INVESTIGATION OF A MINIATURE SPINNING SYSTEM AS A SCREENING AID FOR SPIN FINISH COMPONENTS ON POLYACRYLONITRILE FIBERS

A THESIS

Presented to

The Faculty of the Graduate Division

by

James Franklin Simmons

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Textiles

Georgia Institute of Technology

August, 1967

INVESTIGATION OF A MINIATURE

SPINNING SYSTEM AS A SCREENING AID FOR

SPIN FINISH COMPONENTS ON POLYACRYLONITRILE FIBERS

Approved:

Chairman

Date approved by Chairman:

DEDICATION

I gratefully dedicate this thesis to my wonderful, patient wife, Peggy. Her sacrifices have made this educational venture possible, and her encouragement, faith, and love have been boundless!

ACKNOWLEDGEMENTS

The author is grateful to the Celanese Corporation for the financial aid which it has extended and to Dr. James L. Taylor, Director of the A. French Textile School, for his support and assistance in securing this fellowship.

The author wishes to express his sincerest appreciation to Mr. J.C. Meaders for his assistance on the fiber-to-fiber frictional work, to Mr. R.C. Freeman for his assistance on the full-scale process, to Mr. J.L. Hubbard for his aid in the microscopy work, and to Dow Badische Company for furnishing the fiber.

Special thanks are extended to Dr. C.T. Handy and Mr. K. Joslyn of Textile Research Laboratory, E.I. duPont de Nemours and Co. (Inc.), for their timely support and assistance concerning the Shirley^{R} Miniature Spinning System; to Mr. P.J. Wakelyn for his invaluable time, advice, and assistance throughout this research.

The author feels indebted to his thesis advisor, Mr. W.C. Boteler, for his enthusiastic support and suggestions during this work.

Thanks also goes to Mr. R.B. Belser for graciously giving of his time for service on the reading committee. Appreciation is also expressed to Mr. R.K. Flege for his service on the reading committee.

Finally, the author wishes to express his affection and gratitude to his mother and father for their sacrifices, encouragement, and love.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

SUMMARY

It was the purpose of this research to investigate the correlation between the Shirley[R] Miniature Spinning Plant and a conventional textile processing system and to determine the value of this miniature system as a screening aid for spin finish components on polyacrylonitrile fibers.

The work involved manufacturing yarn on both systems from Zefkrome[R] staple fiber as it came from the producer, and correlating certain test parameters of the completed yarns. Different commercially available spin finish components were applied to the fiber, which was subsequently processed through the miniature system to evaluate its importance as a screening aid. The parameters tested were fiber-to-fiber friction, electrostatic charge build-up during processing, yarn-to-guide friction, yarn evenness, yarn strength, and yarn elongation.

It was found that the usefulness of the Shirley[R] system does not depend on the precise value of the measurements for a yarn but rather on the fact that the principal parameters utilized in measuring yarn quality vary on the Shirley[R] system as they do on full-scale equipment. As a result, fibers, finishes and selected processes may be evaluated for manufacturing purposes in an economical manner.

It was concluded that the Shirley[R] Miniature Spinning Plant is an excellent screening aid for spin finish components on polyacrylonitrile fibers, giving results which are consistent with full-scale textile processing.

CHAPTER I

INTRODUCTION

Statement of the Problem

In any manufacturing process operated on a large scale, such as today's modern textile industry, the testing of the processing feasibility of the fibrous material is very important. Unless adequate testing apparatus and procedures can be developed, there remains an undesirable element of uncertainty as to the character of the final product. In addition, there exists the possibility of wasted time, effort, and material caused by usage of unsuitable raw stock. Usually, only by observation of the fibers during actual processing and by testing the finished product can a valid assessment of the relative spinning value of the fibers be made.

Considering the complex characteristics of fibers and the highly involved process of spinning them, it is easily understandable that there is not an exact relationship between the physical properties of the fiber and those properties of the spun yarn (1). With much experience many textile men have acquired the ability to evaluate and judge a fiber's processing qualities by the use of their eyes and hands. Even though these types of tests are quite subjective in nature, such procedures can be of valuable assistance. However, the only means to accurately determine the behavior and characteristics of a fiber is to spin it into a completed yarn. Therefore, it is necessary for a comprehensive evaluation to process at least some of the raw stock through the entire textile manufacturing operation. Since full-scale or conventional textile machinery requires a relatively large amount of raw material (i.e., 75 to 100 pounds) and a significant amount of time for processing, very thorough testing is not economically feasible. Hence, special equipment and techniques have been developed in order to process very small samples of stock.

Several small-scale and miniature textile processing systems (2, 3,4,5,6,7) have been built in the last 20 years. These miniature spinning plants have been designed to provide a ready means of obtaining quick, reliable evaluations of very small quantities of natural and man-made staple fiber.

There are many applications for small-scale spinning equipment (8). For example:

1. Experimental work on the processing and properties of yarns spun from blends.

2. Color matching of blended yarns.

3. Quality control.

4. Experimental work on the efficiency of the spin finish* components on the staple synthetic fiber.

This latter application is of prime importance to manufacturers and spinners of synthetic fibers and to chemical producers of fiber finishes (9). It is important because synthetic fibers do not process properly through textile equipment without the application of some type of fiber finish.

Natural fibers are hydrophilic and contain fats and oils on

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*synonyms are fiber finishes, textile processing aids, producer finishes.

their surfaces which make them responsive to processing operations. The synthetic fibers, on the other hand, are essentially hydrophobic, which results in an electrostatic charge accumulation on these fibers during processing. In addition, the synthetic fibers contain no surface lubricants as extruded. To render these fibers suitably responsive to processing on textile equipment, spin finishes must be applied to their surfaces.

Since a full-scale plant trial of every potential finish is impractical, miniature textile equipment and techniques which closely approximate full-scale conditions are highly desirable as screening aids.

It is the objective of this investigation:

1. to determine the correlation between the Shirley^{R}* Miniature Spinning Plant and a conventional textile processing system for polyacrylonitrile fibers.

2. to evaluate this miniature plant as a screening aid for spin finish components on polyacrylonitrile fibers.

Organization and Approach

The first phase of the research was a survey of the literature to determine what had been done previously in the specific area of interest and what parameters were considered important to this area. The search revealed that only a few papers had been published concerning the value and correlation of the Shirley^{R} Miniature Spinning Plant with conventional textile systems (10,11,12,13). These researches were concerned only with the processing of cotton.

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*Shirley^{R} is the registered trademark of the Cotton, Silk, and Man-made Fiber Research Association.

It was noted that specific parameters were considered important in such an evaluation. The criteria that were selected to correlate the Shirley[R] system with full-scale textile equipment and to determine its value as a screening aid for spin finishes were as follows:

1. Yarn strength and elongation (14)
2. Yarn evenness (15)
3. Yarn-to-guide friction (16)
4. Fiber-to-fiber friction (17)
5. Electrostatic charge build-up (18)

Yarn strength and elongation were measured by use of the Uster Automatic Single-end Tester. Yarn evenness was determined on the Uster Evenness Tester. The yarn-to-guide friction was evaluated by using the Rothschild F-Meter with the Rothschild four-channel recorder. Fiber-to-fiber friction was investigated by use of a servo-controlled fiber friction apparatus developed by T.E. McBride (19). Electrostatic charge build-up was measured on the Bergischer Rotating Electrostatic Field-Strength Measuring Instrument.

After selection of these five test parameters, Zefkrome[R*] polyacrylonitrile fibers were spun into yarn on the full-scale textile equipment located in the A. French Textile School, Georgia Institute of Technology. Zefkrome[R] fibers from the same bale were processed into yarn on the Shirley[R] equipment located at E.I. duPont de Nemours Company's Textile Research Laboratory, Wilmington, Delaware. These two sets of yarns were then evaluated according to the parameters mentioned above, and the resulting data correlated.

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[*]Zefkrome[R] is the registered trademark of Dow Badische Company's Pigmented Acrylic.

Zefkrome[R] fibers were scoured and treated with certain select commercially available spin finish components. These treated fibers were processed through the Shirley[R] machinery. The data obtained was analyzed and correlated. From these determinations the two systems were compared and the Shirley spinning equipment evaluated as an aid in predicting the quality of manufactured yarn and the performance of spin finishes.

Literature Survey

Miniature Spinning Systems

The first small-scale spinning experiments were developed in England by W.L. Balls and associates during the decade 1920-1929 (20). These spinning experiments were modified to evaluate cotton varieties and new strains in breeding programs. Subsequent to 1950 refined small-scale equipment was designed. At the Shirley Institute a small-scale system was created which used samples of cotton fiber weighing as little as 75 grams (about three ounces) (21). Analysis of the results showed that data from these yarns gave a reliable indication of the relative spinning value of the cotton fibers. This system was also designed as an aid in evaluating new breeds of cotton. The Shirley[R] equipment varied only in minor details from full-scale machinery. Similar techniques were developed at the Giza Spinning Test Mill near Cairo, Egypt and by the Agricultural Marketing Service at Clemson, South Carolina in the United States.

The technique developed at Giza was for spinning cotton samples weighing 60 grams on standard cotton equipment. The results were excellent, a correlation factor of 0.998 between 60-gram and standard cotton yarn strengths (22) was obtained. It is important to note that the use of only a 60-gram sample for spinning need not involve appreciable increase in the sampling error if a large supply of cotton is available, because then there is little difficulty in selecting the 60 grams so that it is representative of a large bulk. Hancock reported that the following textile machines were used in the Giza procedure:

> . . .two carding engines (for double carded preparation) of standard type except that they are fitted with Poulaix wire on doffer, cylinder, and flats; a home-made drum with traverse for making a lap out of first card sliver and another one of bigger diameter for making drawframe laps; a drawframe of five heads; a combined slubber; an intermediate frame (interchangeable) of which 12 spindles are used; a roving frame of 24 spindles in two blocks of 12; and two ring-spinning frames each of 48 spindles in four blocks of 12, creeled for double roving (23).

In the United States the Agricultural Marketing Service developed both carded and combed cotton yarn spinning tests which used approximately 5-10 pounds of cotton fiber. Conventional equipment and procedures were used in this small-scale system for testing new varieties of cotton. After 1950 the sample size was reduced to one pound by devising a miniature opener-cleaner to prepare the sample for processing. The one-pound test, while it followed the classic style, proved to be slow, inefficient, and expensive, and it used too much fiber for early screening work. The test was further refined until a one-half pound sample of cotton fibers could be processed efficiently. This procedure also used modified conventional textile machinery except for the miniature opener-cleaner.

In 1949 it was reported by G. Darkin (24) that a miniature spinning plant manufactured by P. Litty, Leipzig, could process samples of raw cotton as small as one ounce. This system was one of the first truly miniature plants. It consisted not of modified conventional textile equipment but of a miniature card and a single spindle drafting unit with overall dimensions of 2 1/2 x 3 x 2 1/2 feet. The omission of a drawing head equivalent to the conventional drawing frame limited the usefulness of this apparatus. The yarn spun on this system was considerably weaker than that from large-scale systems.

In 1956 the Shirley Institute announced the development and manufacture of a miniature spinning system consisting of a miniature card, drawing frame, and spinning frame (25). This system was not only for the testing of cotton, but also its capability extended to man-made fibers and blends (26). It was used for work on the processing and properties of yarns spun from blends of cotton and man-made fibers. Although this system has been refined, it is the basic plant which was used in this study. The miniature equipment is described in detail in Chapter 2.

In 1959 the Cotton Quality Investigations Laboratory at Knoxville, Tennessee created a miniature test which resembles in several ways the Shirley Institute's technique (27). This procedure required that a 50-gram sample be processed on miniature textile machinery consisting of a card, a drawing frame, and a spinning frame.

Selection of Parameters.

Yarn strength and elongation have been accepted as the most important characteristics of yarn (28). Remanand (29) reported in 1965 that in view of the spinning technique adopted for the Shirley[R] system as compared with industrial procedure and due to the absence of any related data on the subject, it was necessary to investigate the confidence limits of the mean strength of single cotton yarn. He reported that it was important for a good confidence limit to feed the first drawframe passage with a constant weight of cotton fiber. A total of 600 tests were necessary for a confidence limit of ± 0.3 grams per tex for 20 bobbins.

Yarn evenness has been considered important for a long time as a guide for the quality of a yarn (30). The irregularity of the weight per unit length affects the appearance, the breaking strength, and the elongation of a yarn.

It was found that an evaluation of yarns for comparing two different systems and spin finishes should include fiber-to-fiber friction (31), yarn-to-guide friction (32,33), and electrostatic charge build-up (34,35).

Fiber-to-fiber friction measurements have been used by workers in studies of the effects of textile fiber processing and in evaluation of spin finishes (36). This parameter exhibits changes in fiber surfaces or configuration caused during processing through textile equipment (37).

Yarn-to-guide frictional characteristics are used as a criterion for the response to textile processing of finished-treated fibers. The friction coefficient provides an evaluation index in the selection of finishes. Yarn-to-guide friction provides a similar indication concerning fiber damage and finish distribution on the fiber during or as a result of textile processing (38).

The electrostatic charge accumulation is used in assessing the value of a finish on a fiber (39). Modern textile fiber finishes must prevent this excessive build-up on synthetic fibers during processing through textile machinery. Processing troubles--caused by the development of electrostatic charges--are encountered all along the manufacturing procedure but particularly in the carding operation (40).

Thus, it was found that for comprehensive testing of textile fibers and spin finishes, it is necessary to process a portion of the fibers into a completed yarn. Miniature textile equipment and procedures have been devised for this purpose. Certain parameters were found which are used to correlate different spinning processes and the value of different spin finishes. These parameters are fiber-to-fiber friction electrostatic charge build-up, yarn-to-guide friction, yarn strength, yarn elongation, and yarn evenness.

CHAPTER II

MATERIALS, EQUIPMENT, AND INSTRUMENTATION

The Substrate

The fiber used in this research was Zefkrome^R (white) acrylic fiber made by the Dow Badische Company of Williamsburg, Virginia. The Zefkrome^R acrylic fiber was selected because Zefkrome^R is the most critical acrylic fiber for electrostatic charge build-up (41). This fiber is a homopolymer of acrylonitrile. The long, linear backbone of the polyacrylonitrile molecule is composed of acrylonitrile units formed by addition polymerization

$$n(CH_2 = CH\text{-}CN) \longrightarrow (-CH_2-\underset{CN}{\underset{|}{CH}}-)_n$$

of the monomer acrylonitrile. This backbone structure is very important in determining the physical properties of this fiber as are the conditions under which it is manufactured, (i.e., extrusion system used, coagulation bath constituents, and degree of tension applied). All of these variations in producing the fiber lead to slightly different surfaces and cross-sections. The overall cross-section of the Zefkrome^R fiber is circular. The Zefkrome^R fiber, as are all synthetic fibers, is treated by the producer with a small amount of a spin finish to insure adequate response to processing on textile equipment.

The Spin Finish Components

A spin finish is classified normally as containing the following components (42):

1. Lubricants
2. Emulsifiers
3. Antistats.

The following commercially available spin finish components as received from the manufacturers were used (see Table 1):

From: Foremost Food and Chemical Company
El Dorado Division
P.O. Box 599
Oakland, California

Formonyte 1617
Lot No. 4510
Myristyl trimethyl ammonium chloride

From: General Mills
Chemical Division
Kanker, Illinois

Aliquat 6
Lot No. 5D801
Palyityl trimethyl ammonium chloride

From: E.I. duPont de Nemours and Company (Inc.)
Organic Chemicals Department
Dyes and Chemicals Division
Wilmington, Delaware

Zelec NE
Lot No. 420
Fatty alcohol phosphate

TLF -1121- B
Lot No. 420
N- cetyl Betaine

From: Emery Industries, Inc.
Carew Tower
Cincinnati, Ohio

Emery 1112-25-T Antistat
C_{16}-C_{18} unsaturated acid and alkanol amine condensation product mix

Emery 1274-64-T Fiber Finish
ethoxylated fatty glyceride, sorbitan ester
of a fatty acid and Emery 1112-25-T mixture

Finish components may be classified further according to their ionic nature:

1. Anionic
2. Cationic
3. Nonionic
4. Amphoteric

Representative spin finish components were chosen from each of the above categories for use in this study. These compounds and the classes they represent are listed in Table 2.

Full-Scale Textile Processing Equipment

Whitin Synthetic Picker

The first step in the manufacture of a synthetic yarn is to open and blend the fibers. Since synthetic fibers do not have the problem of trash content as do natural fibers, the picker is used primarily to open and blend the fibers, and to form the fibers into an even-running lap for use on the card. Table 3 presents the operating data for the Whitin picker.

Saco-Lowell Granular Top Card

The card is very efficient in opening and cleaning of the fibers. It reduces the bulky lap into a sliver possessing a fairly high order of uniformity with some degree of fiber orientation in the direction of the sliver axis. This achievement is accomplished by breaking up the fiber tufts into individual fibers and paralleling the fibers into a sliver. The operating data for the Saco-Lowell card can be found in Table 4.

Table 1. Spin Finish Components Examined

Compound	Abbreviation Used in this thesis	Chemical Structure
1. myristyle trimethyl ammonium chloride	$C_{14}MeCl$	$C_{14}H_{29}\overset{+}{N}\text{-}(CH_3)_3Cl^-$
2. palmityl trimethyl ammonium chloride	$C_{16}MeCl$	$C_{16}H_{33}\overset{+}{N}\text{-}(CH_3)_3Cl^-$
3. stearyl trimethyl ammonium chloride	$C_{18}MeCl$	$C_{18}H_{37}\underset{\mid \atop CH_3}{\overset{+}{N}}\text{-}(CH_3)_3Cl^-$
4. N-cetyl betaine	$C_{16}COO$	$C_{16}H_{33}\text{-}\underset{\mid \atop CH_3}{\overset{+}{N}}\text{-}CH_2\text{ -COO-}$
*5. Fatty alcohol phosphate	OPO	$R^1 - O - \underset{\mid \atop O-}{\overset{O \atop \parallel}{P}} - OR$
*6. Emery 1112-25-7	1112	
*7. Emery 1274-64-7	1274	

*Due to company security, the formulas of these compounds are not known.

Table 2. Spin Finish Components and Their Classifications

Compound	Type Component	Ionic Nature
$CH_{14}MeCl$	L,A*	cationic
$CH_{16}MeCl$	E,A	cationic
$CH_{18}MeCl$	E,A	cationic
$C_{16}Coo$	E,A	amphoteric
OPO	A	anionic
1112	A	nonionic
1274	L,E,A	nonionic

*L - lubricant

E - emulsifier

A - antistat

Table 3. Operational Data for Whitin Synthetic Picker

Weight per yard of Lap (ounces)	10.50
Width of Lap	38"
Weight of Lap (Total Pounds)	60
Production Rate (Pounds per Hour)	400

Table 4. Operative Data for Saco-Lowell Granular Top Card

Name	Diameter In Inches	Type Clothing	RPM
Lickerin	9	metallic	500
Cylinder	27	metallic	180
Doffer	50	metallic	10.0

Weight Fed (Lap-ounces per Yard)	10.50
Weight Delivered (Grains per Yard)	45
Production Rate (Pounds per Hour)	15

Description of Setting		Setting in Thousandths of an Inch
Feed Plate - Lickerin		12
Preopener - Lickerin		10
Preopener - Cylinder		7
Lickerin - Cylinder		7
Flats:	Back	15
	Second	7
(Carding	Third	7
Plates)	Fourth	7
	Front	7
Doffer - Cylinder		7
Mote Knife:		
	Top	22
	Bottom	17
Mote Knife Angle		15°

Table 4. (Continued) Operative Data for Saco-Lowell Granular Top Card

Licker Screen:		
	Front	29
	Bars	12
Cylinder Screen:		
	Front	187 1/2
	Middle	58
	Back	29
Back Plate		
	Top	17
	Bottom	29
Front Plate		
	Top	22
	Bottom	29

Ideal Feathertouch Drawing Frame

In the drawing process there is a blending of many fibers by doubling together several slivers from carding. This doubling enhances the long range uniformity. Fiber parallelism is obtained by drafting--attentuation of a strand of fibers. Operating data for the Ideal draw-frame are listed in Table 5.

Whitin Woonsocket Roving Frame

Roving frames are designed to perform three basic functions. The roving process is used to reduce the stock in size by drafting of the drawing sliver. Twist is inserted in the roving in order to obtain strength. Finally, the roving is wound onto a roving bobbin for processing on the spinning frame. In accomplishing the reduction in size, a greater degree of parallelism of the fibers is also obtained. Table 6 shows the operating data for the roving frame.

Saco-Lowell SJ Spinning Frame

Spinning is the final process in the formation of a singles spun yarn. The spinning frame, similar to the roving frame, draws out the strand of roving into a finer strand of fibers, and then twists these fibers to a degree that will allow the inherent fiber strength to be realized. Then the frame packages this completed yarn onto a bobbin suitable for subsequent operations. The operating data for the Saco-Lowell spinning frame are stated in Table 7.

Table 5. Operating Data for Ideal Drawing Frame

Machine Details	Front Roll	Second Roll	Third Roll	Back Roll
Roll Type:				
Top	Cushion	Cushion	Cushion	Cushion
Bottom	Fluted	Fluted	Fluted	Fluted
Roll Diameter: (Inches)				
Top	1.40	1.40	1.40	1.40
Bottom	1.40	1.40	1.40	1.40
Roll Settings: (Inches)				
Back to Third		2.56		
Third to Second		2.41		
Second to Front		2.31		
Weight Fed per End (Grains)				45
Weight Delivered (Grains)				55
Production Rate (Pounds per Hour per Delivery)				65
Ends-up in Creel				8

Table 6. Operating Data for Whitin Woonsocket Roving Frame

Machine Details		
Bottom Roll Diameter (inches)	Front	1.125
	Middle	Apron
	Back	1.000
Roll Settings	Front to Middle	2.25
	Middle to Back	2.188
Twist Multiplier		0.90
Weight Fed (Grams per Yard)		55
Hank Roving Delivered		1.0
Production Rate (Pounds per Spindle per Hour)		0.80

Table 7. Operating Data for Saco-Lowell SJ Spinning Frame

Machine Details	
Roll Type and Diameter (inches):	
Front Top	Cushion, 1.125 Diameter
Middle Top	Apron, 1.125 Diameter
Back Top	Cushion, 1.063 Diameter
Front Bottom	Fluted, 1.000 Diameter
Middle Bottom	Apron, 1.094 Diameter
Back Bottom	Fluted, 1.000 Diameter
Roll Setting (inches):	
Front-Middle	1.688
Middle-Back	2.000
Twist Multiplier	3.5
Spindle Speed (RPM)	8000
Hank Roving Fed	1.0
Hank Roving Delivered	15/1 cotton count
Twist Per Inch	13.5
Ends-up in Creel per Bobbin	1
Twist Direction	Z

Shirley^R Miniature Spinning Plant

The Card (43)

This machine is a miniature version of the standard cotton card (see Figure 1). The primary difference between the two is that there are only eight stationary flats across the top of the cylinder on the Shirley^R card. On a full-scale flat-top card revolving flats are used.

The Shirley^R card consists of a feed apron similar to a conveyor belt, feed roller, feed plate, lickerin, cylinder, eight flats, doffer, and oscillating doffer comb. Both the cylinder and doffer are covered with metallic wire instead of fillet, while the spring-loaded flats are fitted with self-stripping fillet wire.

The web of fibers from the doffer comb is wound onto a cylinder or drum at the front of the card. A calender roller which is mounted on the top of the drum consolidates the web of fibers into a fleece. Operating data for the Shirley^R card are presented in Table 8.

The Drawframe (44)

The Shirley^R miniature drawframe is a single delivery machine with a creel which uses a drum either from the card or a preceding drawing operation (see Figure 2). The fiber from the drum is fed through a four-roller, two-zone drafting arrangement equipped with needle bearing, spring weighted, top rollers and Shirley^R fluting on the bottom rollers. Three versions of drawframes are available to accommodate different staple ranges. The long staple (1 1/4 to 2 1/2 in.) machine was used in this research. Flat, reciprocating top and bottom clearers are used.

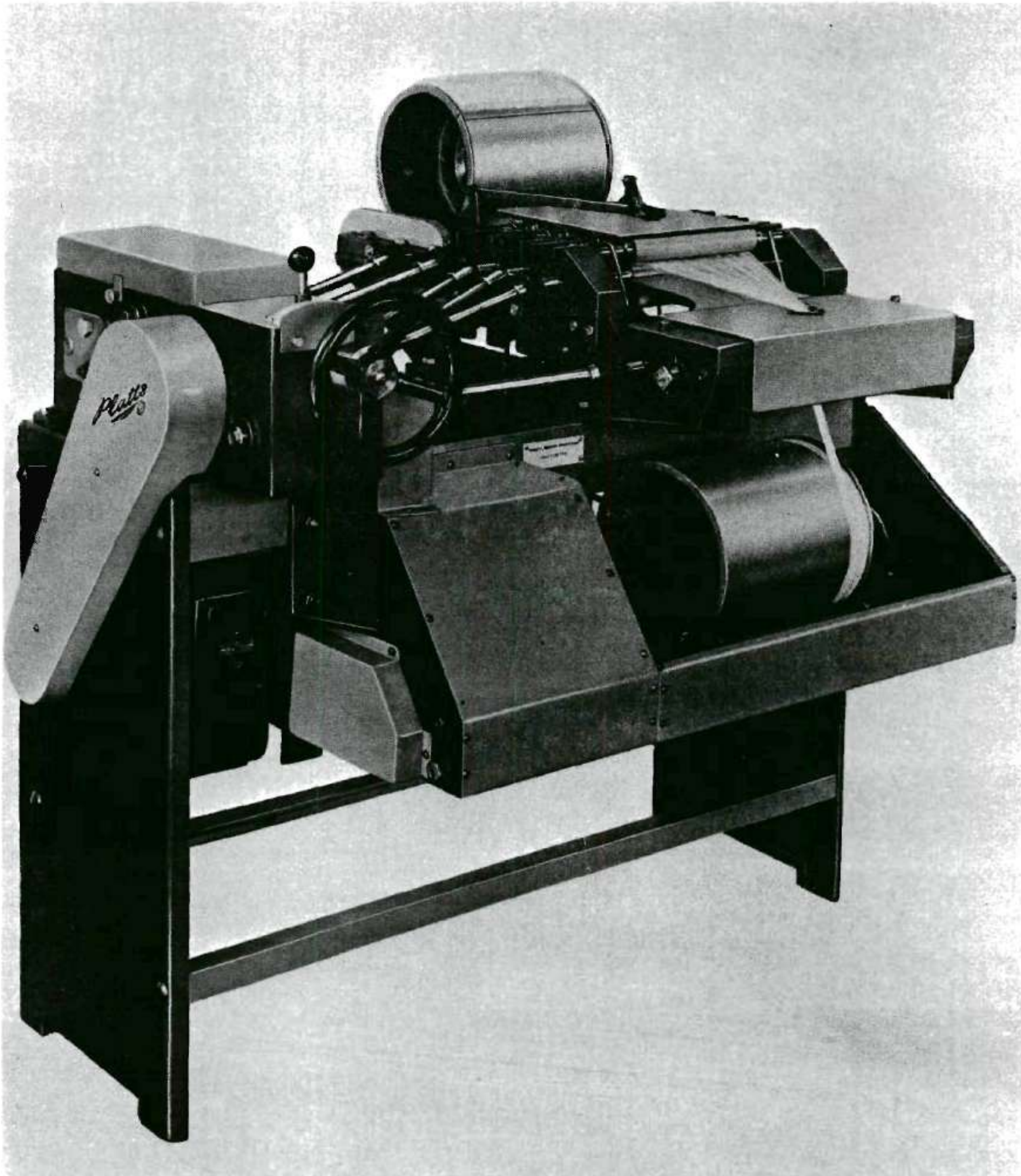


Figure 1. The Shirley[R] Miniature Card

Table 8. Operating Data for Shirley[R] Card

Name	Diameter (In Inches)	Type Clothing	RPM
Lickerin	4	Metallic	350
Cylinder	9	Metallic	900
Doffer	6	Metallic	1

Description of Setting	Setting in Inches
Feed Plate-Lickerin	1/16
Feed Roll-Feed Plate	.010
Feed Roll-Feed Apron	1/32
Deflector Plate-Lickerin	1/32
Lickerin Undergrid	1/32
Lickerin-Cylinder	.005
Cylinder Undergrid	.500
Cylinder-Doffer	.005
Doffer-Undergrid	3/8
Doffer Comb-Doffer	.010
Flats	all flats .050

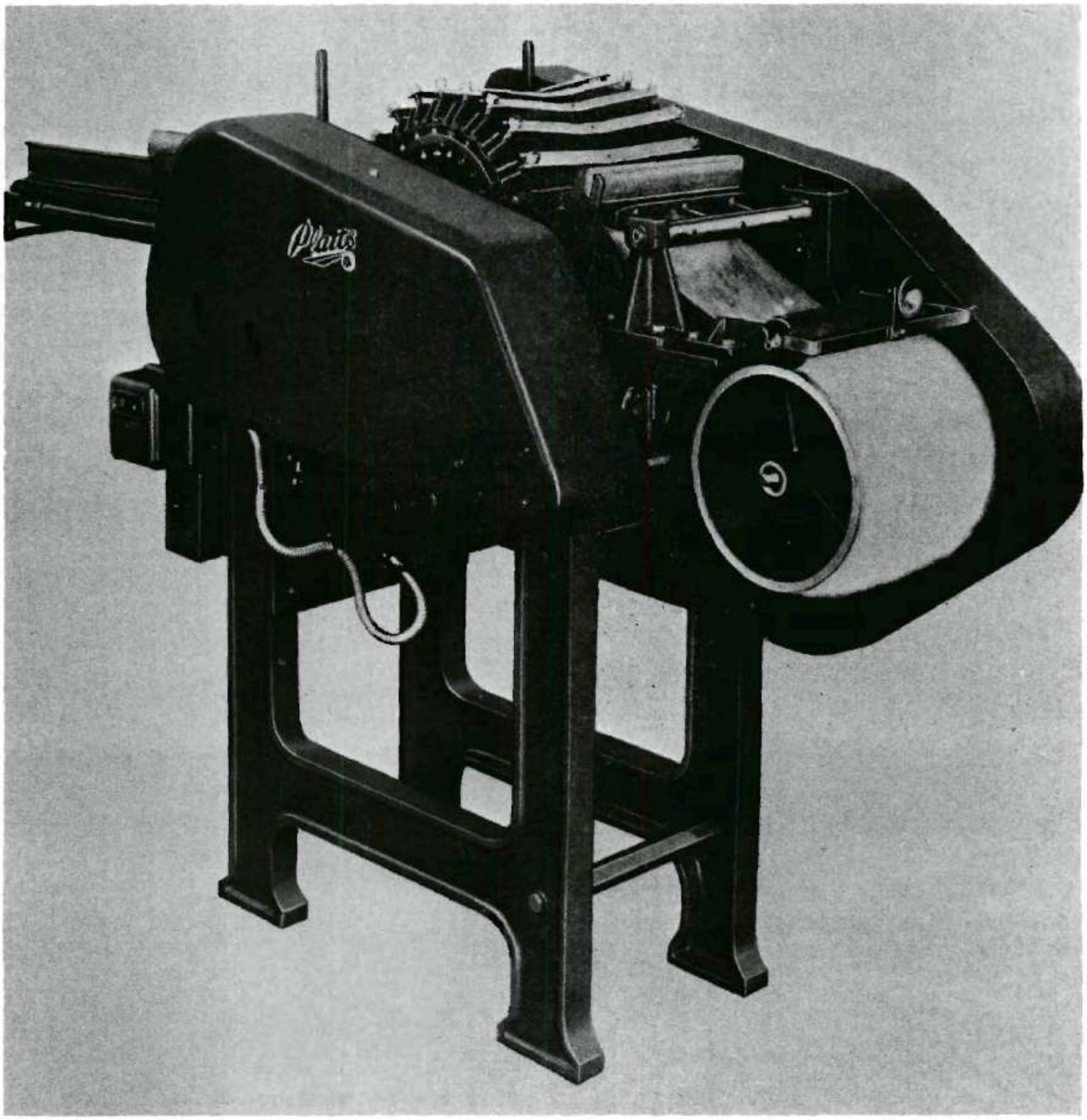


Figure 2. The Shirley^{R} Miniature Drawframe

After drafting, the fiber passes through a trumpet and calender rolls, and is wound in sliver form around a drum at the front of the machine. Inserts with different diameters are provided for the condenser trumpet to adjust for the changes in sliver weight as drafting proceeds. A traverse selection lever enables varying numbers of coils of the drawn sliver to be wound on the drum. This allows the correct number of doublings to be carried out and the sliver to be drafted correctly. Roll settings can be adjusted easily without changing any gearing, since all drives are from a fixed gearbox. Table 9 contains operating data for the Shirley drawframe.

The Spinning Frame (45)

The Shirley^R miniature ring frame is an eight spindle, single sided machine with a creel accommodating two drums of sliver from the draw frame (see Figure 3). The two-zone, Casablanca type apron drafting system can process up to 2 1/2 in. staple fiber. The draft ranges up to 400. The top rollers are covered with synthetic cots and the saddles are spring tensioned with quick release arrangement on the front rollers. A revolution counter is fixed at the end of the front bottom roller.

The frame has revolving front underclearers and stationary top clearers. The single ring rail is carried on pokers and is activated by a standard cop type builder motion. Three sets of spinning rings are provided to cover a wide variety of counts. Change points for twist and draft variation are easily accessible, and change pulleys are provided for a range of spindle speeds. Operating data for the Shirley^R spinning frame are presented in Table 10.

Table 9. Operating Data for Shirley^{R} Drawframe

Machine Details	Front Roll	Second Roll	Third Roll	Back Roll
Roll Type:				
Top	Cushion	Cushion	Cushion	Cushion
Bottom	All rolls have Shirley^{R} fluting			
Roll Diameter (Inches):				
Bottom	1.50	1.25	1.50	1.50
Roll Settings (Inches):				
Back to Third	2.250			
Third to Second	2.188			
Second to Front	2.625			

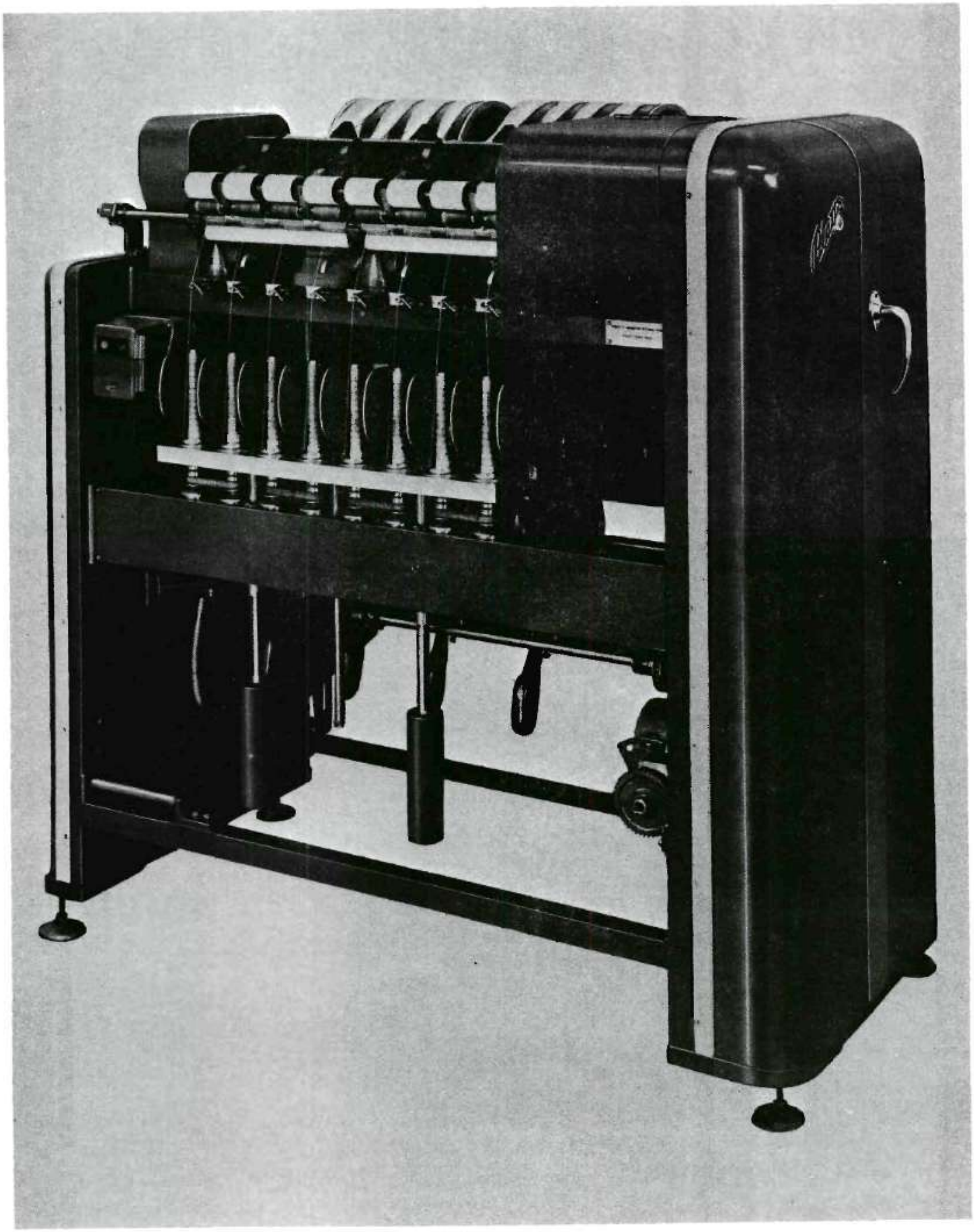


Figure 3. The Shirley^{R} Miniature Spinning Frame.

Table 10. Operating Data for Shirley® Spinning Frame

Machine Details	
Roll Diameter (Inches):	
Top Middle	0.875 Diameter
Top Third	0.875 Diameter
Top Back	1.000 Diameter
Bottom Front	1.000 Diameter
Bottom Second	0.875 Diameter
Bottom Third	1.000 Diameter
Bottom Back	1.000 Diameter
Roll Setting (Inches):	
Front-Middle	3.563 (8 Tensor)
Middle-Back	2.750 (8 Tensor)
Spindle Speed (RPM)	8,000
Hank Roving Delivered	15/1 cotton count
Twist per Inch	13.5
Twist Direction	Z

Testing Instruments

Servo-Controlled Fiber Friction Apparatus

To determine fiber-to-fiber friction a servo-controlled fiber friction apparatus designed and located at the Engineering Experiment Station, Georgia Institute of Technology was used in this work. The basic design and construction of this instrument was discussed thoroughly by McBride (46). It employs a servo-controlled torque restoring apparatus and a suitable motor driven fiber holder to draw a single fiber across another attached to the torque arm. An electrical analog of the friction between the fibers is recorded on an XY plotter. Bryant (47) reviews the literature on frictional apparatus and discusses revisions of the instrument. Operating data for this instrument appear in Table 11.

Rothschild F-Meter with Rothschild four-channel recorder

If a yarn is put around a cylinder at a friction angle θ and moved at constant speed in the direction V, the pulling force T_1 is larger than the retaining force T_2. The difference in the two tensions is the force required to overcome friction.

$$\frac{T_1}{T_2} = e^{\theta\mu}$$

T_1 = tension of outgoing yarn (final tension)

T_2 = tension of incoming yarn (initial tension)

e = base of natural logarithm system

μ = coefficient of friction

Table 11. Operating Data for Servo-Controlled Fiber Friction Apparatus

Instrument Details	
Fiber Type	Zefkrome^{R}
Fiber Tension (Galvanometer)	1164 mg.
Fiber Tension (Arm)	1164 mg.
Vertical Plot Sensitivity (XY Plotter)	100 mv/in.
Conversion Factor	1.87 mg/cm
Chart Speed	0.10 in/sec.
Lever Arm Speed	0.00447 in/sec.

θ = angle subtended over friction pin (friction angle)

The purpose of the F-Meter is the measurement of the coefficient of friction μ for yarn-to-guide friction (48). The above formula, the classical "Capstan" equation, can be written as:

$$\mu = \frac{1}{\theta} (\text{Log } T_1 - \text{Log } T_2)$$

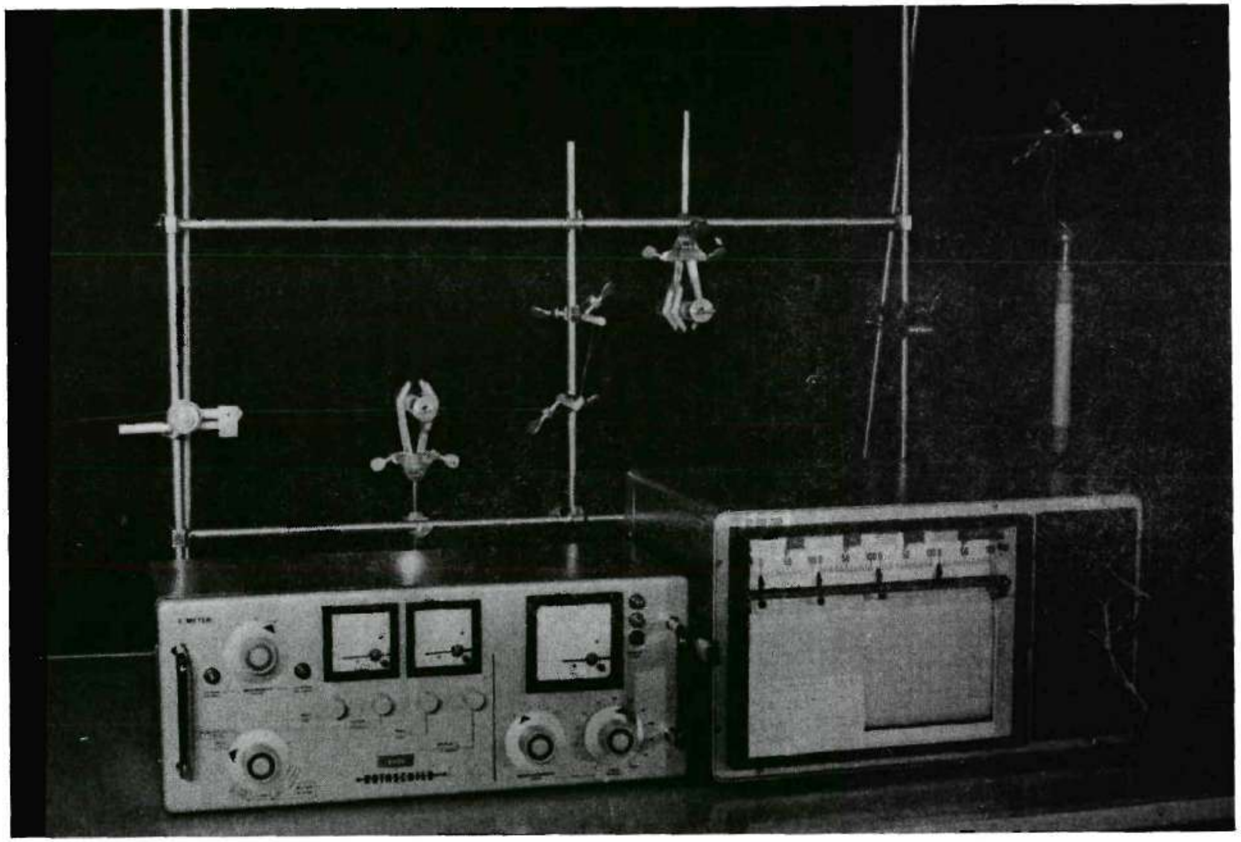
The F-Meter is an analog computer (see Figure 4) which solves this equation. This is done by measuring separately the two tensions, before and after friction, by means of a pair of tension measuring heads (see Figures 5 and 6) which are actually tensiometers. This method offers the advantage of permitting an accurate control of the initial tension T_2; indispensible for comparing coefficients of friction.

With the initial tension T_2 constant, the friction material the same, and the linear yarn speed constant, the resulting coefficient of friction can be compared for yarns of identical count and twist. Figure 12 contains the operating data for this device.

The Rothschild four-channel recorder (see Figure 4) is connected into the F-Meter. This recorder continuously plots the initial tension T_2, the final tension T_1, and the coefficient of friction μ (49).

<u>Bergischer Rotating Electrostatic Field Strength Measuring Instrument</u> (50)

To evaluate the electrostatic charge build-up on the fibers during carding, a Bergischer Rotating Electrostatic Field Strength Measuring Instrument (Field Mill) was used (see Figure 7). The Rothschild Four-Channel Recorder was used to plot a continuous graph of the charge



Rothschild F-Meter Rothschild Four-Channel Recorder

Figure 4. Rothschild F-Meter with Rothschild Four-Channel Recorder

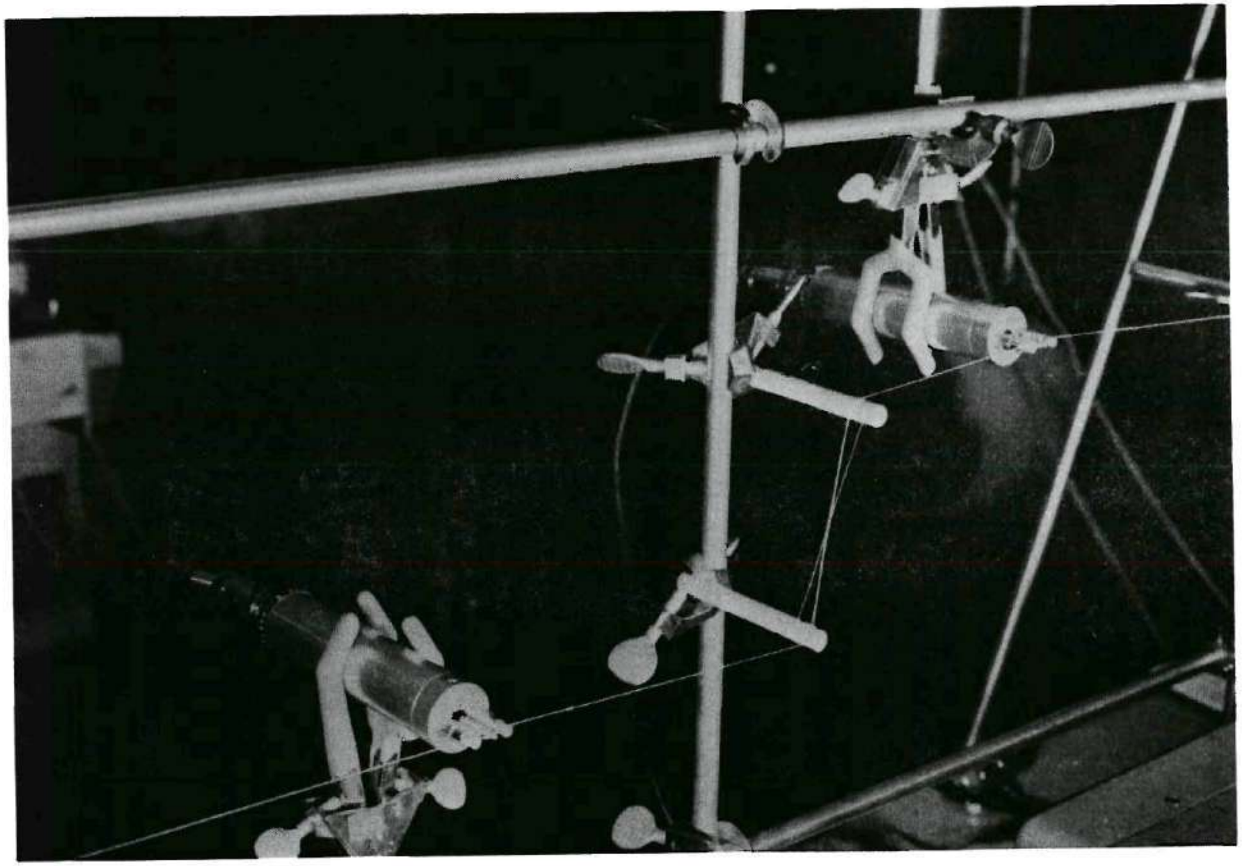


Figure 5. Rothschild Tension Measuring Heads as Used in This Research

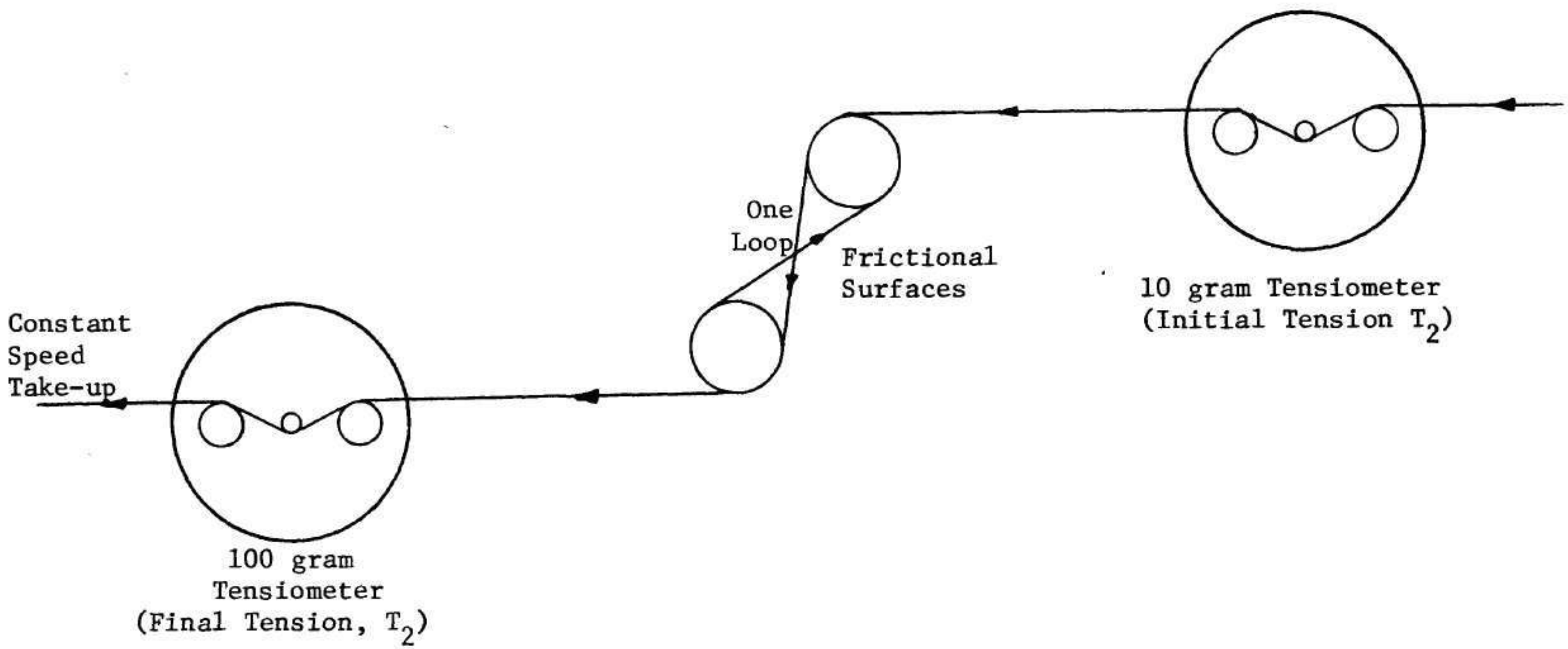
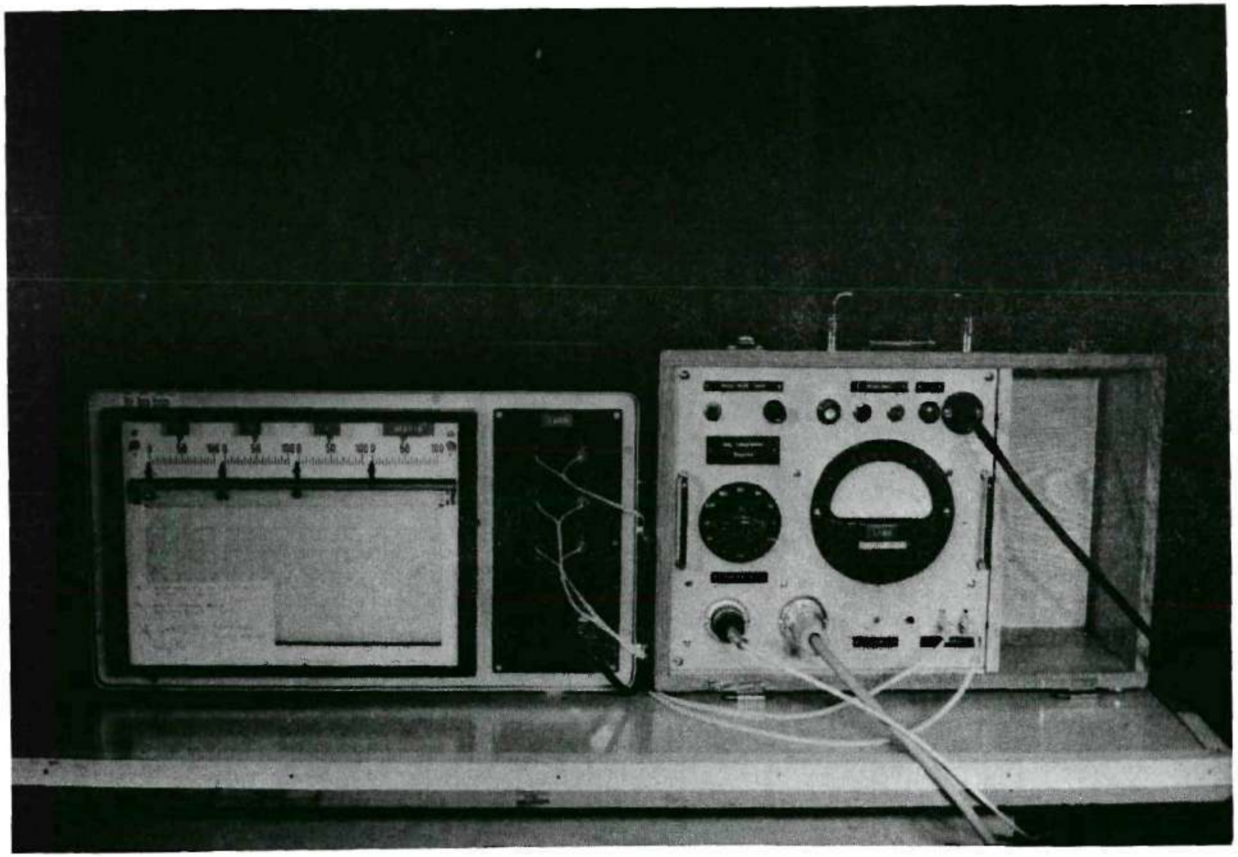


Figure 6. Schematic Diagram of Yarn Arranged on the Rothschild Tension Measuring Heads and Frictional Surface

Table 12. Operating Data for Rothschild F-Meter

Material Tested	Full-Scale Yarn	Shirley[R] Yarn	Spin Finish Yarn
Number of Bobbins per Sample	20	20	1
Number of Feet Tested per Bobbin	250	250	250
Number of Feet per Yarn Sample	5000	5000	250
Instrument Details:			
Pretension Setting	1	1	1
T_1 Measuring Head (Grams)	100	100	100
T_2 Measuring Head (Grams)	10	10	10
Take-up Drive Speed (Feet per Min.)	165	165	165
Length of Test (Minutes)	1.5	1.5	1.5
Test	1/10 Nor.	1/10 Nor.	1/10 Nor.
Recorder Chart Speed (mm per hour)	3600	3600	3600
Type of Pins	Ceramic	Ceramic	Ceramic
Contact Angle	560°	560°	560°



Rothschild Four-Channel Recorder Bergischer "Field Mill"

Figure 7. Bergischer Rotating Electrostatic Field Strength Measuring Instrument with Rothschild Four-Channel Recorder

build-up. The Field Mill was mounted on the Shirley[R] card (see Figure 8) during miniature processing and on the Saco-Lowell card during conventional processing. Several authors (51,52) have measured static on a card web on another moving system in textile processing in a similar manner with a Field Mill.

In measuring electrostatic charge build-up, problems arise when attempting to report results in well-defined, absolute units that would make the results comparable with those of other investigators (53). Even if the results are well-defined units, a comparison with other data may be meaningless unless sufficient geometrical and electrical data describing the experimental arrangement and instrument characteristics are given.

One of the primary problems in making dynamic measurement of a varying field strength (volts per meter) is the effect of time. One method for resolving this problem is to use a special type chopper electrode (see Figure 9) or "field mill" (54). In this instrument the electrostatic field, formed between the charged material and stationary sensing electrode, is chopped or "milled" by a grounded rotating shield; hence, the name "field mill".

Gayler (55) discusses the measuring of electrostatic charge build-up by several different instruments and principles and the problems encountered in making this measurement. He concludes that the "field mill" is the only really accurate and reliable system for induction measurements carried out over an extended period of time; also that the "field mill" is the most convenient and accurate instrument.

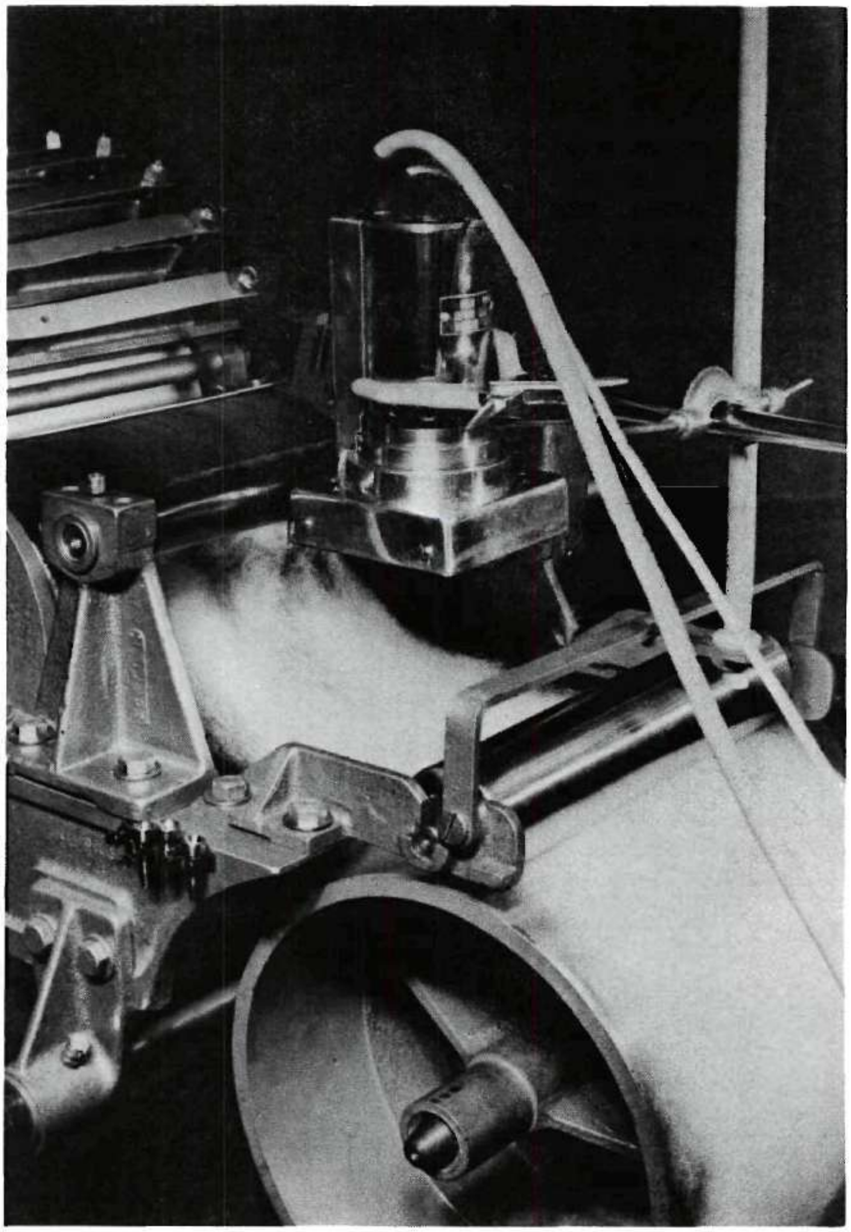


Figure 8. Bergischer "Field Mill" Measuring Head Mounted on the Shirley[R] Card

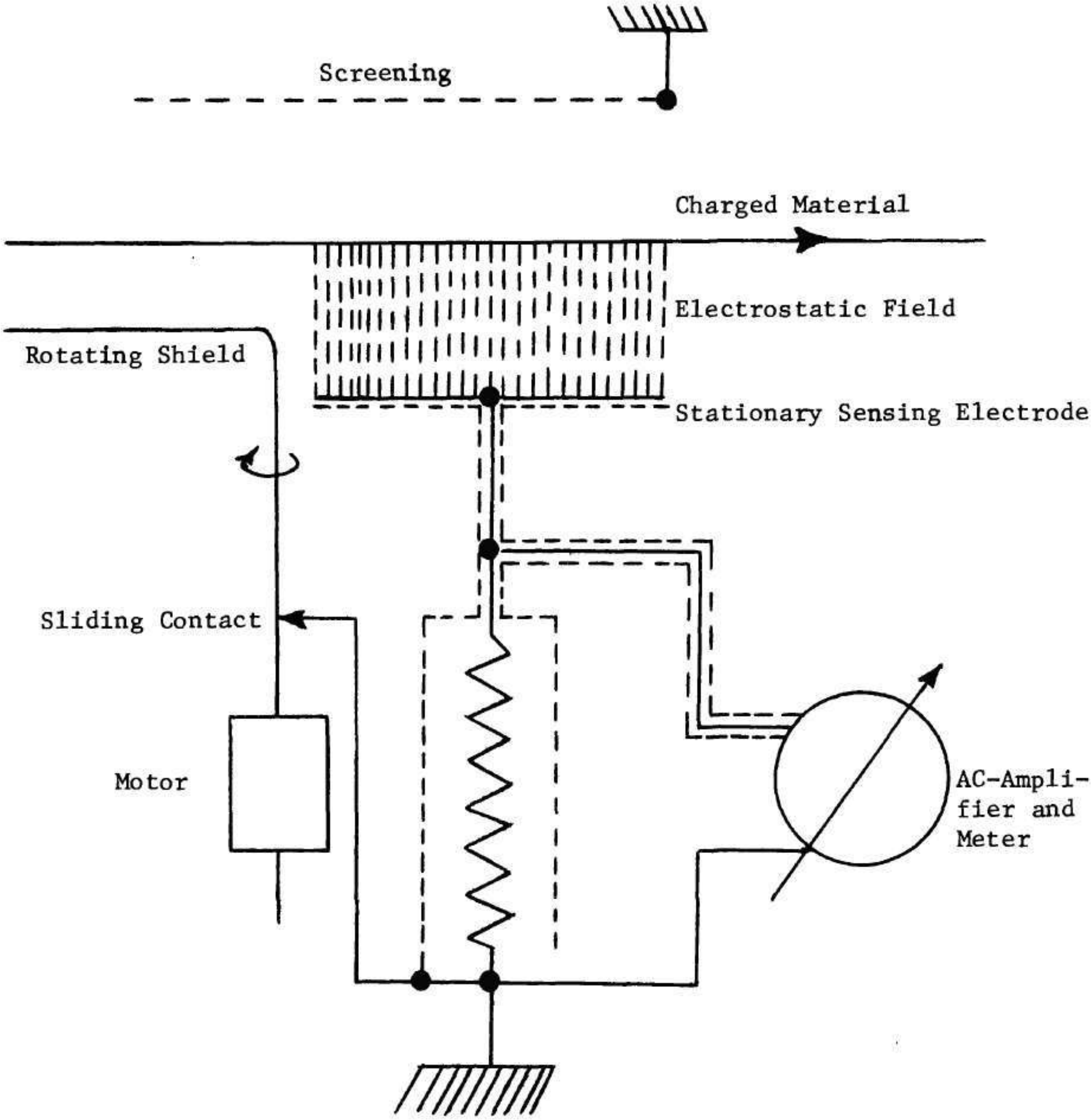


Figure 9. Inductive Measuring Principle
using a Chopper Type Electrode (54)

The Uster Automatic Single-End Tester

This instrument, developed by Zellweger Limited, has been designed to make a series of tests on any one package automatically. The apparatus totals the individual elongation and strengths, records the number of tests performed, and provides a graphic picture of the strength distribution (56).

The Uster automatic tester uses the inclined plane principle of loading, in which the tension on the specimen increases proportionately with time. With this instrument the rate of loading can be set so that the maximum load is reached in from 10 to 90 seconds with a gauge length of 20 inches. Operating data for this tester are found in Table 13.

The Uster Evenness Tester

This instrument, manufactured by the Zellweger Company, operates on the principle that a change in the mass of the dielectric (non-conducting material) in the condenser will change the capacitance. The measuring comb or slot of the tester is a set of condensers with an air dielectric. When some material (e.g., yarn) other than air is placed between the plates of one of the condensers, the capacitance is changed in proportion to the mass of that material. As the mass of the material changes, the capacity of the condenser changes in proportion. Thus, the Uster Evenness Tester, with its integrator and imperfection indicator, can determine the irregularity of the weight per unit length in a textile material from this change in capacitance (57). Table 14 lists the operating data for the Uster Evenness Tester.

Shadowgraph

The shadowgraph is a direct reading scale for weighing yarn skeins.

Table 13. Operating Data for Uster Automatic Single-End Tester

Material Tested	Full-Scale Yarn	Shirley[R] Yarn
Number of Bobbins per Sample	20	20
Number of Breaks per Bobbin	50	50
Number of Breaks per yarn sample	1000	1000
Automatic Tester:		
Pre-Test Tension Setting	5	5
Test Gauge Length	20"	20"
Loading Time to Break (Seconds)	10 ± 3	10 ± 3
Time to Complete Cycle (Seconds)	20 ± 3	20 ± 3
Range of Breaking Load (Grams)	1000	1000
Range of Elongation (Per Cent)	40	40
Machine Constants:		
e Value (Elongation)	0.4	0.4
K Value (Breaking Strength)	2.1	2.1

Table 14. Operating Data for Uster Evenness Tester

Material Tested	Full-Scale Yarn	Shirley[R] Yarn
Number of Bobbins for Sample	20	20
Number of Integrator Readings per Bobbin	10	10
Number of Readings per Yarn Sample	200	200
Evenness Tester:		
Length of Test (Minutes)	5	5
Material Speed (yd./min.)	50	50
Yards Tested per Bobbin	250	250
Type of Test	Normal	Normal
Integrator Reading (Per Cent)	C.V.	C.V.
Comb Slot	6	7
Range of Scale (Per Cent)	± 100	± 100
Low Places Setting	-30%	-30%
Thick Places Setting	#4	#4
Neps Setting	#4	#4

This instrument can be calibrated in order to determine yarn number, weight, or both of a standard yarn skein. It was used to determine the count of each bobbin used in this research.

Suter Twist Tester

This twist tester is a rather simple instrument composed primarily of two jaws, one rotatable and the other stationary. The sample of yarn is placed between the two jaws, and the twist is removed by rotating one jaw. A counter records the number of revolutions, the number of revolutions is then divided by the gauge length of ten inches to derive the twists per inch in the yarn.

Performance Rating

In this method of testing, a visual observation is made of the response to processing of the fiber during each of the manufacturing steps. A rating of one indicates no deviation from normal processing, and a rating of four indicates excessive trouble. Thus, performance rating is a qualitative measurement of the performance of the fiber through each processing procedure. An example of a performance rating form is shown in Table 15.

Blue M Power-O-Matic Electric Oven

The electric oven was used to heat-set or stabilize the twist in all of the bobbins of yarn. Since the glass transition temperature of Zefkrome^{R} is 104°C (58), the yarns were allowed to heat-set for one hour at 110°C in order that the molecules could become fixed resulting in a dimensionally stable yarn.

Table 15. Example of a Performance Rating Form

Exp #__________ Denier __________ Author __________ R.H.% __________

Specimen #______ Length __________ Date __________ Temp F° ________

Finish ______________________ Amount Used ______

Rating	CARDING
1 2 3 4	Fly:
1 2 3 4	Neps:
1 2 3 4	Loading:
1 2 3 4	Web Cohesion:
1 2 3 4	Static:
1 2 3 4	Web Evenness:
1 2 3 4	Other:
Processing Grade 1 2 3 4	
	DRAWING
1 2 3 4	Fly:
1 2 3 4	Lapping:
1 2 3 4	Licking:
1 2 3 4	Static:
1 2 3 4	Drafting:
1 2 3 4	Sliver Evenness:
1 2 3 4	Other:
Processing Grade 1 2 3 4	General Comments:

CHAPTER III

EXPERIMENTAL PROCEDURE

Full-Scale Textile Processing

Seventy-five pounds of Zefkrome[R] acrylic fiber were selected at random from the bale which had been stored at constant temperature and humidity in the A. French Textile School building, Georgia Institute of Technology. These fibers were processed through the sequence of operations shown in Figure 10 on the conventional equipment described in Chapter II. Operational data for these processes are reported also in that chapter.

The resulting picker lap was placed on a Saco-Lowell Lap Meter, and ten one-yard samples were cut and weighed. The average weight was 10.55 ounces per yard. This lap was produced in a laboratory with relative humidity of 54 per cent and a temperature of 71 degrees F.

The picker lap was placed on the Saco-Lowell card and processed into 45-grain sliver. The card was allowed to run for approximately 15 minutes without feeding any stock in order to remove as much foreign matter as possible. The first and last cans of sliver were discarded because the sliver weights were low. Twenty cans of sliver were produced at a relative humidity of 55 per cent and 72 degrees F. temperature.

The card sliver was then processed through a breaker drawing and a finisher drawing. Thirteen cans of 55-grain finisher drawing sliver were prepared. As in the carding process, each can of sliver was

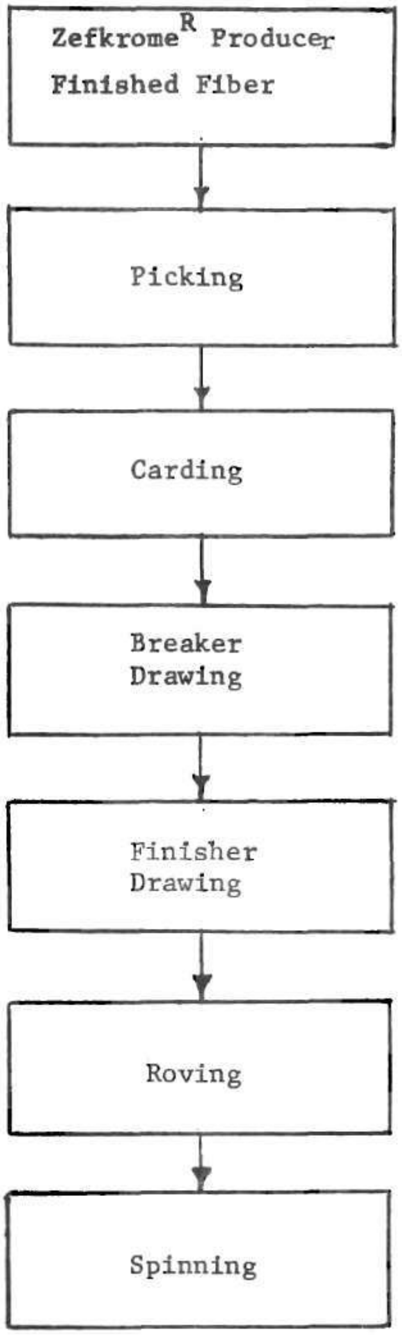


Figure 10. Sequence of Operations for Full-Scale Processing

checked to determine sliver weight per yard. The drawing sliver was made in a laboratory at 55 per cent relative humidity and 71 degrees F.

The cans of finisher drawing sliver were creeled into the roving frame. From these thirteen cans, twenty-six 14 x 7 packages of roving were produced. This 1.0 hank roving was manufactured at 72 degrees F and 54 per cent relative humidity.

The twenty-six packages of roving were spun into yarn on twenty-six spindles of the Saco-Lowell spinning frame under the same conditions as the roving. As with the roving, each bobbin of material was tested to determine the yarn count and twist per inch (see Table 20 in appendix).

During each of the full-scale processing procedures, a performance rating was assigned. The overall performance rating of each process was considered to be excellent.

Shirley[R] Miniature Spinning Plant Processing

Five pounds of Zefkrome[R] fiber were selected at random from the bale. Due to the high bulk characteristic of the fiber, a specimen size of only 20 grams was used. The fibers were processed through the sequence of operations shown in Figure 11 on the Shirley[R] equipment described in Chapter II. The operational data for these processes are presented in that chapter. All processing was at 54 per cent relative humidity and 72 degrees F.

The 20 grams of stock were placed on the feed apron of the card and opened by hand. The opened fiber was spread out over approximately 20 inches of the apron. The individual fibers, upon processing through the card, were converted into a fleece on the drum. This fleece was cut

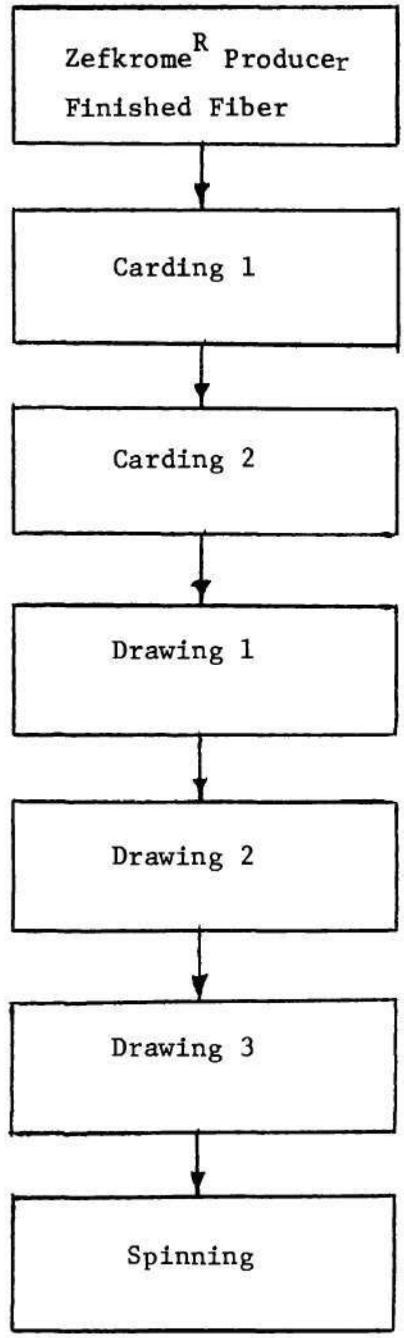


Figure 11. Sequence of Operations for Shirley^R Processing

across its width and placed on the card's feed apron. The fleece was divided into approximately four equal parts which were stacked and fed into the card a second time.

The flats, cylinder wire, trash tray under the lickerin, and the plain cylinder undercasing were cleaned after each passage.

Upon completion of the second passage, the drum carrying the fleece was transferred to the drawframe. The fleece was cut across its width and fed into the back rolls in such a manner that the fibers were drafted in the same direction as in conventional processing. The first passage utilized the 5/32 inch diameter Shirley[R] adapter in the web trumpet. The traverse gear lever was placed in the No. 10 position in order to obtain ten complete coils on the delivery drum.

For the second passage, the delivery or take-up drum was placed, without turning it around, in the creel of the drawframe (this ensures that in the next passage the direction of the fibers will be reversed as in conventional processing). The adapter in the web trumpet was changed to the 4/32 inch size, and the traverse gear lever moved to the position marked 20. Then every alternate coil of sliver on the drum in the creel was broken or cut. The resulting five coils were fed from beneath the drum into the back rolls for the second passage, after placing a new delivery drum in position.

The delivery drum, containing 20 coils of sliver from the second drawing, was transferred to the creel. The sliver on this drum was trimmed to 10 complete coils for the third passage by cutting every alternate coil along a straight line. The adapter was changed to the 3/32 inch diameter size, but the traverse gear lever was left in the No. 20

position. The 10 alternate coils were fed into the back rolls, and the third passage was run. Twenty coils of sliver were again produced and transferred to the creel of the spinning frame.

Each drum of sliver fed four spindles of the spinning frame so that every fifth coil had to be trimmed to give four ends of sliver, each five coils in length. Two drums were required to operate the eight spindles. A drum intended for feeding the four spindles to the right of the spinning frame had to be placed with the spigot end of the drum to the left in the take-up position on the drawframe. A drum intended to feed the four left hand spindles had to be placed in the take-up position with the spigot end at the right hand side. Then, the drums could be positioned on the spinning frame with the spigotted ends to the outside and the free end of the sliver feeding from the top right hand side of each drum.

The above procedure was carried out until the five-pounds of fiber had been spun onto 20 miniature spinning bobbins. Each bobbin was tested for twist and yarn number (see Table 20 in Appendix). As in full-scale processing, a performance rating was made by the author on each of the manufacturing operations. The overall performance rating of each process was considered excellent.

Physical Tests

Each of the 20 bobbins of yarn from the two different manufacturing operations was heat-set for one hour at 110°C. The bobbins were then removed and allowed to condition for 24 hours in the Physical Testing Laboratory of the A. French Textile School. The laboratory maintained standard conditions of 70°F temperature and 65 per cent relative humidity. Breaking strength, elongation, and yarn evenness measurements were conducted in this laboratory. Standard test procedures set by the American Society of Testing Materials (59) were followed in each of these measurements.

Tests for Evenness

The Uster Evenness Tester and auxiliary equipment were used in determining the per cent coefficient of variation of the yarns. The total set-up included the evenness tester, a quadratic integrator, and an imperfection counter. The data obtained are presented in Tables 25 and 26.

Evenness tests were conducted in the following manner. The integrator was cleared for 30 seconds to remove any data stored in the memory from past tests. By moving the lever, the memory of the integrator was activated to permit storage of the data from the yarn being drawn through the measuring comb. The memory had a one-minute capacity, and the first reading was obtained one minute after memory activation. The readings were taken every half minute thereafter until the total numbered ten. The standard deviation of the yarn diameter, expressed as a per cent of the average or per cent coefficient of variation (% C.V.), was obtained from the quadratic integrator. Operating data are listed in Table 14.

In conjunction with the evenness test, the yarn was examined with the imperfection counter for a period of five minutes. The imperfection indicator registered an actual count of the neps in the yarn as it passed through the measuring slots during the period of evaluation.

Measurements of Breaking Strength and Elongation

The Uster Automatic Single-End Tester was used to measure the elongation and breaking strength of the yarn from each bobbin. The inclined plane principle gives the constant rate of loading condition utilized in this tester. Operation data can be found in Table 13.

The yarn was automatically loaded and broken, and data was recorded on cumulative sum counters for breaking strength and elongation. Readings from the counters were evaluated using the formulas in the instruction manual for the tester. The average elongation was computed from:

$$E \text{ in per cent} = \frac{S \times 10}{n} + e$$

where: E = Elongation in per cent

S = Total of the Elongations

e = 0.4 (machine constant)

n = Number of breaks made

The average breaking strength was calculated from:

$$P_t \text{ in per cent} = \frac{S_p \times 10}{n} + K$$

where: P_t = Breaking strength in per cent

S_p = Total of breaking strengths

K = 2.1 (machine constant)

n = Number of breaks made

$$P \text{ in grams} = \frac{P_t \times M}{100}$$

where: P = Breaking strength in grams

P_t = Breaking strength in per cent

M = Weight used in machine.

The data are recorded in Tables 27 and 28.

The frequency distribution of the breaking strength was also obtained from the instrument. During the measurements, a small steel ball was deposited into the appropriate slot corresponding to the breaking strength of each specimen. At the end of a series of measurements, the balls formed the frequency distribution which was then recorded. (See Figures 25 and 26 in Appendix.)

Measurements of Fiber-to-Fiber Friction

Samples of yarn from full-scale processing and from Shirley[R] processing plus two Zefkrome[R] fiber samples, one as it came from the bale with the producer finish and one with finish extracted, were examined for frictional properties*. Operating data are shown in Table 11. The measurements were performed under normal conditions with relative humidity usually 50-54 per cent and the temperature 71-75°F. These measurements are shown in Tables 21 and 22.

The resultant data in the form of frictional graphs from the XY plotter were analyzed. By using planimeter integration, the area under each curve was calculated. Dividing this quantity by the length of the base line over which integration was performed gave the average deflection of the plotter pen:

$$\overline{H} = \frac{(A)\ (2.54)^2}{(2L)}$$

where: $\overline{H}$ = average deflection in cm

A = area under curve (planimeter reading) in square inches

---

*With the assistance of Mr. J.C. Meaders of the Engineering Experiment Station of Georgia Institute of Technology.

2.54 = number of cm per inch

L = length of integrated portion of graph in cm

The coefficient of kinetic friction was obtained by using the following expression:

$$\mu_k = \frac{\text{Friction Force}}{N_f} = \frac{\overline{H}\ (1.87)}{N_f}$$

where: μ_k = Kinetic coefficient of friction

1.87 = Conversion factor in mg per cm for the scale. (Obtained from calibration of instrument.)

$\overline{H}$ = Average deflection in cm

N_f = Average normal force in mg (Measured before and after each test and numerical mean obtained.)

A coefficient of static friction was obtained also by using the average height of the ten highest peaks of the frictional trace. This coefficient was computed by using the following formula:

$$\mu_s = \frac{\text{Friction Force}}{N_f} = \frac{H_{max}\ (1.87)}{N_f}$$

where: μ_s = Static coefficient of friction

H_{max} = Average height of ten highest peaks in cm

N_f = Average normal force in mg

1.87 = conversion factor in mg. per cm.

Another item of interest was determined from the stick-slip traces--the ratio of the coefficient of static friction to the coefficient of kinetic friction (μ_s/μ_k). This value appears to be characteristic of a fiber material and configuration. Changes in it occur when changes occur in the fiber surface or configuration as may result from processing damage.

The XY plot produced for a specific fiber has a characteristic form specific to fiber material and its configuration. This character may be observed for a fiber after a series of more than ten repeated runs. This character change should be useful in the evaluation of fiber finishes or coating materials (60).

Tests for Yarn-to-Guide Friction

Each of the bobbins of yarn was tested on the Rothschild F-Meter to determine the amount of friction developed by running the yarn over a pair of one-quarter inch diameter ceramic pins at a wrap angle of 560° (see Figures 10, 11, 12). The value of the coefficient of friction μ was recorded continuously on the recorder during the entire test. Operating data can be found in Table 10. The tests were conducted at 40 per cent relative humidity and 72°F. temperature.

The results of measuring the friction in 250 feet of each sample were calculated from the charts obtained from the recorder. The area under each curve was measured by using a planimeter. The average deflection ($\overline{H}$) of the needle was converted to scale reading of μ from 0 to 1 on the chart paper which is 5.5 inches wide (see Figure 20). The coefficient of friction μ was computed from the following equations:

$$\overline{H} = \frac{(A)\ (2.54)^2}{L}$$

where: $\overline{H}$ = Average deflection in cm

A = Area under curve (Planimeter reading) in square inches

L = Length of base line in cm

$$\mu = \frac{\overline{H}}{5.5}$$

where: μ = Coefficient of friction

$\overline{H}$ = Average deflection in cm

5.5 is conversion factor (based on height of the chart).

The results of these measurements can be seen in Tables 23 and 24.

Measurements of Electrostatic Change Accumulation During Carding

The Bergischer Rotating "Field Mill" was used to determine the amount of charge accumulation on the card web. A continuous plot of the charge build-up was recorded on the four-channel recorder with chart speed of 1200 mm. per hour. The measuring head was mounted vertically at a point ten cm. above the web surface (see Figure 8) and 2 cm. from the doffer comb. Tests were conducted on the full-scale card and on the Shirley[R] miniature card at 55 per cent humidity and 72°F temperature.

The areas beneath each of the graphs from the recorder were determined by use of a planimeter. Dividing this quantity by the length of the base line at zero gave the average deflection of the needle. This reading was converted to scale readings. The static field strength in volts per meter (V/M) was obtained from the scale readings as follows:

$$\overline{H} = \frac{(A)\ (2.54)^2}{L}$$

where: H = Average deflection in cm

A = Area under curve (planimeter reading) in square inches

L = Length of base line in cm

$$2.54 = \text{conversion factor (cm/in)}.$$

(a) For scales with increments of three K

$$\frac{\overline{H}}{2.75/3} = \text{Scale reading (SR)}$$

$$SR \times 10^2 = \text{Field Strength (FS)}$$

(b) For scales with increments of one K

$$\frac{\overline{H}}{0.275} = SR$$

$$SR \times 10^2 = FS$$

Scales	V/M Magnitude (FS)
0.3K	0-300
1K	0-1000
3K	$0\text{-}3 \times 10^3$
10K	$0\text{-}10 \times 10^3$
⋮	
3M	$0\text{-}3 \times 10^6$

The data are shown in Table 16.

Microscopy Work

Yarns from both systems were submitted to Mr. J.L. Hubbard of the Engineering Experiment Station, Georgia Institute of Technology.

Fibers from these yarns were examined by use of the microscope to detect damage to the surface of the fiber. Fiber defects per centimeter were counted during examination of the fiber.

Also, end breaks from yarn broken on the Uster Automatic Single-End Tester were examined with the microscope to determine if there was any difference in the appearance of the yarns at the point where the break occurred.

Finish Application to Fiber (Staple)

Each of the finishes indicated in Table 1 was applied as a solution to 40-grams of scoured Zefkrome fiber. To obtain the desired results, 0.25 per cent on the weight of the fiber (owf) of the finish was weighed out and diluted to 120 ml. (2.285×10^{-3} moles/liter) with distilled water (61). This solution was just enough to completely saturate the 40-gram fiber sample. The fibers, after saturation, were air-dried at 70°F and 65 per cent relative humidity for four days to obtain condition of equilibrium, then moved to and conditioned 24 hours in the 70°F, 40 per cent relative humidity laboratory where they were tested.

Shirley^R Processing of Finish-Treated Fibers

Each of the 40-gram fiber samples was spun into yarn on the Shirley equipment following the procedure set forth earlier in this chapter except for the atmospheric conditions. Spinning was performed at 40 per cent relative humidity and 70°F temperature in order to accentuate the electrostatic charge accumulation.

Physical Testing

Measurements of the finish-treated fibers were performed as follows:

1. Electrostatic charge build-up during carding
2. Performance rating
3. Fiber-to-fiber friction
4. Yarn-to-guide friction

These measurements were conducted as described earlier in this chapter. From these data an evaluation of the Shirley[R] system as a screening aid was made. These data are presented in Table 19.

CHAPTER IV

DISCUSSION OF RESULTS

Analysis of Data

During this research several different parameters, considered to be important to the investigation of a miniature spinning system as a screening aid for spin finish components on polyacrylonitrile fibers, were measured. From these measurements an attempt was made to ascertain what correlations, if any, could be drawn between the miniature spinning system and the full-scale system as to its importance as a research tool for spin finishes. All of the data from these measurements should be considered not as absolute values but as comparative values.

These data were statistically evaluated to determine if the differences observed could be classified as being either significant or due to error.

"Student's" - t distribution factors were computed to determine at a 0.05 level of significance whether the observed difference between two means was significant or whether it could be attributed to chance or testing error (62). The test statistic formula becomes:

$$z = \frac{\left|\bar{x}_1 - \bar{x}_2\right|}{\sqrt{\frac{\sigma_1^2}{n_1-1} + \frac{\sigma_2^2}{n_2-2}}}$$

where: x_1 = Mean of Shirley[R] test result

x_2 = Mean of Full-Scale test result

σ_1^2 = Variance of Shirley^R test result

σ_2^2 = Variance of Full-Scale test result

n_1 = Sample size of Shirley^R test

n_2 = Sample size of Full-scale test

Z = Significant value

To correlate the data, coefficients of correlation were calculated by use of the following formula:

$$r = \frac{n\Sigma XY - (\Sigma X)\ (\Sigma Y)}{\sqrt{[n\Sigma x^2 - (\Sigma X)^2][n\Sigma Y^2 - (\Sigma Y)^2]}}$$

where: r = Correlation coefficient

n = Sample size

X = Mean for Shirley^R test result

Y = Mean for Full-Scale test result

Σ = Summation

Values for r vary from +1.0 to -1.0. For industrial data a coefficient of correlation, whether plus or minus, between 0.80 and 1.00 is considered as excellent, between 0.60 and 0.80 as good, between 0.30 and 0.60 as fair, and from 0 to 0.30 as of doubtful value (63).

Along with the correlation coefficients, the data comparing the two systems of yarn manufacturing were graphically plotted. A regression curve was calculated by use of the least squares method to determine the extent of the relationship between the two systems.

In this approach two conditions are satisfied for the regression line: the algebraic sum of distances of points from the line must be zero, and the sum of the squares of these deviations from the line must be a minimum (which in effect determines the line). This line has the equation of the general form Y = a + bx, assuming the relationship is linear (64).

The formulas for the regression line are:

$$\Sigma Y = an + b\ X$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2$$

$$Yc = a + bx$$

where:

- a = Intercept
- b = Slope of regression line
- n = Number of pairs of observations
- Yc = Calculated value of Y for any real value of X
- Y = Observation from Full-Scale test
- X = Observation from Shirley^R test

Correlation of Shirley^R Miniature Spinning Plant with Full-Scale Spinning Operation

Electrostatic Charge Build-up

It was found that no significant difference at 95 per cent confidence interval existed between the two different processes for the amount of electrostatic charge build-up (see Figure 12). This result, shown in Tables 16 and 18, was as expected since charge accumulation was more dependent on the fiber type, finish, humidity, and temperature (65). With these held constant, the carding processes in the two systems were so similar that no difference which might be caused by differences in the mechanical processing could be detected.

Fiber-to-Fiber Friction

A trend from the data could be seen which indicated that a

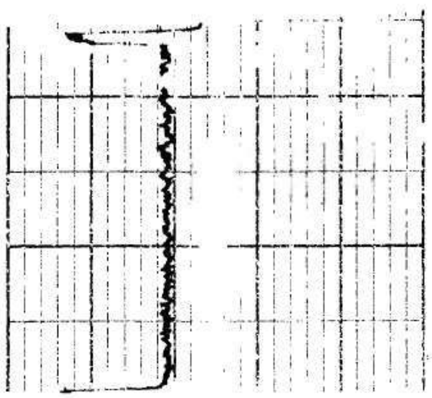


Chart from Shirley[R] Yarn

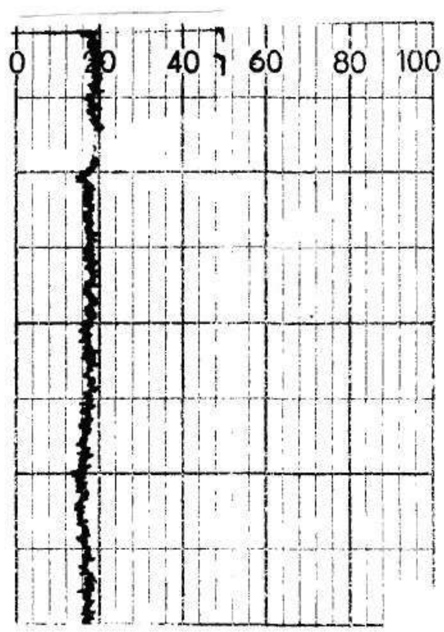


Chart from Full-Scale Yarn

Figure 12. Sample of Chart Plotted for Electrostatic Charge Build-Up on Fibers During Carding

Table 16. Mean Values of Yarn Properties Examined*

Parameter	Shirley^R Yarn	Full-Scale Yarn
Electrostatic Field Strength (V/M)	-255	-250
Yarn Breaking Strength (grams)	410.2	475.7
Yarn Elongation (per cent)	21.95	18.60
Yarn Evenness (per cent CV)	20.64	18.56
Neps (#/test)	4.75	1.70

*For detailed data see Tables 25, 26, 27, and 28 respectively.

difference in the fiber-to-fiber friction existed between the two systems. Although not enough data were compiled for a statistical evaluation (66), evidence for this conclusion was found not only from the large differences between the coefficients of friction of the two systems and the unprocessed fiber (see Tables 17 and 18), but also from the surface photographs taken of representative fibers from the yarn produced on the two systems.

As can be seen in Figure 13, the two yarns were apparently the same in appearance. But, when fibers were pulled from these yarns and compared, the full-scale fiber samples had more surface imperfections than the Shirley[R] samples and the unprocessed fibers as can clearly be seen in Figures 14, 15, and 16. These surface imperfections were fiber damage caused by the mechanical processing of the fibers. The more surface damage done to a fiber, the higher were the fiber-to-fiber coefficients of friction (66). Hence, a critical difference between the Shirley[R] system and the conventional textile operations was the more extensive fiber damage that occurred in the full-scale processing. The average defects for fibers from full-scale yarn was 11.8 per centimeter, 3.3 defects per centimeter for fibers spun on Shirley[R] system, and only 0.8 defects per centimeter for unprocessed fibers.

This difference can probably be explained by the fact that much more vigorous and rigorous processing occurred in full-scale operations (i.e., higher speeds, larger clothing in carding, etc.). Also, a difference may exist because the Shirley[R] system included no roving process as in conventional processing. No work has been done concerning fiber damage in roving so this can only be postulated. Typical

Table 17. Mean Frictional Values of Test Yarns and Unprocessed Zefkrome[R] Fiber

Parameter	Shirley[R] Yarn	Full-Scale Yarn	Zefkrome Unprocessed Fiber
Fiber-to-Fiber Friction*:			
Area (in.^{2})	5.15	5.41	8.20
$\overline{H}$ (cm)	1.80	1.89	2.84
μ_k	0.165	0.176	0.261
μ_s	0.394	0.451	0.570
$\overline{H}$max (cm)	4.25	4.85	6.35
μ_k/μ_s	2.36	2.64	2.22
Yarn-to-Guide Friction*:			
μ	0.208	0.235	----

*For detailed data see Tables 21, 22, 23, and 24 respectively.

Table 18. Statistical Data Obtained for Yarns Examined

Parameter	Significant Z(95% C.I.)	Actual Z	Mean Value and Standard Deviation for Shirley^{R} Yarn		Mean Value and Standard Deviation for Full-Scale Yarn		Correlation Coefficient
*Electrostatic Charge Build-up (V/M)	*	*	-2.55		-2.50		*
*Fiber-to-Fiber Friction:	*	*					*
μ_k			0.166		0.176		
μ_s			0.394		0.451		
μ_s/μ_k			236		2.63		
Yarn-to-Guide Friction (μ)	2.09	4.74	0.208	0.005	0.235	0.0010	0.924
Yarn Evenness (% CV)	2.09	6.71	20.64	0.88	18.56	1.02	0.961
Yarn Breaking Strength (grams)	2.09	4.71	410.2	23.13	475.7	18.55	0.927
Yarn Elongation (%)	2.09	2.56	21.95	0.734	18.60	1.06	0.873

*No statistical data available.

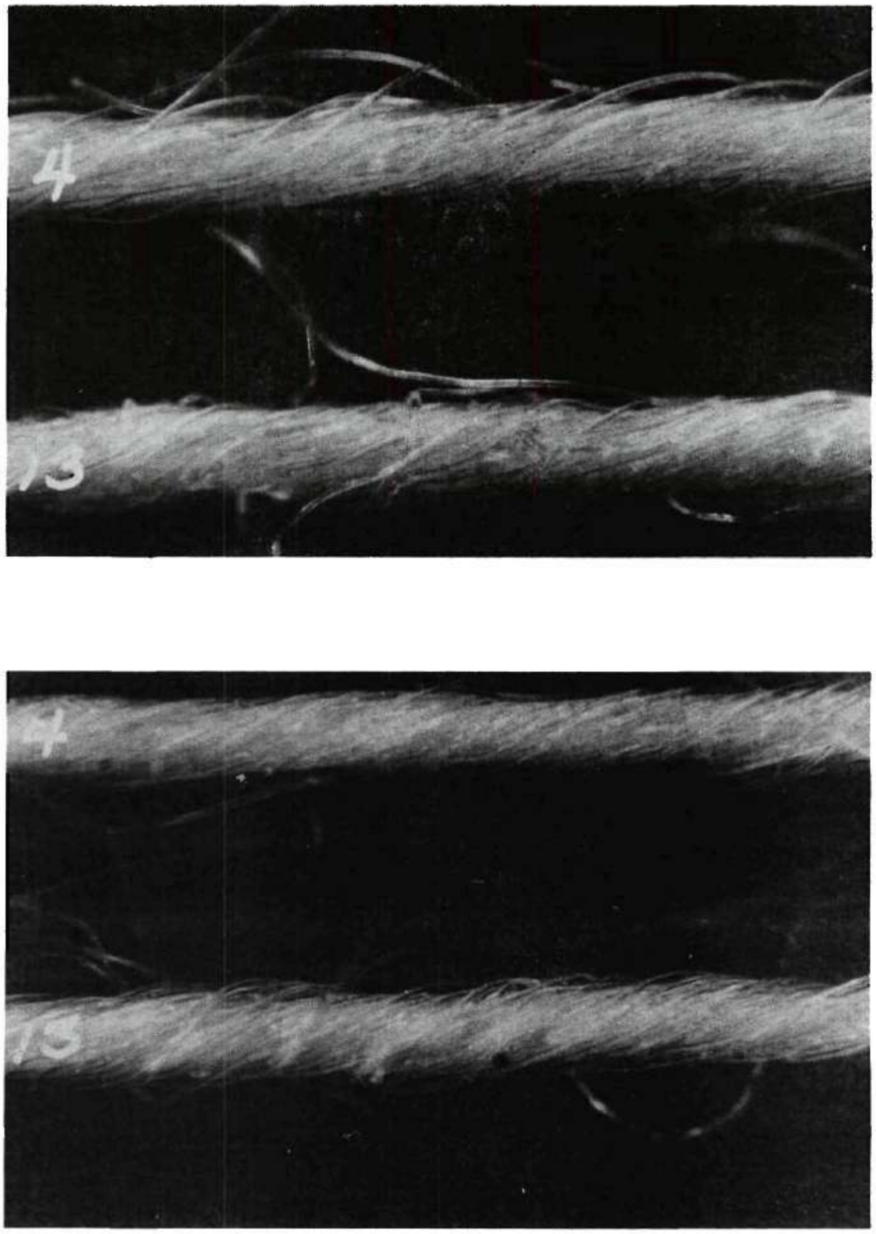


Figure 13. Photomicrograph(45X) Comparison of Appearance of Typical Yarns Spun on Shirley[R] System and on Full-Scale System (#4-Shirley; #13-Full-Scale)

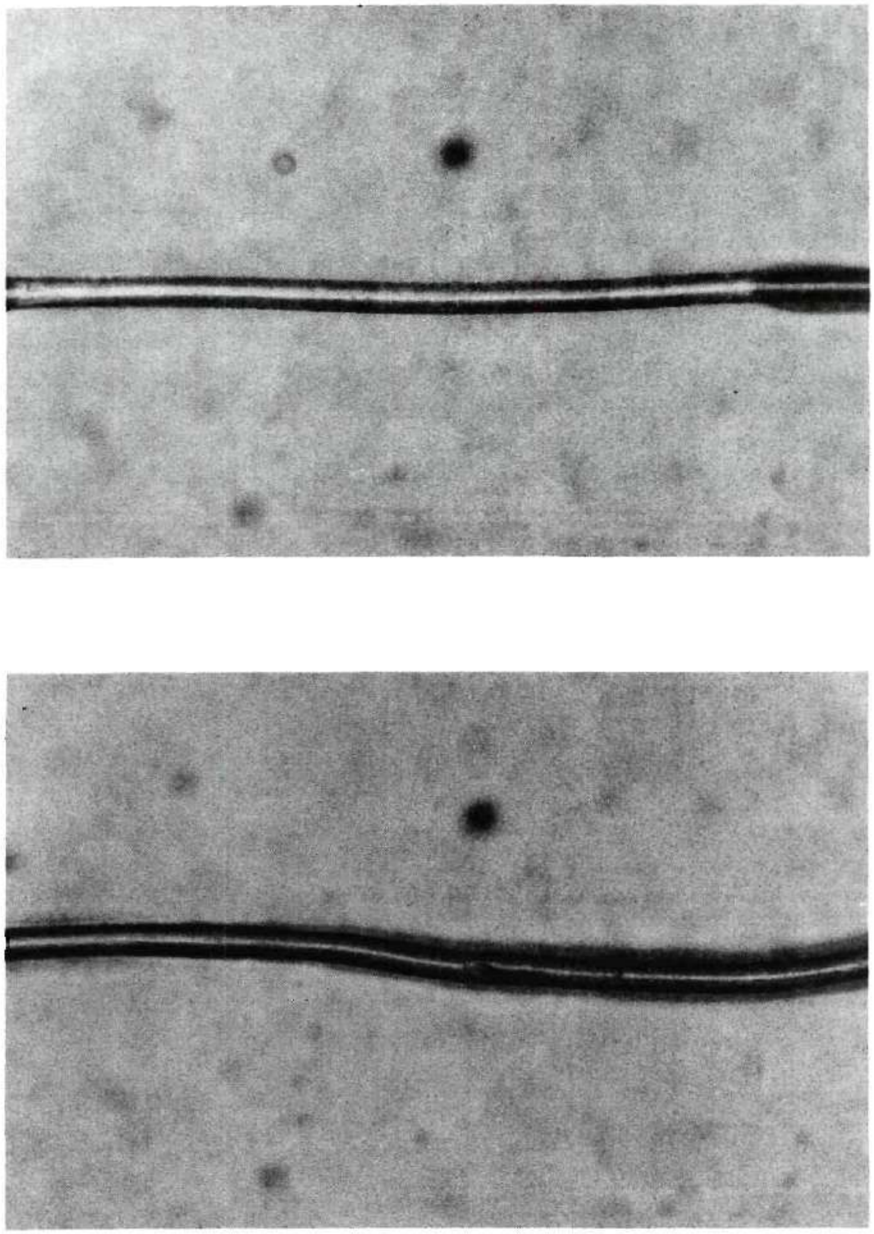


Figure 14. Photomicrograph(235X) of Unprocessed Zefkrome[R] Fibers

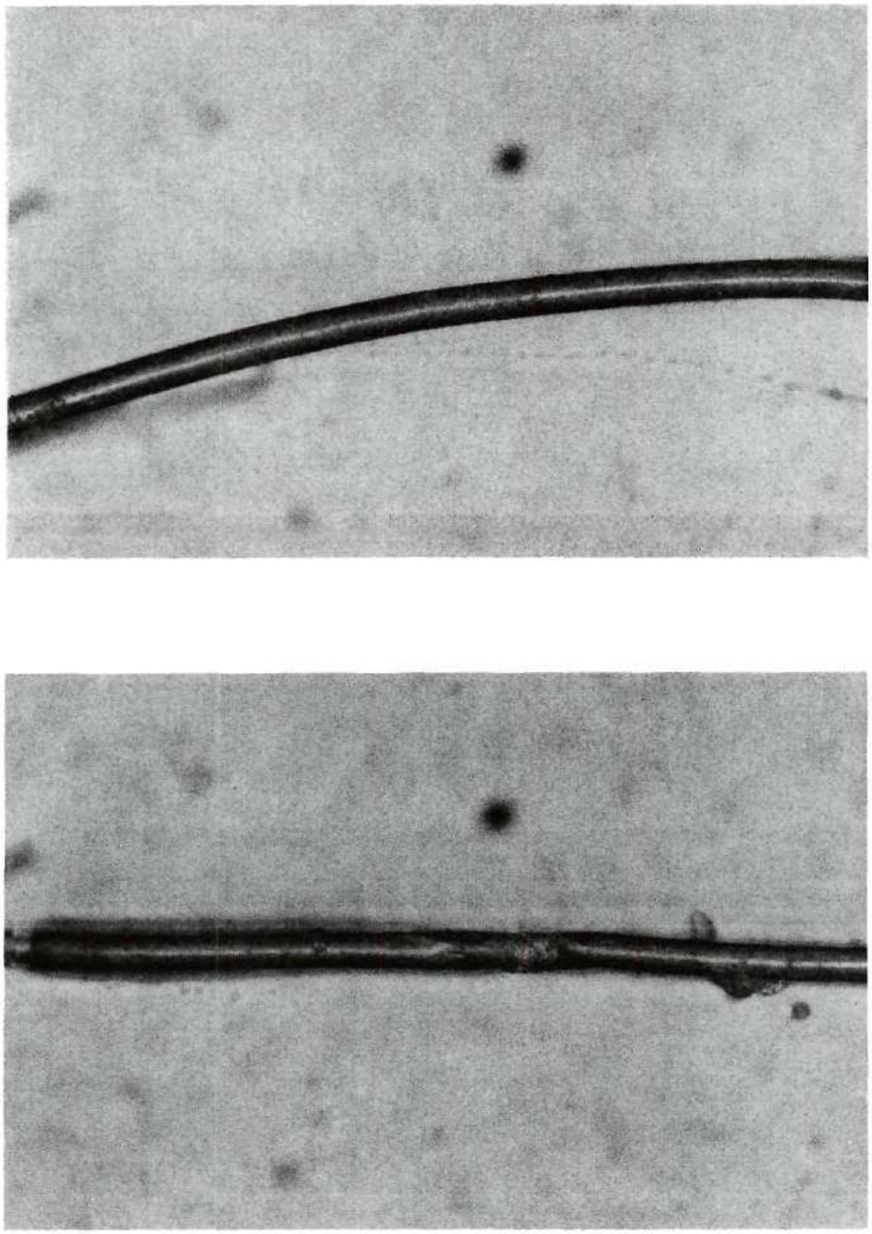


Figure 15. Photomicrograph(235X) of Fibers from Yarn Manufactured on Shirley^{R} System

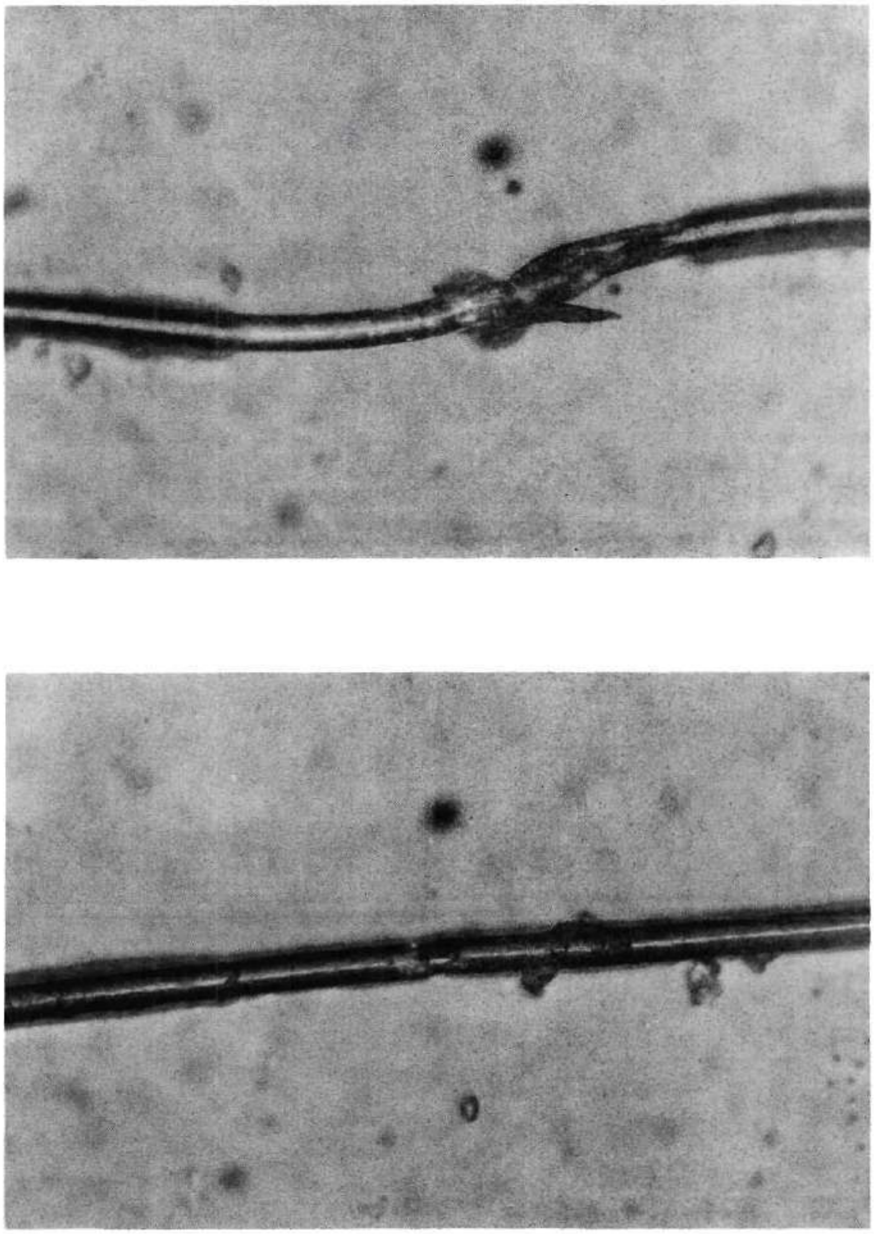


Figure 16. Photomicrograph(235X) of Fibers from Yarn Manufactured on Full-Scale System

fiber-to-fiber curves can be seen in Figures 17 and 18.

Yarn-to-Guide Friction

A significant difference at 95 per cent confidence level was found to exist between the results from the two systems for yarn-to-guide friction (see Table 18). It was found that when these data were plotted graphically and correlated (see Figure 19), a correlation coefficient of +0.924 existed. This is an excellent correlation. Typical yarn-to-guide curves for both systems appear in Figure 20.

The difference in yarn-to-guide friction may be related to the difference in fiber damage occurring in the two systems. A less damaged fiber in a yarn would have a smoother surface. This would enable it to slide more easily over the ceramic pins used in testing. Also, since the fibers were treated with a producer finish, the less damaged fiber would have more finish on its surface to provide lubricity.

Yarn Evenness

A significant difference was found with 95 per cent confidence interval between the evenness of the yarn produced on the two differing systems (see Table 18). As can be seen in Figure 21, when the data were plotted, a correlation factor of +0.961 was found. This correlation was excellent.

The evenness of the Shirley^{R} produced yarn was expected to be worse than that of the conventional yarn. This difference was no doubt due to the much more critical nature in spinning quantities of a few ounces rather than pounds. Also, more neps were produced on the Shirley^{R} system as expected from reports of the Shirley^{R} manufacturer (67).

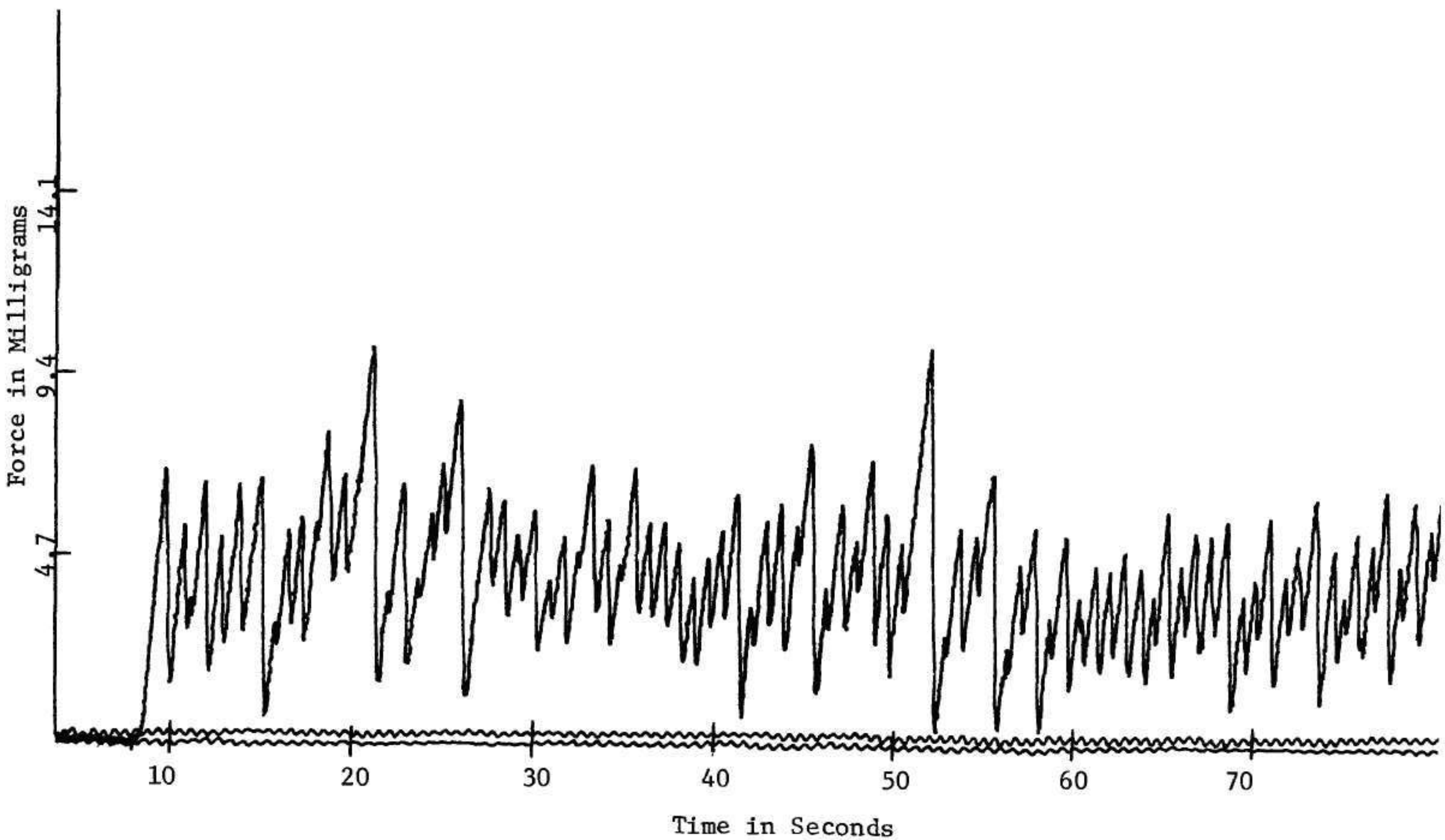


Figure 17. Typical Fiber-to-Fiber Frictional Data Plot for Fibers from Yarn Produced on Shirley^{R} System

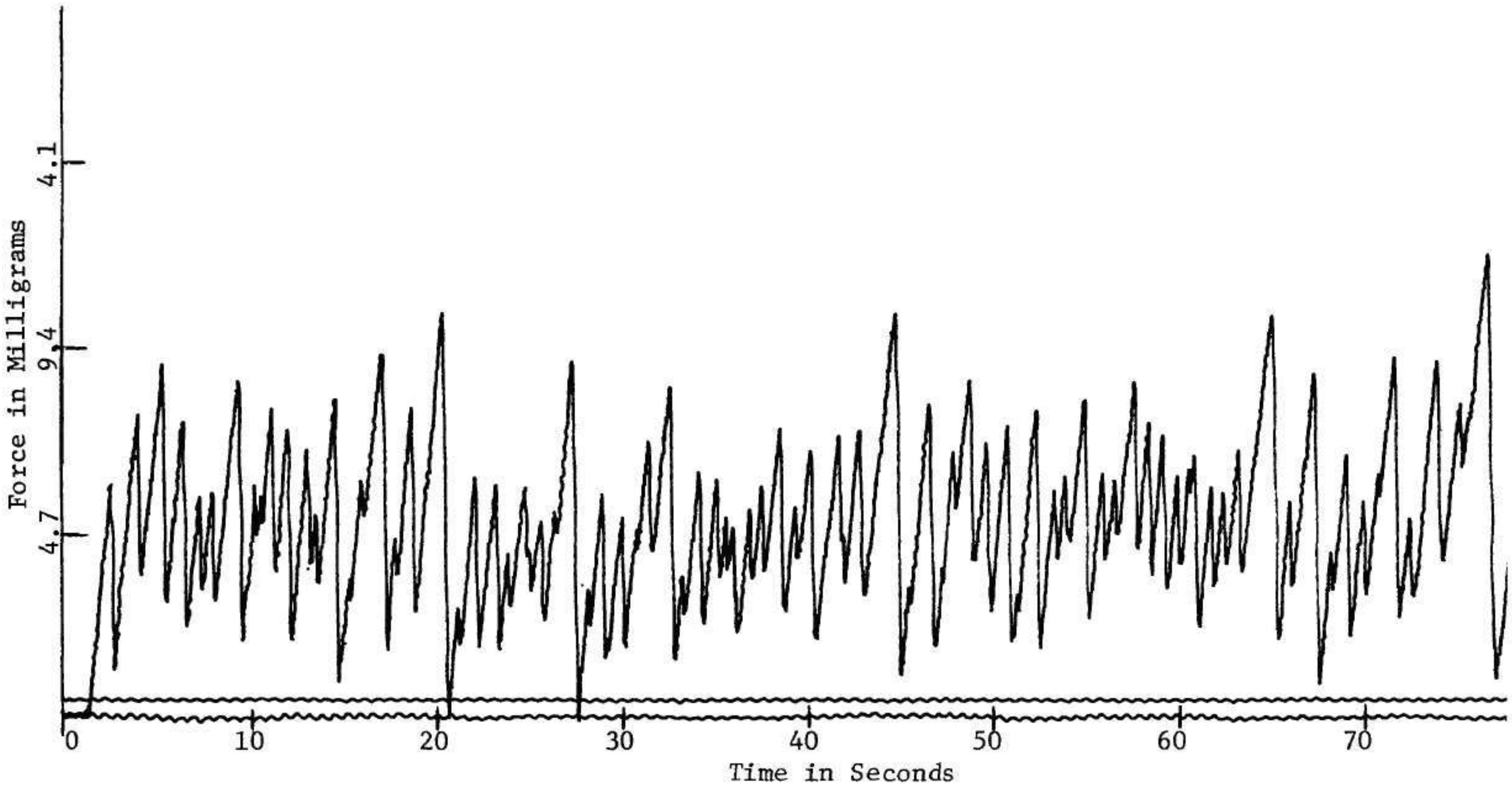


Figure 18. Typical Fiber-to-Fiber Frictional Data Plot for Fibers from Yarn Produced on Full-Scale Textile Equipment

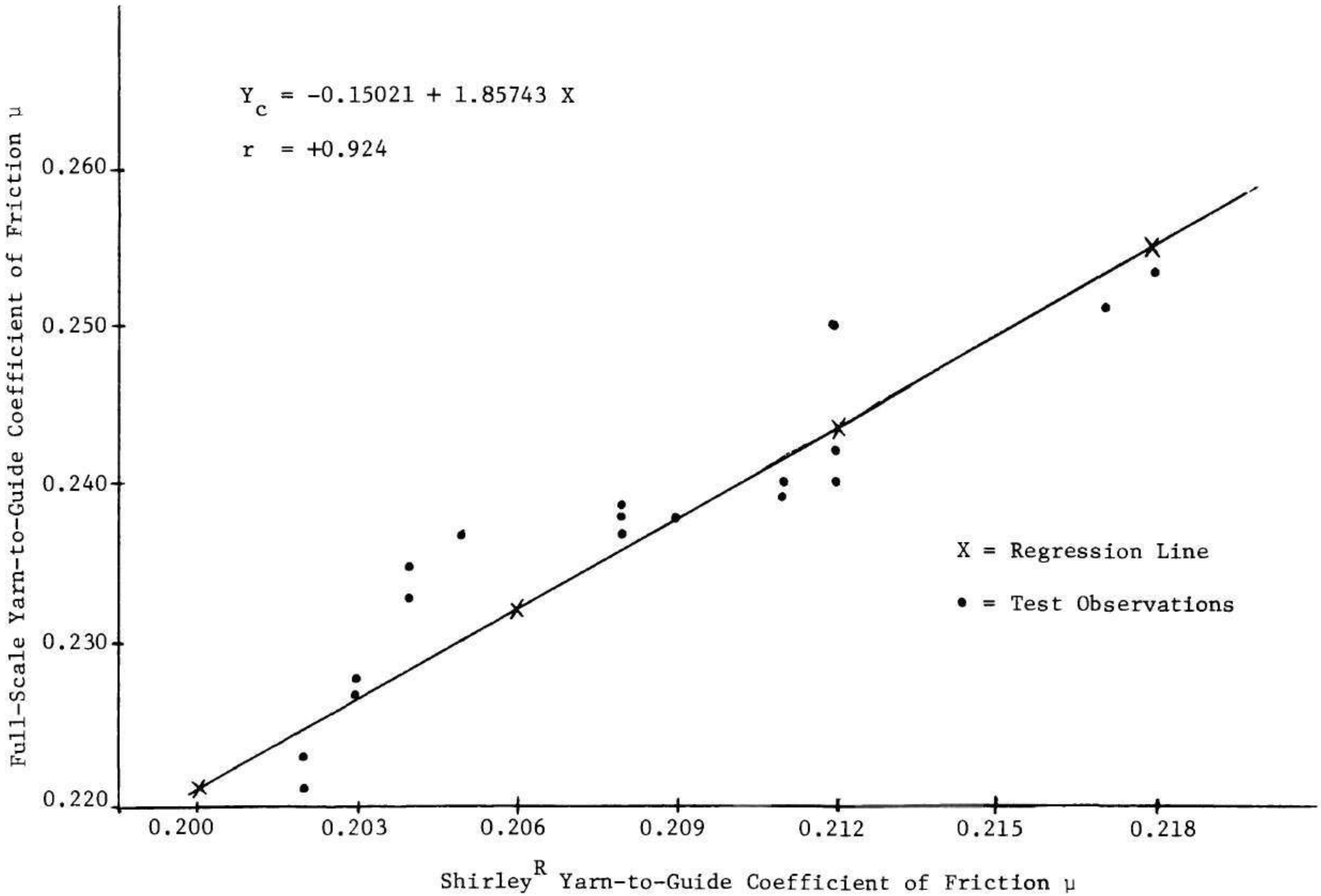


Figure 19. Shirley[R] Yarn-to-Guide Friction Data vs. Full-Scale Yarn-to-Guide Friction Data

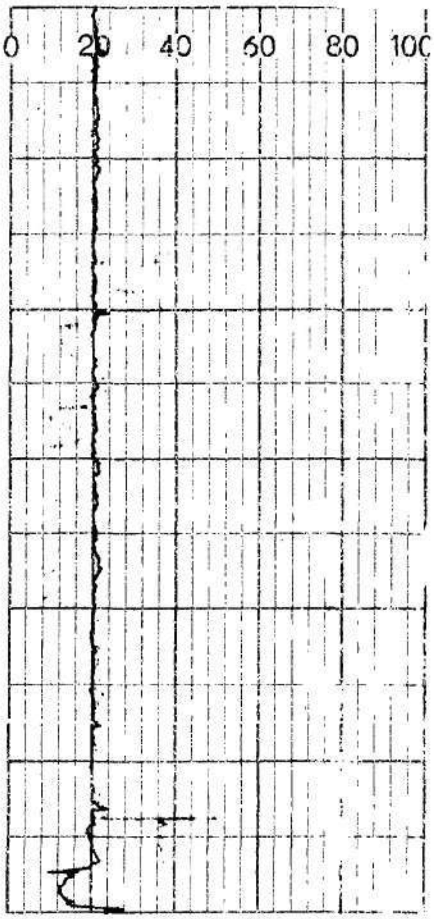


Chart for Shirley[R] Yarn

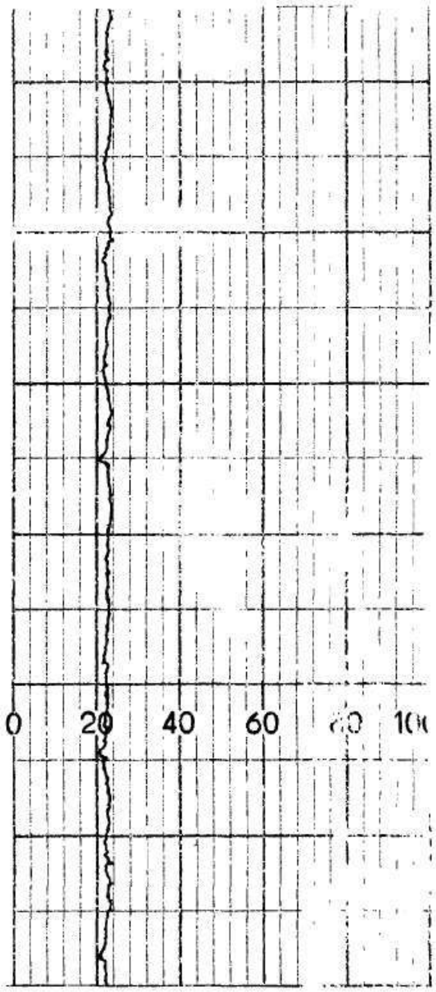


Chart for Full-Scale Yarn

Figure 20. Examples of Yarn-to-Guide Friction Chart for Yarns Spun on Full-Scale System and on Shirley[R] System

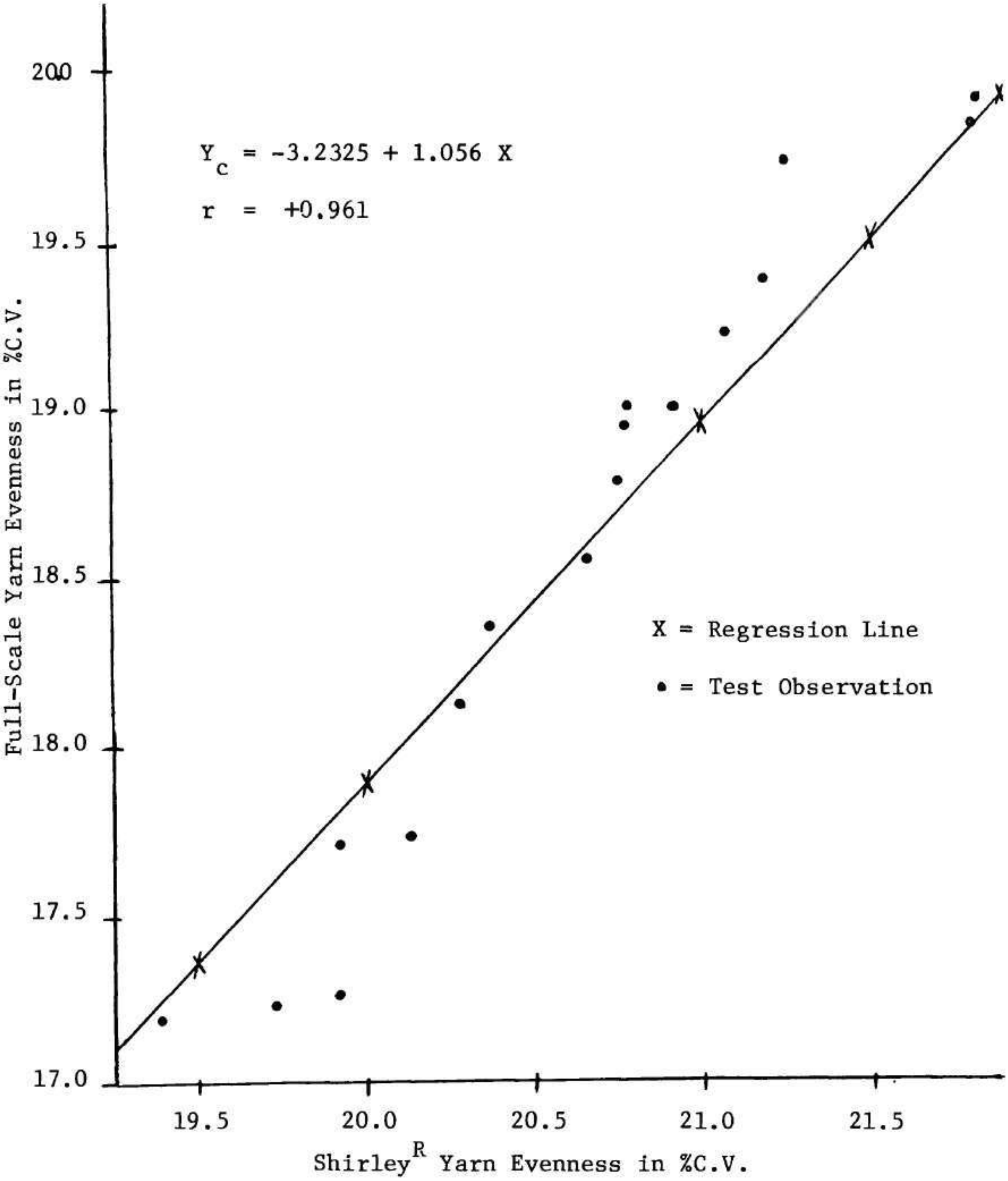


Figure 21. Shirley[R] Yarn Evenness Data vs. Full-Scale Yarn Evenness Data

Yarn Strength and Elongation

A significant difference with 95 per cent confidence interval between the elongations and strengths of the yarn produced on the conventional system and on the Shirley^R system (see Table 18) was found. A correlation coefficient of +0.873 was found for elongation which was considered excellent (see Figure 22). A coefficient of correlation of +0.927 was found for yarn strength (see Figure 23). This was an excellent correlation.

The yarn strength of the conventionally processed yarn was higher than the Shirley^R yarn whereas the elongation of Shirley^R yarn was higher than full-scale yarn. This was normal since elongation generally decreases with an increase in strength. The difference in strength and elongation of the two differing yarns may be attributed to the fact that there was less fiber damage to the Shirley^R yarn. With less fiber damage the fibers within the yarn may tend to slide over and past each other when placed under tension, thus causing the yarn to have greater elongation with corresponding lower strength. On the other hand, more damaged fibers in the conventional yarn may "lock" together due to these damaged places on the fiber surface (one might consider this similar to the Directional Frictional Effect caused by the scales on Wool fibers (68)). Therefore, due to the "locks" that may be formed, the fiber-to-fiber interlocking was higher, creating a stronger yarn.

As added evidence for this interpretation, Figure 24 compares a representative yarn end from each system after being broken on the Instron Automatic Single-End Tester. It can be seen that the Shirley^R yarn end has more frayed fiber ends than the conventional yarn. This

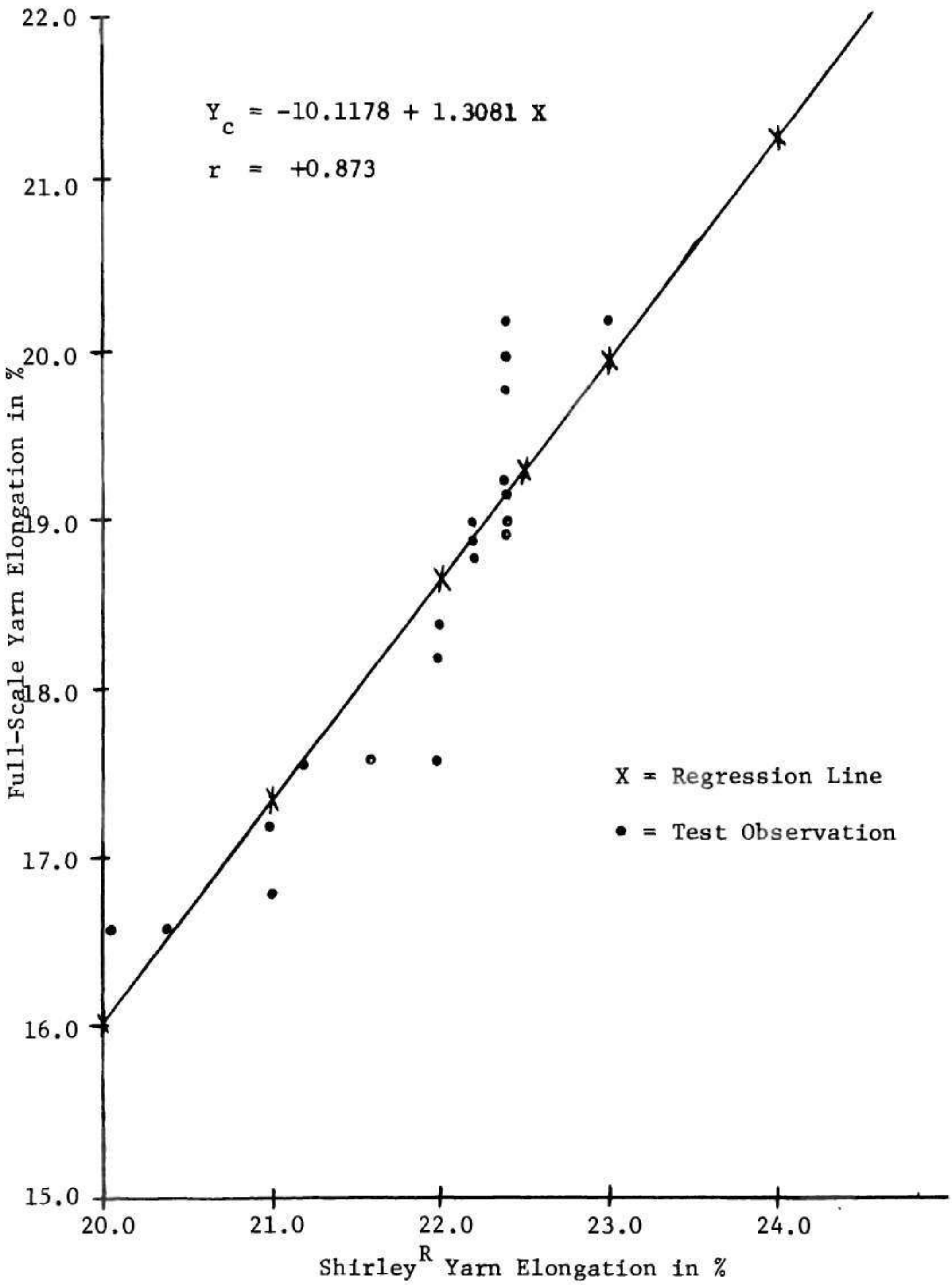


Figure 22. Shirley[R] Yarn Elongation Data vs. Full-Scale Yarn Elongation Data

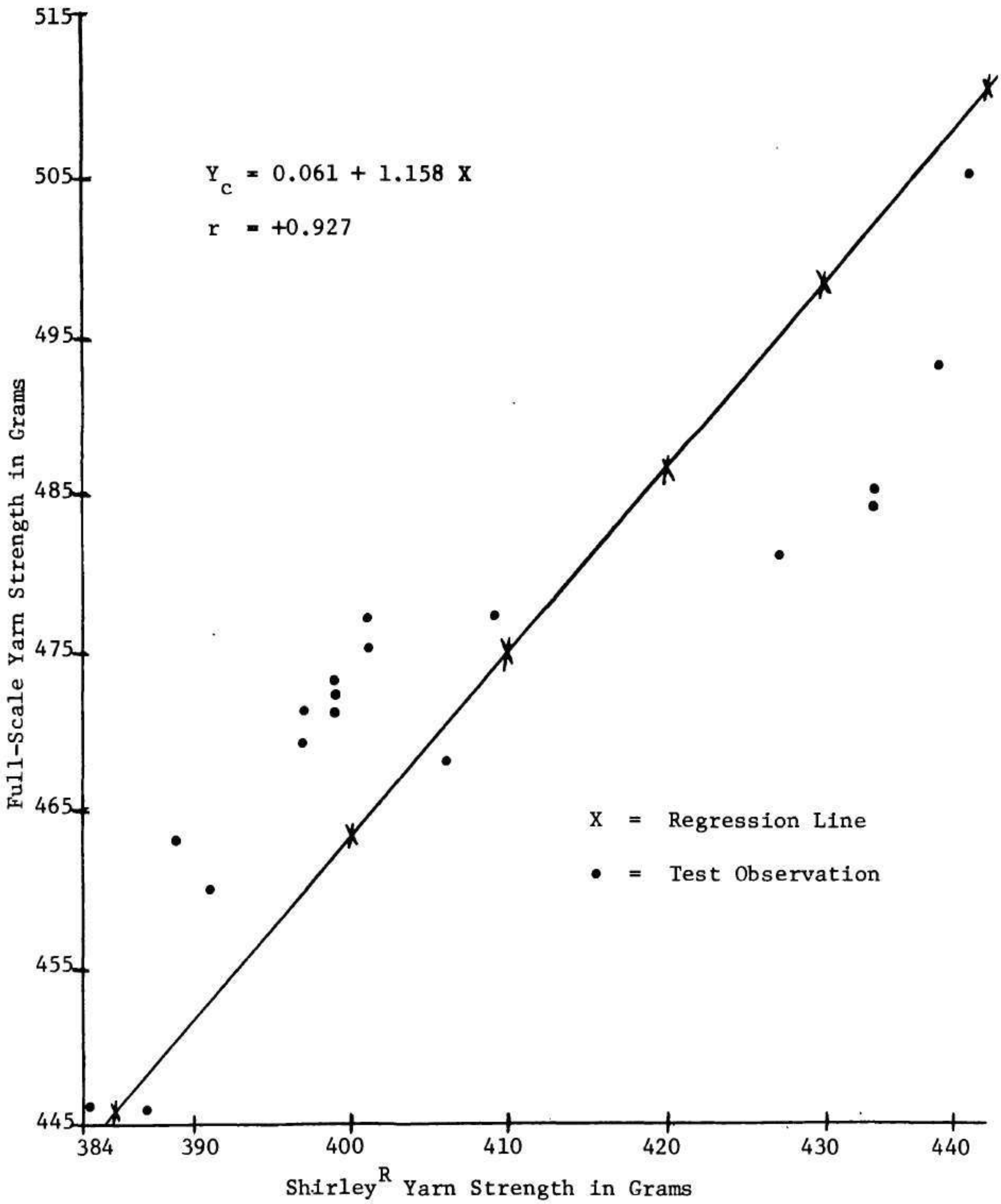
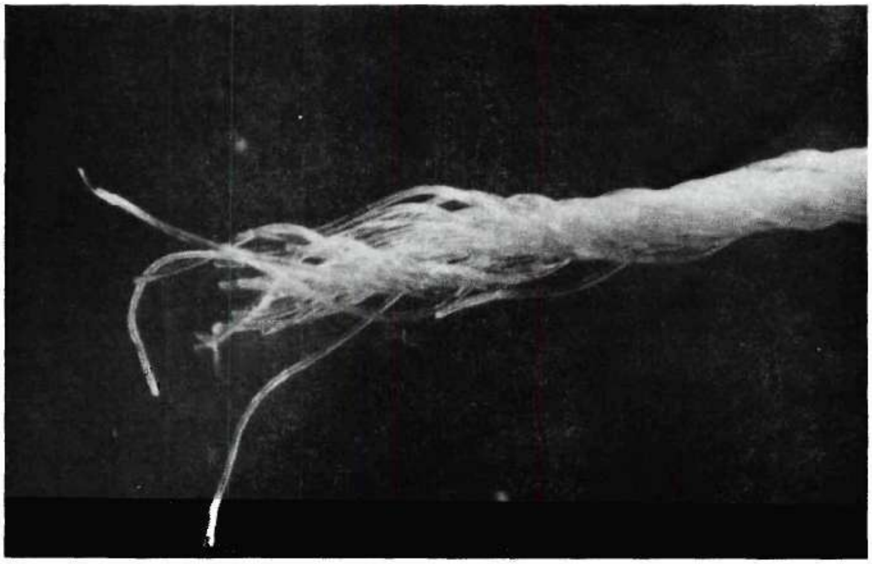
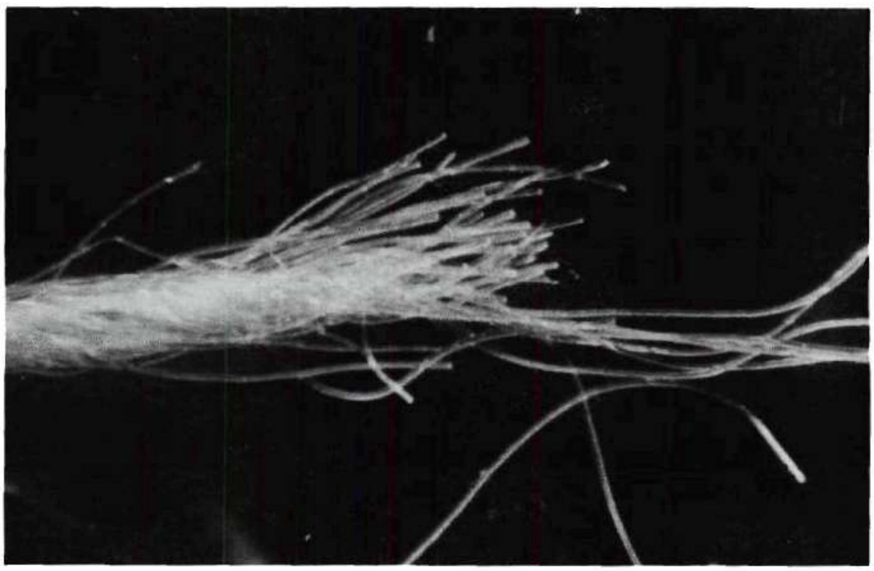


Figure 23. Shirley[R] Yarn Strength Data vs.
Full-Scale Yarn Strength Data



Broken End - Full-Scale



Broken End - Shirley[R]

Figure 24. Photomicrograph(45X) Comparison of Broken Yarn Ends from Shirley[R] Processing and from Full-Scale Processing After Breaking on Uster Tester

may be attributed to the fact that when the Shirley^R yarn was tensioned, many of the fibers, instead of cleanly breaking, slipped past one another, thus, giving fewer fibers per cross-section to bear the stress, and resulting in lower strength. A yarn which does this would be expected to have a more frayed broken end than a yarn in which the fibers, due to fiber-to-fiber interlocking, broke before slipping extensively.

Performance Rating

Each process in the two systems was evaluated as being excellent. The primary difference in performance occurred in the Shirley drawing and spinning processes. When using the drum to feed slivers, a phenomenon occurs known as "fiber-robbing" (69), in which fibers from one end of sliver on the drum adhere to fibers in another end of sliver (in effect, one end robs another of fibers). It is not known how much effect fiber-robbing has on the physical properties of the completed yarn, but it is easily imaginable that this may be a cause of yarn unevenness.

Shirley^R System Used to Screen Spin Finish Components

Having determined the correlation of Shirley^R processing with full-scale textile operations, the Shirley^R system was evaluated as to its value as a research tool to determine the processability of different spin finish components.

Electrostatic Charge Build-Up

It can be seen from Table 19 that the spin finish components which were pure antistatic agents had much lower field strength values than the other components. This was as expected and demonstrated that the Shirley^R miniature card did the same type of processing as the

Table 19. Mean Values of Results from Finish-Treated Fibers Processed on Shirley[R] Miniature Spinning Plant

Spin Finish Component	Electrostatic Charge Build-Up (V/M)	Fiber-to-Fiber Friction			Yarn-to-Guide Friction	Performance Rating
$C_{14}MeCl$ (L,A)	33	0.212	0.435	2.02	0.244	1
$C_{16}MeCl$ (E,A)	72	0.198	0.433	2.20	0.228	2
$C_{18}MeCl$ (E,A)	82	0.245	0.536	2.17	0.223	2
$C_{16}COO$ (E,A)	91,507	0.265	0.513	2.15	0.281	3
OPO (A)	965	0.272	0.574	2.16	0.358	2
1112 (A)	1,228	0.152	0.326	2.19	0.182	2
1274 (L,E,A)	3,526	0.195	0.402	2.06	0.156	1
Unfinished (Scoured) Zefkrome[R]	251,000	0.291	0.609	2.10	0.400	4

full-scale card. Thus, the Shirley^R card can be used to determine the amount of electrostatic charge build-up to expect from different antistatic agents. This result corresponded to the previous section's findings on electrostatic charge accumulation.

Fiber-to-Fiber Friction

Table 19 shows that those components having lubricity properties have lower fiber-to-fiber friction than the other difference components. This indicated that the Shirley^R miniature system had not adversely affected the properties of the components.

Yarn-to-Guide Friction

It was shown in Table 19 that the yarn-to-guide friction results were lowest for those yarns coated with spin finish components which have lubricity properties. Again this indicated that the Shirley^R plant had given results which would be consistent with results from conventional equipment.

Performance Rating

Table 19 demonstrated that the fibers coated with the components that primarily compose the entire spin finish mixture (i.e., lubricant, antistat, and emulsifier) processed better than those fibers treated with only different components of a spin finish. Once more the Shirley^R system presented results expected from a full-scale textile process.

As can be seen from these results, the Shirley^R Miniature Spinning Plant is a valuable screening aid for evaluation of spin finish components on polyacrylonitrile fibers and that its results have excellent correlation with those obtained from full-scale textile operations. The Shirley^R system does not adversely affect the fibers or the finish components. The usefulness of the Shirley^{R} plant does not depend on the precise value of the measurements for a yarn species but rather on the fact that the principal parameters utilized in measuring yarn quality vary in the same manner for a given fiber as they do in the manufacturing plant. Hence, fibers and processes giving high relative yarn quality on the Shirley^{R} system give similarly high quality in conventional yarn manufacturing. As a result, variables introduced by changes of fibers, finishes, and selected processes may be evaluated for manufacturing purposes in a manner economical of time and materials.

CHAPTER V

CONCLUSIONS

The following conclusions, based on data obtained from this investigation, are presented. They are limited somewhat by the type of fiber used, machinery used for processing, and the range of variables studied.

1. Although the values for each parameter evaluated were significantly different for the two processing systems (except for electrostatic change accumulation), there existed excellent correlation factors for each parameter; therefore, the results on the Shirley^{R} miniature plant are consistent and can be correlated with results from the full-scale process.

2. The Shirley^{R} miniature system has no adverse effect on the fiber or the spin finish properties, and results can be obtained which should be consistent with any full-scale textile process.

3. The Shirley^{R} miniature spinning system, with excellent correlation with full-scale processing, is an excellent screening aid for spin finish components for polyacrylonitrile fibers.

CHAPTER VI

RECOMMENDATIONS

During this research, several effects related to the work which appear worthy of additional research, have arisen. These, in turn, suggest additional areas of investigation, which are listed below.

1. An investigation of the difference between the miniature plant yarn and the conventional system yarn caused by the absence of the roving operation in the miniature system.

2. A study of the fiber damage which occurs in each step of the miniature operation as compared to the fiber damage which occurs during each operation of full-scale processing.

3. An investigation of the effect that "fiber-robbing" has on the physical properties of the yarn manufactured on the miniature system.

4. An examination of the effect of the difference in fiber surface damage between conventional spun yarn and miniature spun yarn has on the physical properties of the yarn.

It is recommended that research investigation be performed to explore these additional problems.

APPENDIX

Table 20. Count and Twist Data for Yarns Produced on Shirley[R] System and on Full-Scale System

Test Number	Shirley[R] Yarn Count	Shirley[R] Yarn Twist	Full-Scale Yarn Count	Full-Scale Yarn Twist
1	14.7	13.5	14.5	13.5
2	14.4	13.2	14.2	13.4
3	14.8	13.1	15.4	13.4
4	15.2	13.3	15.1	13.6
5	14.7	13.7	14.9	13.5
6	15.0	13.6	14.9	13.7
7	14.2	13.5	14.7	13.0
8	14.6	13.9	15.1	13.8
9	15.1	13.0	14.6	13.5
10	14.5	13.6	14.6	13.7
11	14.9	13.5	14.9	13.5
12	15.0	13.8	14.6	13.6
13	14.2	12.9	15.4	13.6
14	14.7	13.7	15.0	13.1
15	14.6	13.5	14.0	13.5
16	14.9	13.1	14.7	13.1
17	15.1	13.6	14.5	13.2
18	14.7	13.9	14.6	13.6
19	14.8	13.5	15.2	13.5
20	14.6	13.5	14.2	13.4
Mean Value	14.7	13.5	14.9	13.5

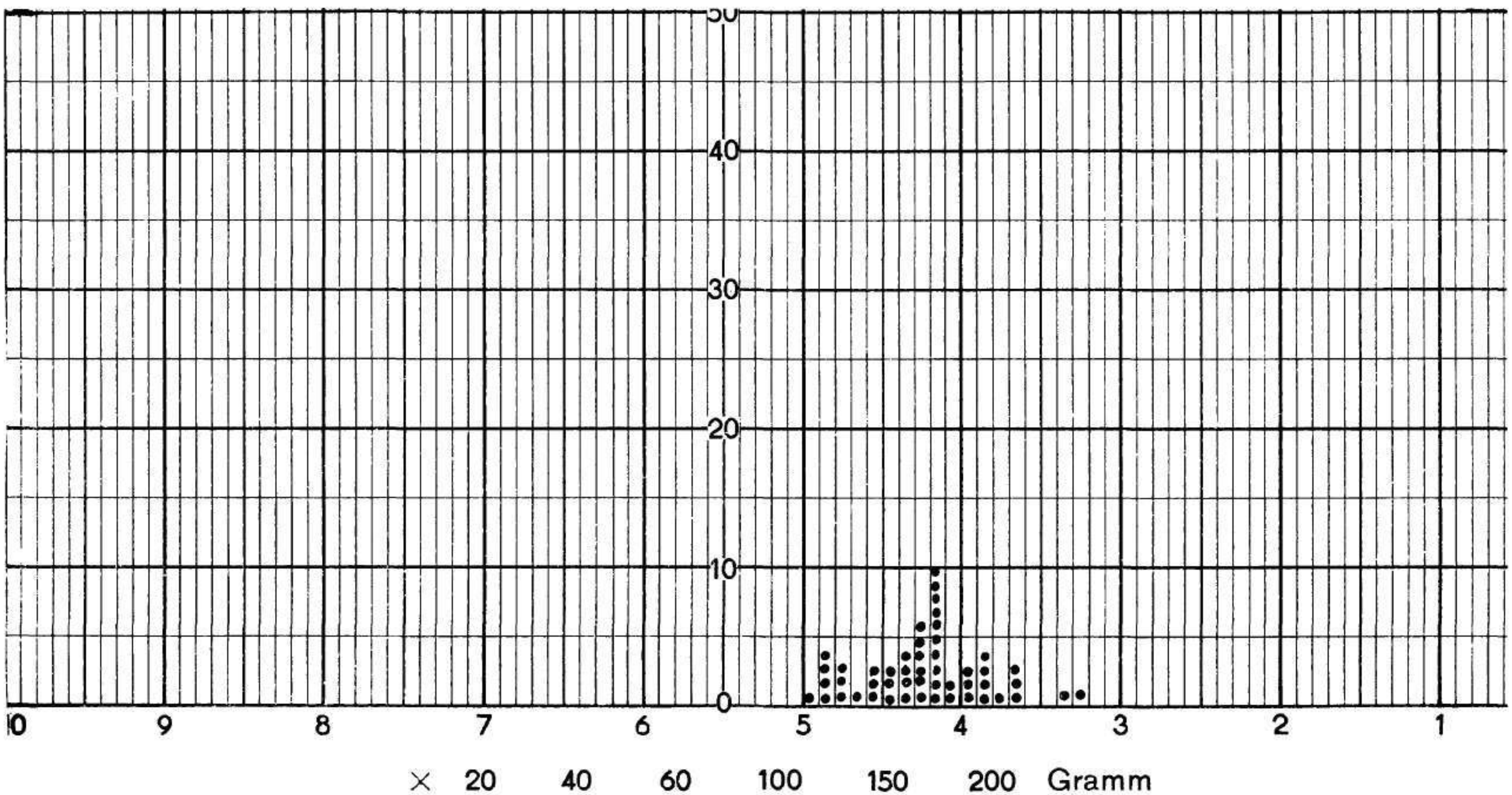


Figure 25. Typical Frequency Distribution Diagram from Uster Automatic Single-End Tester for Yarn Produced on Shirley^{R} System

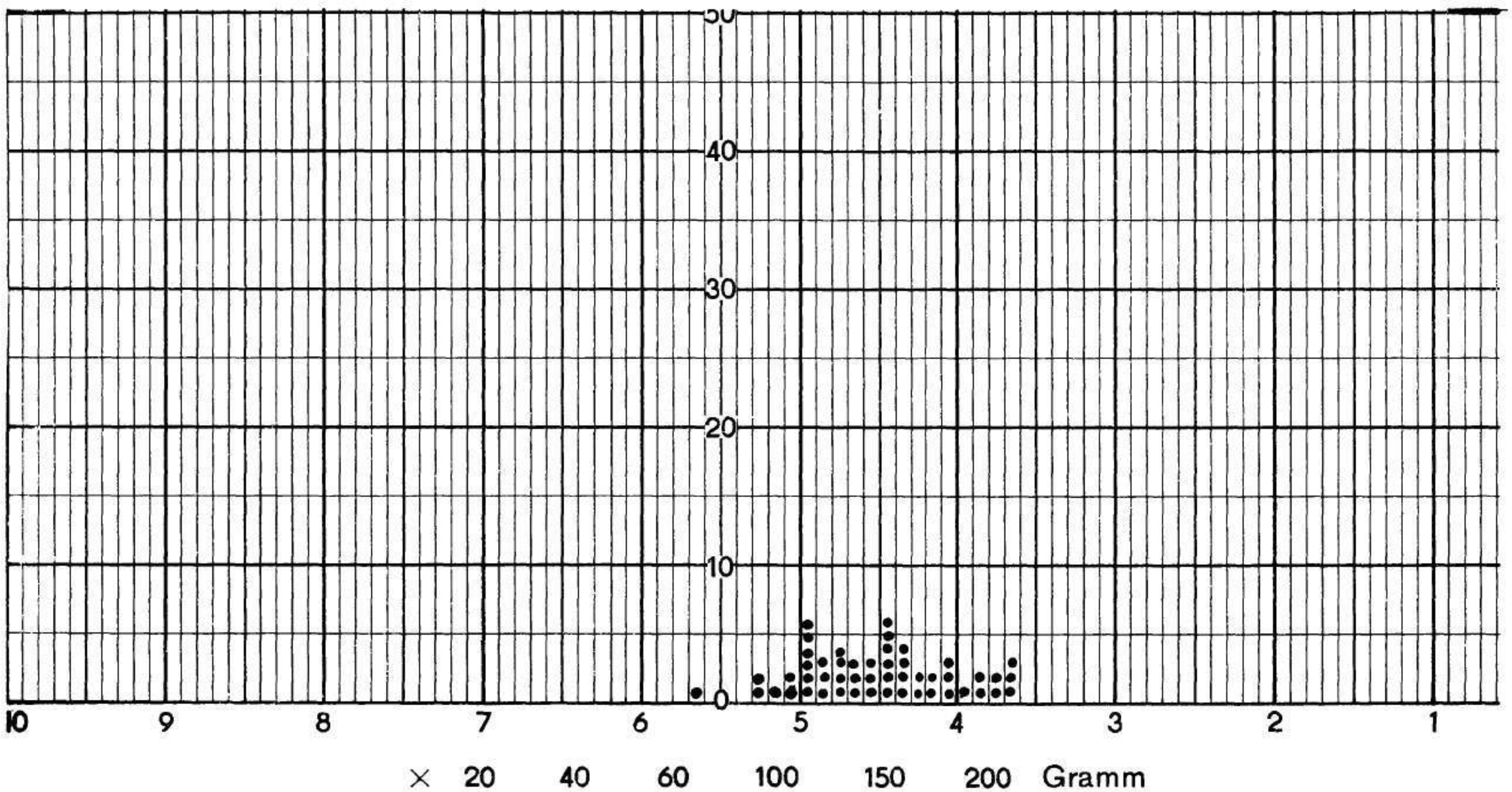


Figure 26. Sample of Frequency Distribution Diagram from Uster Automatic Single-End Tester for Yarn Produced on Full-Scale System

Table 21. Fiber-to-Fiber Friction Data for Yarn Produced on Shirley^R Miniature Equipment as Measured by Servo-Controlled Friction Apparatus

Test Number	Area (in^2)	$\overline{H}$(cm)	μ_k	μ_s	Hmax (cm)	μ_s/μ_k
1	4.82	1.68	0.155	0.403	4.38	2.60
2	4.56	1.61	0.148	0.489	5.32	3.31
3	4.62	1.61	0.148	0.455	4.89	3.07
4	6.10	2.13	0.198	0.418	4.50	2.11
5	5.85	2.04	0.189	0.438	4.71	2.32
6	4.91	1.71	0.159	0.350	3.76	2.20
7	5.64	1.97	0.181	0.431	4.36	2.22
8	6.48	2.28	0.210	0.495	5.38	2.36
9	4.70	1.64	0.151	0.351	3.81	2.33
10	5.14	1.81	0.165	0.305	3.35	1.85
11	4.86	1.69	0.154	0.314	3.45	2.04
12	4.05	1.42	0.129	0.277	3.04	1.95
Mean Value	5.14	1.80	0.165	0.394	4.25	2.36

Table 22. Fiber-to-Fiber Friction Data for Yarn Produced on Full-Scale Equipment Measured by Servo-Controlled Friction Apparatus

Test Number	Area (in^2)	$\overline{H}$(cm)	μ_k	μ_s	Hmax (cm)	μ_s/μ_k
1	4.30	1.50	0.140	0.321	3.45	2.29
2	5.65	1.97	0.183	0.434	4.67	2.37
3	4.39	1.53	0.142	0.426	4.58	3.00
4	6.45	2.25	0.212	0.477	5.05	2.25
5	4.29	1.50	0.141	0.478	5.08	3.39
6	5.87	2.05	0.193	0.470	4.99	2.44
7	4.01	1.40	0.130	0.433	4.66	3.33
8	4.90	1.71	0.159	0.439	4.73	2.76
9	4.38	1.53	0.142	0.402	4.32	2.83
10	6.85	2.39	0.220	0.547	5.95	2.49
11	7.06	2.46	0.226	0.532	5.78	2.35
12	6.81	2.37	0.218	0.456	4.96	2.09
Mean Value	5.41	1.89	0.176	0.451	4.85	2.63

Table 23. Yarn-to-Guide Coefficient of Friction for Yarn Produced on Shirley^R Miniature Equipment as Measured by Rothschild F-Meter

Test Number	Coefficient of Friction μ
1	0.217
2	0.208
3	0.209
4	0.205
5	0.203
6	0.218
7	0.212
8	0.211
9	0.208
10	0.201
11	0.212
12	0.202
13	0.203
14	0.202
15	0.212
16	0.204
17	0.204
18	0.211
19	0.201
20	0.208
Mean Value	0.2076
Standard Deviation	$\pm$0.0505

Table 24. Yarn-to-Guide Coefficient of Friction for Yarn Produced on Full-Scale Equipment as Measured by Rothschild F-Meter

Test Number	Coefficient of Friction μ
1	0.253
2	0.223
3	0.235
4	0.233
5	0.223
6	0.221
7	0.238
8	0.240
9	0.251
10	0.213
11	0.227
12	0.238
13	0.237
14	0.250
15	0.242
16	0.228
17	0.237
18	0.238
19	0.239
20	0.240
Mean Value	0.235
Standard Deviation	$\pm$0.0101

Table 25. Evenness Data for Yarn Spun on Shirley[R] Miniature Equipment as Measured by Uster Evenness Tester

Test Number	Coefficient of Variation (%)
1	19.05
2	20.13
3	21.80
4	19.93
5	21.07
6	20.75
7	23.09
8	21.83
9	20.33
10	20.38
11	19.37
12	19.92
13	20.66
14	19.74
15	19.92
16	20.78
17	20.92
18	20.77
19	21.19
20	21.25
Mean Value	20.64
Standard Deviation	$\pm$ 0.88

Table 26. Evenness Data for Yarn Spun on Full-Scale Equipment as Measured by Uster Evenness Tester

Test Number	Coefficient of Variation (%)
1	17.02
2	19.92
3	17.24
4	18.12
5	18.35
6	18.94
7	18.78
8	17.71
9	19.00
10	19.84
11	19.73
12	20.62
13	17.53
14	17.84
15	19.22
16	19.37
17	18.55
18	17.19
19	17.26
20	19.00
Mean Value	18.56
Standard Deviation	$\pm$ 1.024

Table 27. Breaking Strength and Elongation Data for Yarn Spun on Shirley^{R} System as Measured by Uster Automatic Single-End Tester

Test Number	Strength (grams)	Strength (%)	Elongation (%)
1	433	43.3	22.0
2	447	44.7	22.2
3	387	38.7	20.0
4	397	39.7	21.0
5	433	43.3	22.4
6	399	39.9	21.6
7	399	39.9	20.4
8	437	43.7	22.4
9	427	42.7	22.4
10	459	45.9	22.4
11	397	39.7	22.2
12	401	40.1	23.0
13	409	40.9	22.4
14	377	37.7	22.0
15	383	38.3	22.4
16	399	39.9	21.2
17	391	39.1	22.2
18	401	40.1	22.4
19	389	38.9	22.4
20	439	43.9	22.0
Mean Value	410.2	41.02	22.0
Standard Deviation	± 23.13	± 2.313	± 0.734

Table 28. Breaking Strength and Elongation Data for Yarn Spun on Full-Scale Equipment as Measured by Uster Automatic Single-End Tester

Test Number	Strength (grams)	Strength (%)	Elongation (%)
1	484	48.4	19.8
2	475	47.5	16.4
3	441	44.1	18.4
4	471	47.1	17.6
5	443	44.3	16.6
6	481	48.1	19.0
7	472	47.2	19.0
8	463	46.3	19.0
9	477	47.7	19.0
10	505	50.5	20.2
11	473	47.3	18.2
12	493	49.3	17.6
13	469	46.9	18.8
14	446	44.6	17.6
15	485	48.5	19.2
16	477	47.7	18.9
17	465	46.5	17.2
18	471	47.1	19.2
19	509	50.9	20.2
20	513	51.3	20.0
Mean Value	475.65	47.565	18.6
Standard Deviation	$\pm$ 18.55	$\pm$ 1.855	$\pm$ 1.06

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