning frame with the exception of the drawing frame where the speed was to be varied. As will be pointed out later, the actual draft on the drawing frame varied at different speeds although the machine draft was held constant; to compensate for this, since all lots of yarn produced were to be 25s, the draft on the roving and spinning frames had to be altered in some cases.

The picker was used as a double processing unit to accomplish a better blending and to arrive at more uniform laps. The raw stock was placed in the feed hopper, thence to the blending hopper, and finally through the beater section of the picker. After four laps had been made, they were creeled in behind the beater section and processed once more, hence the term double processed.

These laps were then processed on the roller top card producing three lots of six cans each of card sliver. Each of these lots was processed as a unit through the drawing frame. As soon as one can in the lot became empty, the whole lot was discarded and an entirely new lot creeled in.

The speed of the front roll of the drawing frame was varied from 105 feet per minute through 680 feet per minute in increments of 25 feet per minute up to 480 and then in increments of 50 feet per minute. The speed was varied by manipulation of the Reeves Variable Speed Transmission and as many readings of the bottom front roll shaft were taken on the tachometer as were necessary to obtain three successive identical readings. The speed in feet per minute was then calculated by multiplying the RPM by the effective circumference of the roll in feet. Seven partially filled cans of drawing sliver were made for each lot. The speed in feet per minute of the front roll is shown for each lot in Table 7.

Table 7. Drawing Frame Front Roll Speeds (feet per minute)

Lot	Speed	Lot	Speed	Lot	Speed
1	105	8	280	15	455
2	130	9	305	16	480
3	155	10	330	17	530
4	180	11	355	18	580
5	205	12	380	19	630
6	230	13	405	20	680
7	255	14	430		

Seven spindles were used on the roving frame, selected in a random manner throughout the frame to compensate for individual spindle variations, to produce fourteen bobbins of roving per lot. In like manner, seven spindles were used on the spinning frame to produce seven bobbins of yarn per lot. At the beginning it was determined to spin approximately 350 yards of yarn per bobbin; knowing this then and the organization of weights and drafts, it was a simple matter to determine the amount of end product required from each process.

The product of each process from the picker through the spinning frame was sized to determine its weight; in the case of card slivers, a minimum of six determinations per lot was made on one-yard lengths; in the case of drawing slivers, a minimum of three determinations per lot was made on one-yard lengths; in the case of roving a minimum of six determinations per lot was made on twelve-yard lengths; and finally, on yarn a minimum of seven determinations per lot was made on 120-yard lengths. In no case was any test performed on the yarn until it had reached an equilibrium as prescribed by ASTM standards (15).

All slivers and yarns were tested for uniformity on the Uster Tester with Linear Integrator. Speeds used were four yards per minute for slivers and eight yards per minute for yarn. Initial readings were taken two and one-half minutes after passage of stock was begun and thereafter at 30-second intervals. Conversion factors were determined from the Average Value readings and from the table prepared by the Uster Corporation (16) and the Integration readings were corrected accordingly. Lengths tested were as follows:

Card sliver	36 yards per lot
Drawing sliver	18 yards per lot
Yarn	72 yards per lot

The tensile strength and the elongation at break of the yarn was determined by use of the Autodynamographe. Ten readings per bobbin were recorded for a total of seven bobbins per lot. Elongation was recorded as a per cent and tensile strength in grams.

CHAPTER IV

DISCUSSION OF RESULTS

Peacock's conclusion in 1938 (17) was that the tensile strength increased with an increase in the drawing roll speed and his highest roll speed also resulted in the highest tensile strength. With this as a point of departure then, it was theorized initially in this study that by gradually increasing the roll speed of the drawing frame, the speed at which the tensile strength reached its peak and then deteriorated could be determined. However, a cursory examination of the tensile strength chart (Fig. 5) will reveal that such is not the case nor can the matter be resolved so simply. It can be seen that the pattern of the tensile strengths at different speeds is very irregular with many peaks and valleys. This could be attributed to one of two things: the varying roll speed does in fact build yarns of different tensile strengths or, and this is much more likely, the variations noted in the average tensile strengths for a specified speed were due entirely to experimental error which is random in nature. From this latter point of view, a Null Hypothesis was established that the variations in the average tensile strength (for a given speed) about the true mean were equal to zero. A statistical hypothesis is never proved nor is it disproved; subsequent calculations may cast much doubt upon it, thereby impugning it, or they may cast little doubt upon it, thereby making the hypothesis tenable.

Before any calculations were made, it was assumed that the variation in tensile strength in each lot was due to two factors: within bobbin variation and between bobbin variation. Statistical methods were used to determine the variations and their significance.

R charts showing the within bobbin variation and having $\pm 3\hat{\sigma}_R$ control limits were established for each lot. The charts showed that the within bobbin variation was in control for each lot or speed, i.e., the variation from break to break within a bobbin was the same for all bobbins made at all speeds. The manner of construction of the R charts was as follows:

The center line was established at $\bar{R}$ and $\bar{R} = \frac{\Sigma R}{n}$,

where R equals the range of tensile strength within each bobbin and n equals the number of bobbins per lot.

The Upper Control Limit (UCL) was established at $\bar{R} + 3\hat{\sigma}_R$ and the Lower Control Limit (LCL) at $\bar{R} - 3\hat{\sigma}_R$, and it is shown (18) that $\hat{\sigma}_R = \frac{\sigma'_w}{d_2}(\bar{R})$ where $\sigma'_w = .797$ and $d_2 = 3.078$ for a sample size of ten.

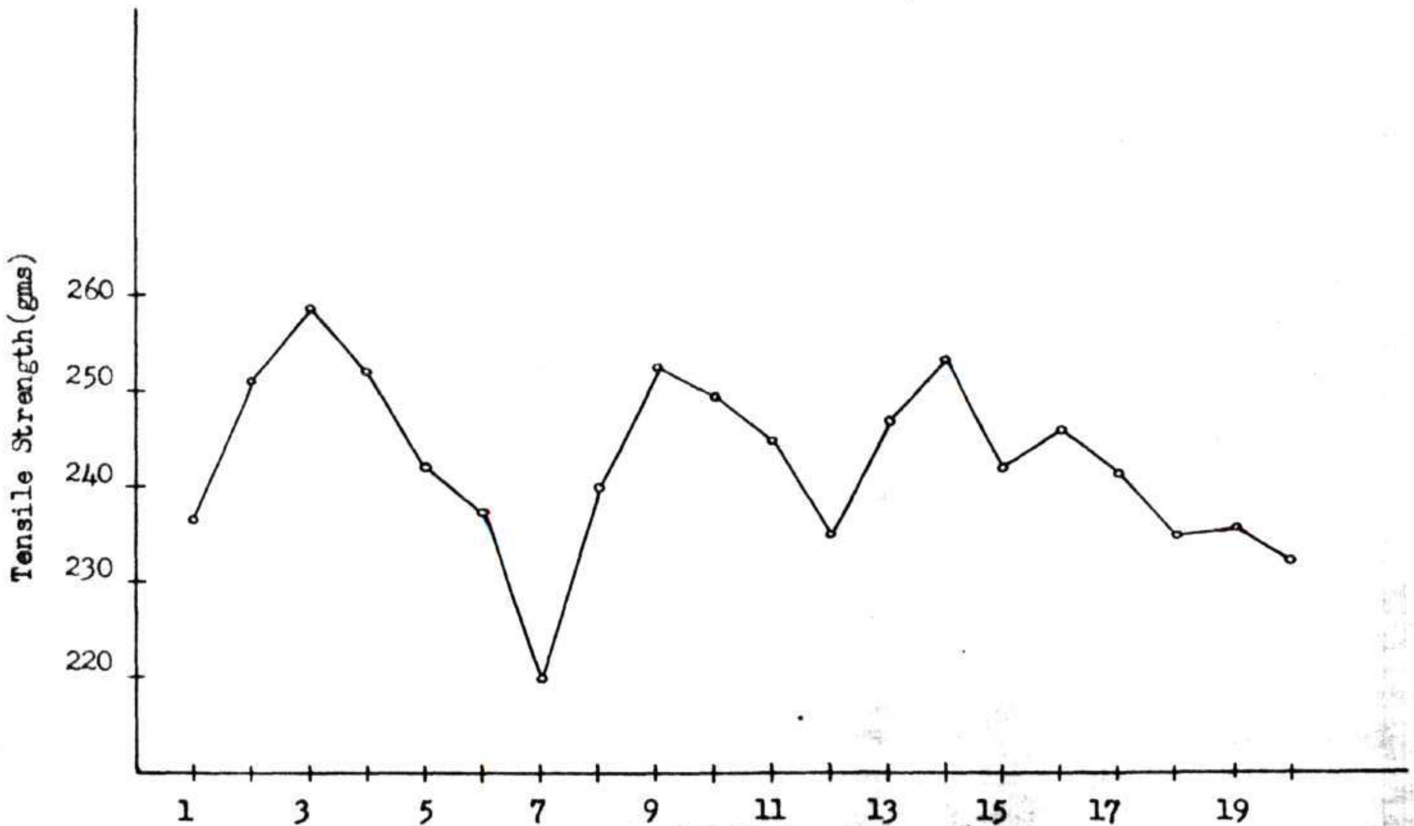


Figure 5. Tensile Strength for Each Lot (speed)
(See Table 8 Appendix)

$\bar{X}$ charts showing the between bobbin variation and having $\pm 3\hat{\sigma}_{\bar{X}}$ control limits were established for each lot, and in this case all but two of the charts showed some points out of control. From this it was evident that the average strength shifted from one bobbin to another in a random manner. The manner of construction of the $\bar{X}$ charts was as follows:

The center line was established at $\bar{\bar{X}}$ and $\bar{\bar{X}} = \frac{\Sigma \bar{X}}{n}$ where $\bar{X}$ is the arithmetical average of all ten breaks per bobbin and the n is the number of bobbins per lot. The UCL was set at $\bar{\bar{X}} + \frac{3\hat{\sigma}}{\sqrt{N}}$ and the LCL at $\bar{\bar{X}} - \frac{3\hat{\sigma}}{\sqrt{N}}$ where $\hat{\sigma} = \frac{\bar{R}}{d_2}$ and N equals the number of breaks per bobbin and d_2 having the same value as in the calculation for the R charts. The R and $\bar{X}$ charts for yarn lot No. 1 are shown in Fig. 6.

As a further and more complete test of the established hypothesis, a complete analysis of variance was made. This procedure is very nicely explained by Brownlee (19) who states

> It is a valuable property of variance that if a process has a number of factors each making a contribution to the variance of the final product, then this total variance is equal to the sum of the component variances. This statement is less obvious

than it may seem. Thus, if we were using standard deviations as our measure of variability, it would not be true to say that the standard deviation of the final product was equal to the sum of the standard deviations produced by the several factors. This property of additiveness of variance makes possible the technique known as the "Analysis of Variance", whereby the total variance of a process can be analysed into its component factors, the relative importance of which can then be assessed.

Since all R charts were in control and had about the same center line, the $\bar{R}$'s were pooled and σ_x (the within bobbin standard deviation) was computed for each lot in the following manner:

$$\text{Within Bobbin Variation} = \frac{\sum_{i=1}^{20} \bar{R}_i}{20\, d_2} = \frac{\bar{\bar{R}}}{3.078} = \hat{\sigma}'_{wB} \qquad (3)$$

where $\bar{R}_i$ is the average range for the i th lot

and $\bar{\bar{R}} = \frac{\Sigma \bar{R}}{20}$

$$\text{Between Bobbin Variation} = n\,\sigma^2_{BB} + \sigma^2_{wB} = 10\,\sigma^2_{BB} + \sigma^2_{wB} \qquad (4)$$

$$= \left[\frac{\sum_{i=1}^{7} (\bar{x}_{i.} - \bar{\bar{x}}_{..})^2}{n-1}\right] \qquad (5)$$

where $\bar{X}_{i.}$ is obtained by totaling the breaks of each bobbin in a lot, squaring these totals, summing the squares and dividing by the total number of breaks per bobbin.

and

$\bar{\bar{X}}$.. is determined by obtaining the grand total of all seventy breaks in one lot, squaring this grand total and dividing by 70 or the number of breaks per lot.

and

(n-1) represents the degrees of freedom or in this case 7-1 since there are seven bobbins per lot.

then

σ^2_{BB} is found by use of formulas (3), (4), and (5) above.

$$\text{then } 3\,\sigma_{\bar{x}} = 3\left[\frac{\sigma^2_{WB}}{10 \times 7} + \frac{\sigma^2_{BB}}{7}\right]^{1/2} \qquad (6)$$

where $\sigma_{\bar{x}}$ is the standard deviation for the average of ten breaks on each of seven bobbins.

Then a control chart for the tensile strengths at the various speeds was constructed using $\pm 3\sigma_{\bar{x}}$ as upper and lower control limits for each point. But, since an $R_{\bar{x}}$ chart (Fig. 7) showed that all points were in control, the σ^2_{BB}'s were pooled and a single upper and lower control limit was established for all the lots taken together. This chart (Fig. 8) showed that all points but one were in control (individual limits were constructed for this point and it was found to be in control), hence the null hypothesis was found tenable.

In a similar manner control charts were constructed for yarn uniformity (Fig. 9) and the elongation at break (Fig. 10), and they showed that all points were in control.

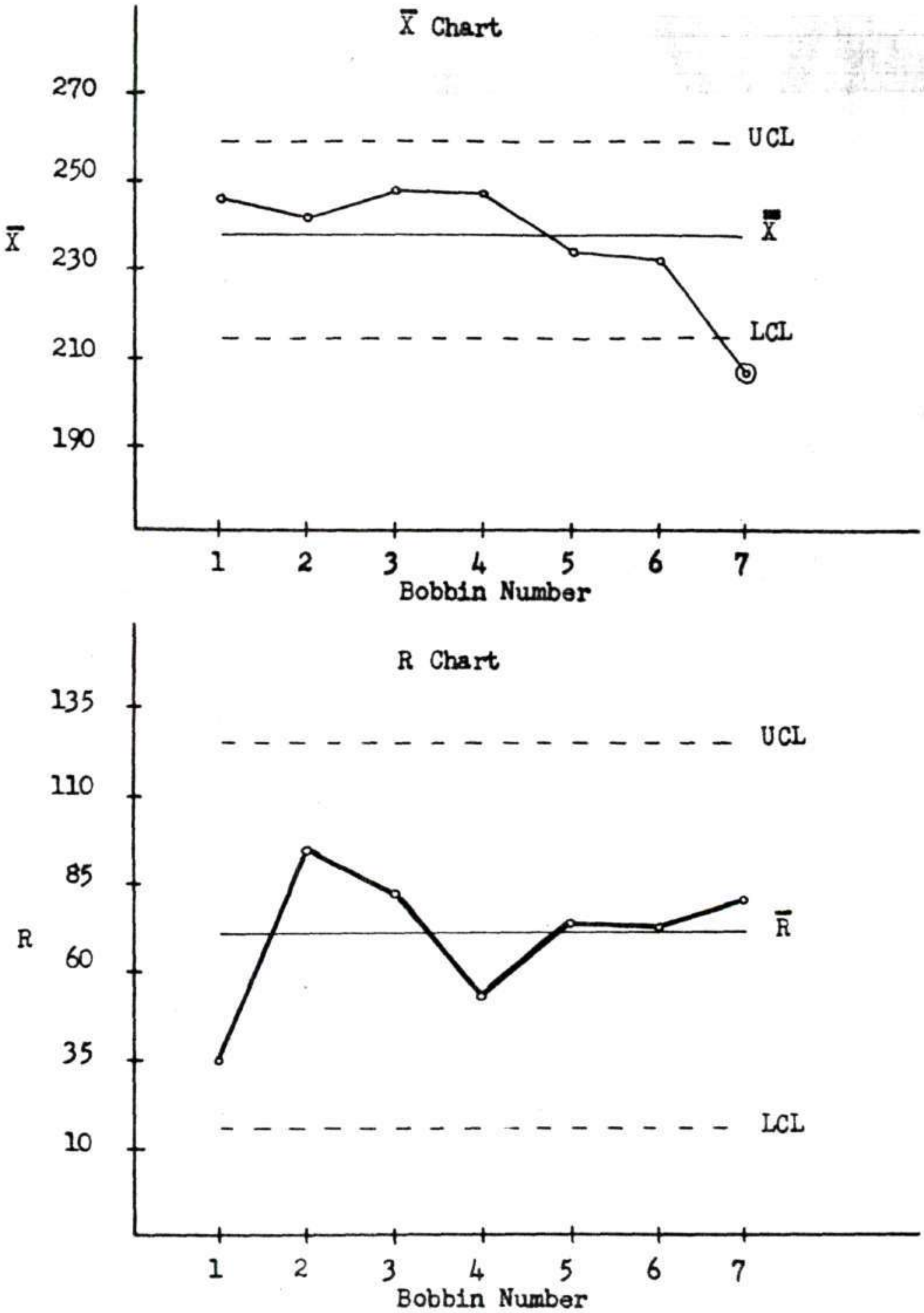


Figure 6. $\bar{X}$ and R Charts for Lot No. 1

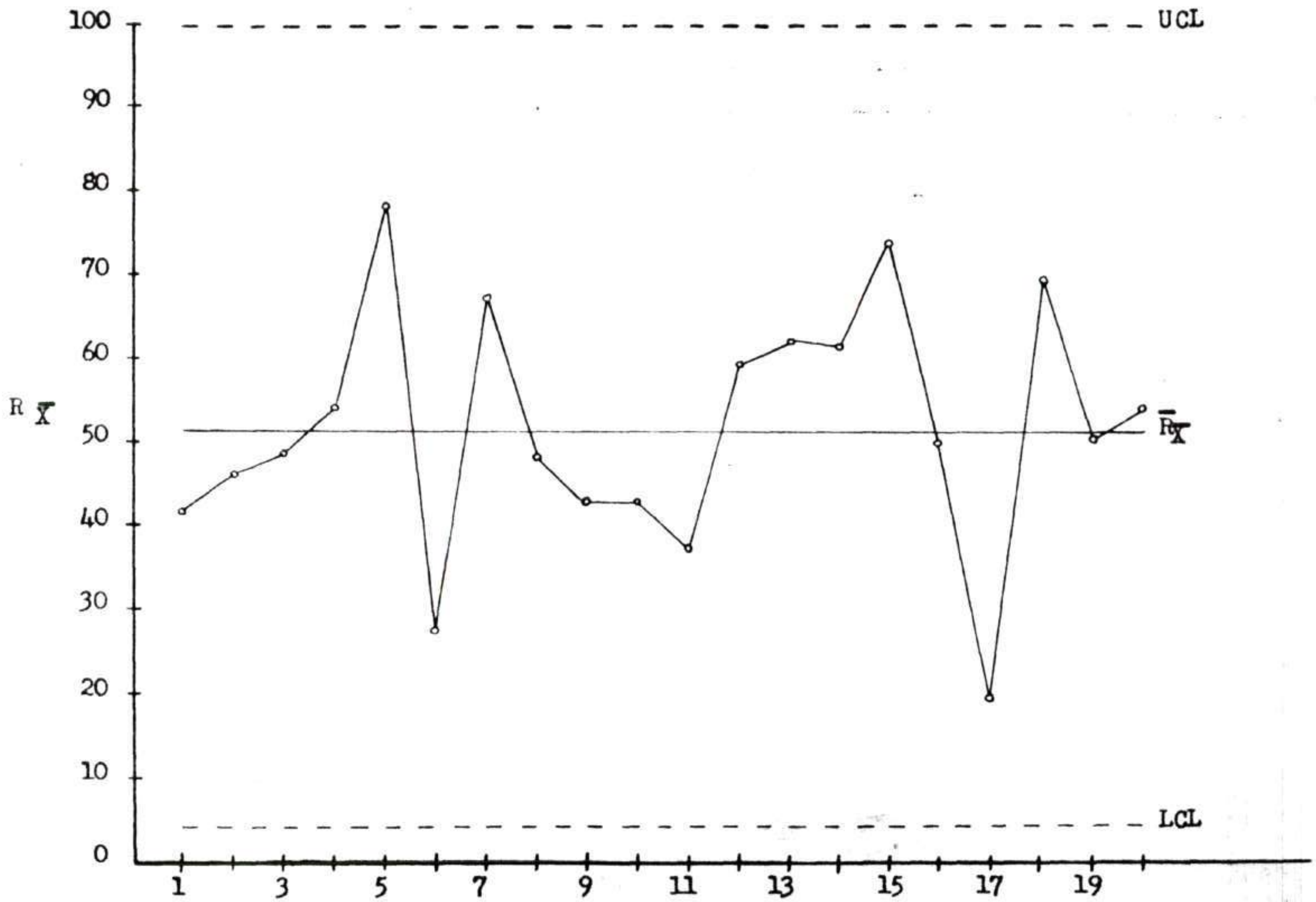


Figure 7. R Chart for the $\bar{X}$'s of Each Lot
(See Table 8 Appendix)

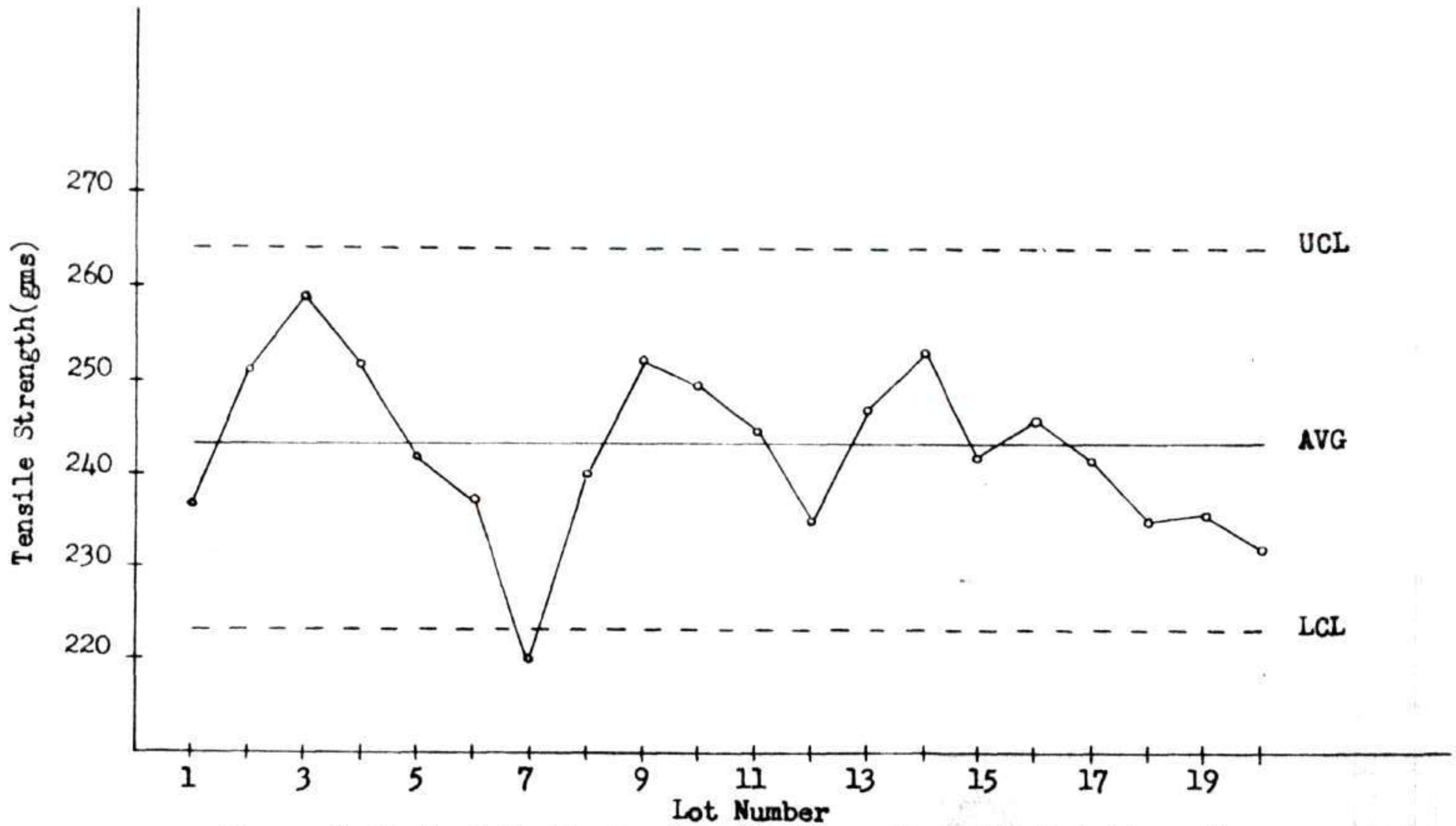


Figure 8. Control Limits for Tensile Strength for Each Lot(speed)

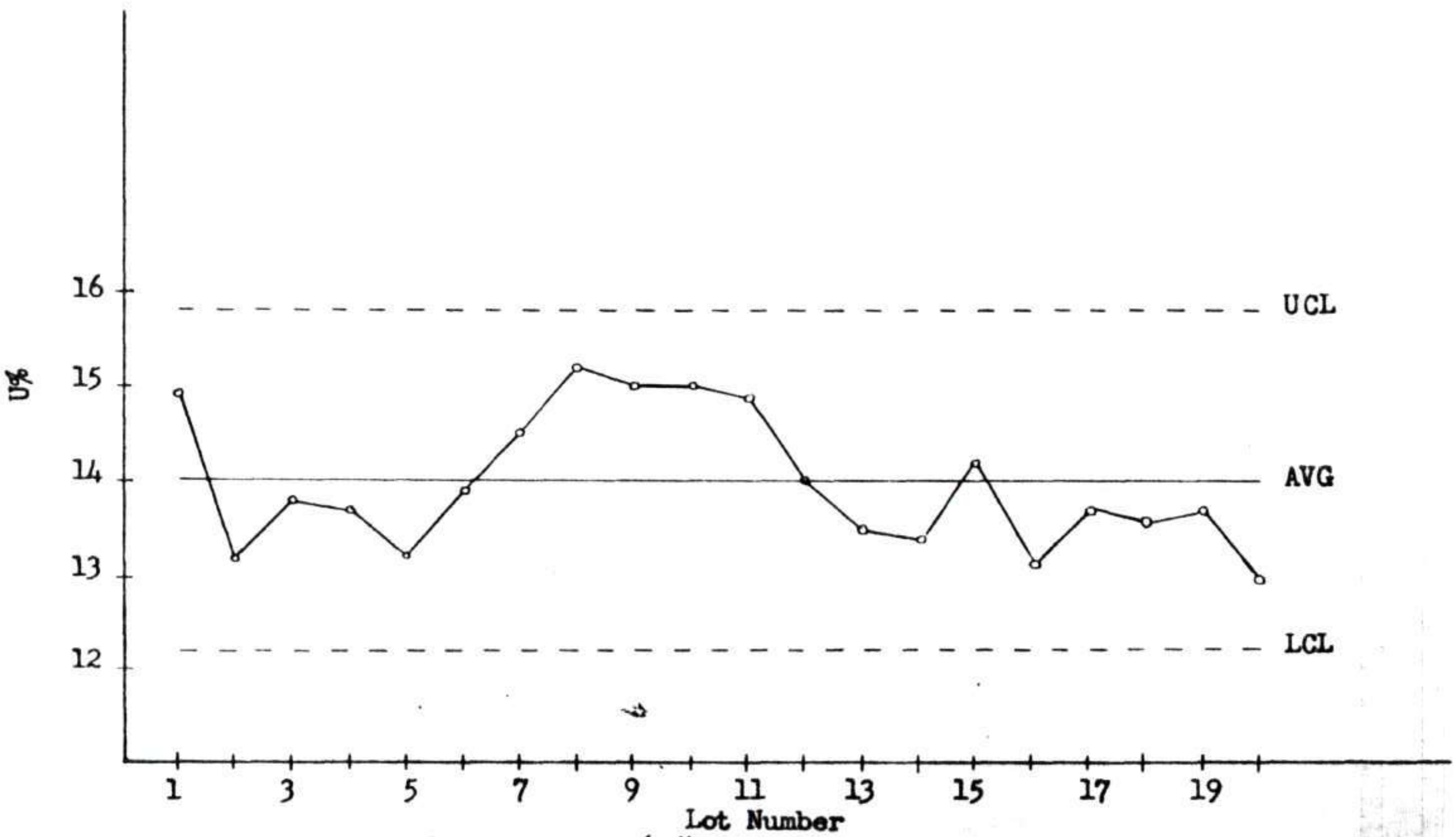


Figure 9. Yarn Uniformity(U%) for Each Lot with Control Limits
(See Table 10 Appendix)

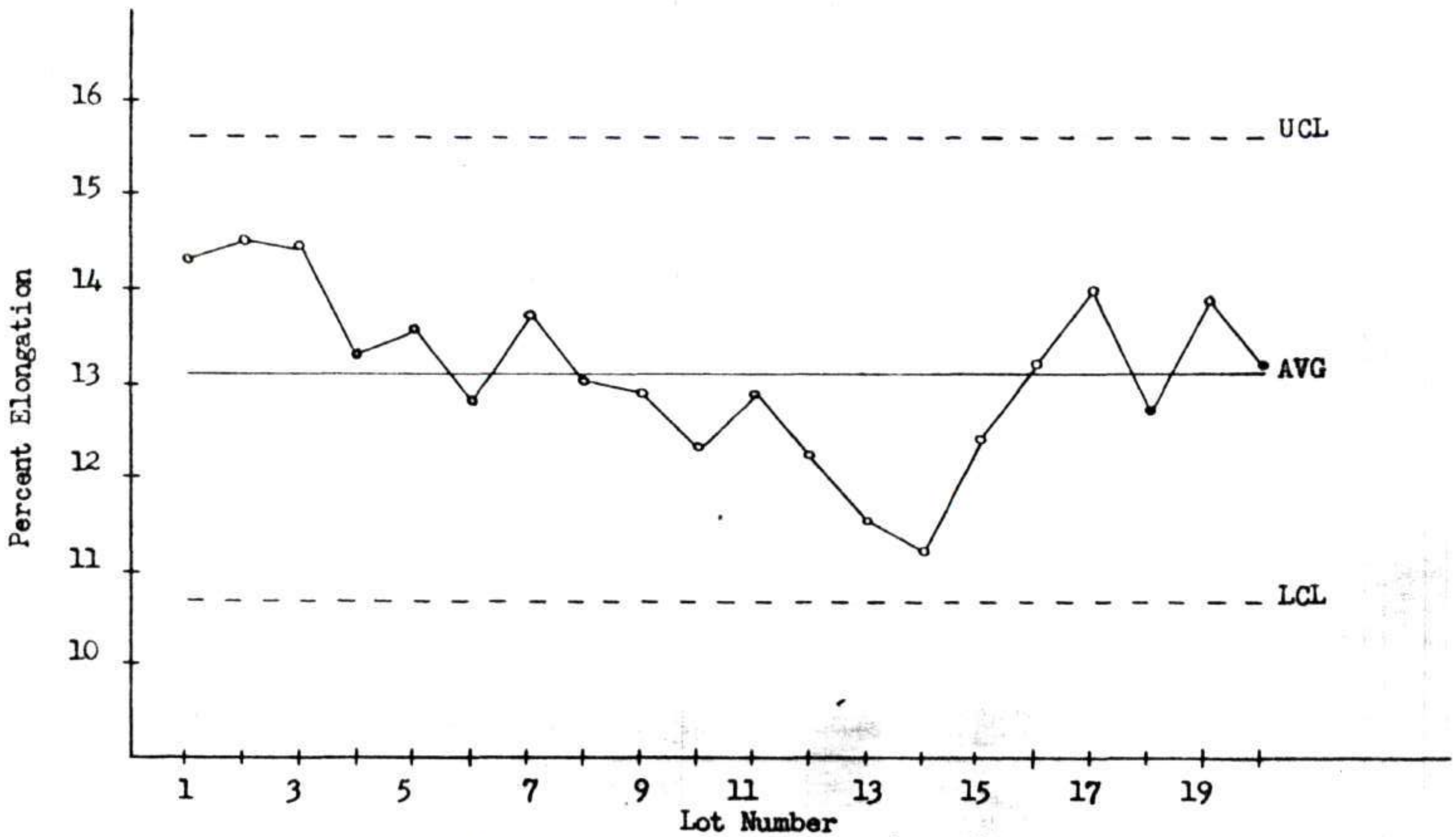


Figure 10. Elongation at Break for Each Lot (speed) with Control Limits
(See Table 10 Appendix)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

In the preceding chapter it was shown quite conclusively, by use of statistical and quality control methods, that an increase in the roll speed of the drawing frame had no effect on the tensile strength of the yarn. And similarly, an increase in roll speed had no effect on the yarn uniformity or the elongation at break. These results are indeed startling when viewed in light of time-honored practice in the textile industry.

However, it must be cautioned that before the industry can accept the results of this study with wide open arms, several factors should be considered in detail and evaluated in their entirety.

That this was a laboratory experiment and executed under near ideal conditions cannot be ignored. Time was of no consequence nor was production any problem. As much care was exerted as was necessary to keep stock and machines running smoothly.

Before the results of this experiment can possibly have any practical application, a drawing frame designed for high speed work must be developed. There are some on the market now which could easily form the nucleus for further work. The drawing frame used in this experiment exhibited vibrations at the higher speeds. Because of these vibrations, excessive wear was noted on all moving parts despite elaborate attention to lubricating details.

It is recommended that similar studies be conducted using a variety of drawing frames and a variety of different fibers.

As a separate and distinct problem and one that could contribute in great measure to the industry, the design of a high speed drawing frame could be undertaken.

And perhaps the greatest test of the practicality of applying the results of this experiment could be realized if the speed of a portion of the drawing frames in a selected mill could be increased in increments of 25 per cent and complete cost analyses made at each speed.

APPENDIX

Table 8. Values of $\bar{X}$ and R for Each Bobbin Per Lot and Values for $\bar{\bar{X}}$, $\bar{R}$, and $R_{\bar{X}}$ for Each Lot (Tensile Strengths)

Lot No.	Bobbin No.	$\bar{X}$	R	$\bar{\bar{X}}$	$\bar{R}$	$R_{\bar{X}}$
1	1	246.5	35	236.7	70.3	41.4
	2	241.7	95			
	3	246.8	83			
	4	247.7	53			
	5	235.3	73			
	6	232.9	72			
	7	206.3	81			
2	1	249.3	72	252.2	78.0	46.1
	2	242.3	46			
	3	254.6	67			
	4	241.7	115			
	5	236.8	55			
	6	282.9	75			
	7	257.7	116			
3	1	260.1	87	260.3	74.6	48.6
	2	271.1	67			
	3	255.0	96			
	4	240.3	48			
	5	288.9	74			
	6	256.1	49			
	7	250.9	101			
4	1	244.3	102	253.3	91.0	54.7
	2	286.0	140			
	3	257.5	92			
	4	242.3	58			
	5	249.4	72			
	6	231.3	76			
	7	262.0	96			
5	1	227.0	102	242.5	81.7	78.6
	2	197.8	72			
	3	247.7	83			
	4	276.4	62			
	5	257.5	101			
	6	240.5	109			
	7	250.4	43			

Table 8. Values of $\bar{X}$ and R for Each Bobbin Per Lot and Values for $\bar{\bar{X}}$, $\bar{R}$, and $R_{\bar{X}}$ for Each Lot (Tensile Strengths) (Continued)

Lot No.	Bobbin No.	$\bar{X}$	R	$\bar{\bar{X}}$	$\bar{R}$	$R_{\bar{X}}$
	1	232.1	60			
	2	229.8	71			
	3	223.6	76			
6	4	250.7	58	238.2	81.7	27.1
	5	240.7	98			
	6	246.8	108			
	7	243.4	67			
	1	194.3	85			
	2	212.5	138			
	3	223.1	81			
7	4	225.6	94	220.1	81.6	67.3
	5	221.1	49			
	6	261.6	59			
	7	203.3	65			
	1	232.9	69			
	2	245.7	50			
	3	225.9	51			
8	4	267.2	101	240.7	72.0	48.0
	5	219.2	52			
	6	234.4	102			
	7	259.6	79			
	1	260.3	69			
	2	241.2	94			
	3	272.0	76			
9	4	227.8	93	252.6	78.0	42.5
	5	278.5	71			
	6	236.0	80			
	7	252.4	63			
	1	252.0	57			
	2	254.9	82			
	3	230.5	85			
10	4	261.9	111	249.6	73.6	42.5
	5	267.5	61			
	6	255.5	52			
	7	225.0	66			

Table 8. Values of $\bar{X}$ and R for Each Bobbin Per Lot and Values for $\bar{\bar{X}}$, $\bar{R}$, and $R_{\bar{X}}$ for Each Lot (Tensile Strengths) (Continued)

Lot No.	Bobbin No.	$\bar{X}$	R	$\bar{\bar{X}}$	$\bar{R}$	$R_{\bar{X}}$
	1	233.8	95			
	2	248.3	59			
	3	256.7	71			
11	4	255.7	74	244.9	73.4	36.7
	5	220.0	37			
	6	253.5	77			
	7	246.3	101			
	1	272.4	65			
	2	227.3	61			
	3	236.2	60			
12	4	228.0	71	235.8	64.1	59.5
	5	212.9	71			
	6	247.3	69			
	7	226.8	52			
	1	274.8	67			
	2	213.1	84			
	3	231.0	60			
13	4	247.5	75	247.5	74.7	61.7
	5	241.1	72			
	6	272.3	70			
	7	252.6	95			
	1	262.8	74			
	2	242.0	72			
	3	225.6	45			
14	4	234.9	84	253.4	70.0	61.4
	5	262.9	75			
	6	258.5	77			
	7	287.0	63			
	1	275.5	100			
	2	201.7	90			
	3	252.5	70			
15	4	226.2	58	242.7	77.7	73.8
	5	245.1	44			
	6	241.8	117			
	7	255.9	65			

Table 8. Values of $\bar{X}$ and R for Each Bobbin Per Lot and Values for $\bar{\bar{X}}$, $\bar{R}$, and $R_{\bar{X}}$ for Each Lot (Tensile Strengths) (Continued)

Lot No.	Bobbin No.	$\bar{X}$	R	$\bar{\bar{X}}$	$\bar{R}$	$R_{\bar{X}}$
	1	273.7	47			
	2	261.9	68			
	3	232.3	45			
16	4	242.3	100	247.2	66.0	49.9
	5	245.2	86			
	6	251.3	30			
	7	223.8	86			
	1	242.5	52			
	2	247.3	77			
	3	231.9	107			
17	4	241.3	73	242.5	68.7	19.0
	5	234.7	73			
	6	249.0	36			
	7	250.9	63			
	1	229.7	72			
	2	203.6	34			
	3	247.8	46			
18	4	243.4	102	235.8	64.1	68.9
	5	221.1	67			
	6	272.5	33			
	7	232.4	95			
	1	270.0	64			
	2	221.7	126			
	3	241.5	52			
19	4	248.1	64	235.9	73.7	51.5
	5	224.6	70			
	6	218.5	50			
	7	227.5	90			
	1	247.8	129			
	2	270.0	62			
	3	221.6	100			
20	4	227.3	80	233.3	88.7	53.8
	5	216.6	80			
	6	233.3	89			
	7	216.2	81			

$\bar{R}_{\bar{X}} = 51.65$

Table 9. Control Limits for $\bar{X}$ and R Charts

Lot No.	$\bar{X}$ UCL	$\bar{X}$ LCL	R UCL	R LCL
1	258.5	214.9	124.9	15.7
2	276.3	228.1	138.7	17.3
3	283.4	237.2	132.7	16.5
4	281.4	225.2	161.8	20.2
5	267.8	217.2	145.3	18.1
6	261.9	214.5	136.6	17.0
7	245.3	194.9	145.1	18.1
8	263.0	218.4	128.0	16.0
9	276.7	228.5	138.8	17.2
10	272.3	226.9	130.9	16.3
11	267.5	222.3	130.4	16.4
12	255.6	216.0	114.0	14.2
13	270.6	224.4	132.8	16.6
14	275.0	231.8	124.4	15.6
15	266.7	218.7	138.1	17.3
16	267.6	226.8	117.4	14.6
17	263.7	221.3	122.1	15.3
18	255.7	215.9	114.1	14.1
19	258.8	213.2	131.1	16.3
20	260.7	205.9	157.7	19.7

Table 10. Mean Elongation at Break and U% for Each Lot of Yarn

Lot No.	Elongation (%)	U%
1	14.3	14.9
2	14.5	13.2
3	14.5	13.8
4	13.3	13.7
5	13.5	13.2
6	12.8	13.9
7	13.7	14.5
8	13.0	15.2
9	12.9	15.0
10	12.3	15.0
11	12.9	14.9
12	12.3	14.0
13	11.5	13.5
14	11.2	13.4
15	12.4	14.2
16	13.2	13.1
17	14.0	13.7
18	12.7	13.6
19	13.9	13.7
20	13.2	13.0
Mean Value	13.1	14.0

Saco-Lowell Lap Meter Record

PICKER RM. NO. MACH. NO. Model #4 1951

Standard Wt. per Yard
12.5 oz.

Standard Total Weight of Lap. With Rod 38 Lbs.

Actual Total Net Weight of Lap. Less Rod 36 Lbs.

Temperature { Wet 62° / Dry 70° }

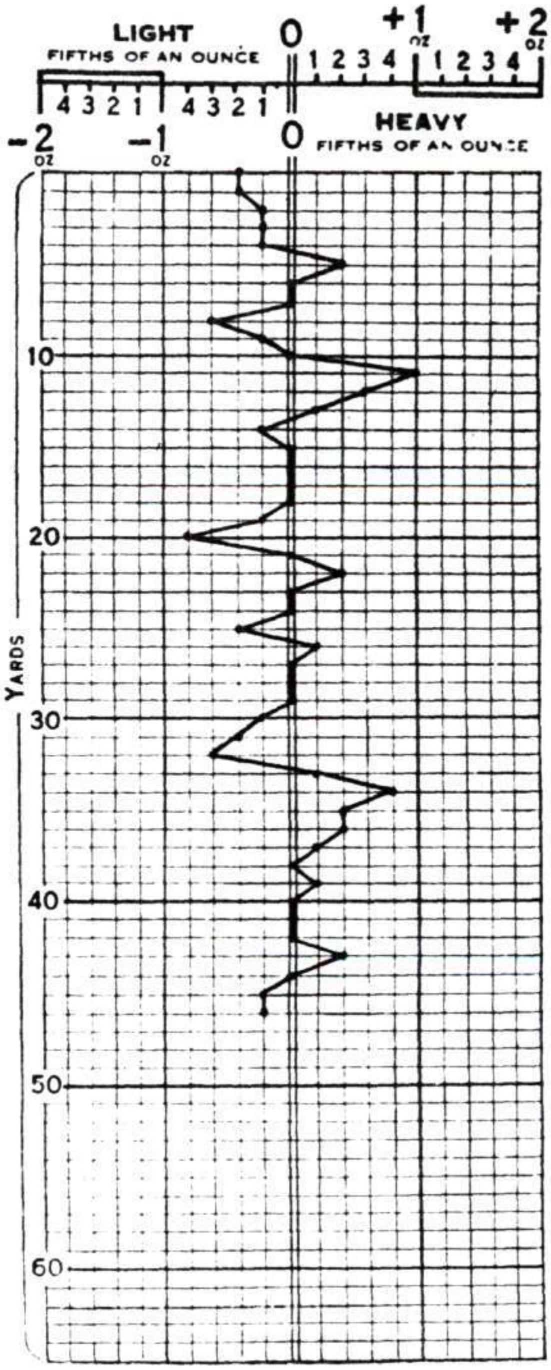
Rel. Humidity 65%

Actual Average Weight per Yard 12.5 Oz.

No. of Yards within Limits ...
Within Limits % ...

Total Number of Yards Weighed 46

Notes



Tested By Cancelliere

Date [illegible] March 1955

FORM 35014

Fig. 11. Saco Lowell Lap Meter Record

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