Determining FIBER-LENGTH DISTRIBUTION OF COTTON by Electrical Resistance Measurements

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CONTENTS

SUMMARY AND CONCLUSIONS

Evaluation of cotton fiber samples showed that the electrical resistance method of measurement can detect small changes in the length distribution pattern. This is illustrated by the changes in shape of the curves obtained by use of the resistance device, and by length-frequency data. The effect of the moisture content of the cotton when ginned was revealed clearly in the resistance measurements. Suter-Webb array data on these samples show this same relationship between gin treatment effects and the length distribution pattern (table 2).

Length-frequency data such as the information recorded by the resistance device can be entered directly into an analog computer. This computer can be programmed to give length information about the sample being measured. This information can be any length factor in which the user is interested, such as mean length, distribution of fibers of different lengths, uniformity factors, and others. Since there are considerable differences in the curves shown in this report, these differences would be analyzed by the computer and causes of the differences could be determined.

Considerable research is needed to determine what length information is important in predicting processing characteristics of a particular cotton. When these length factors are determined, information relating to them can be obtained from a length-frequency curve similar to that produced by the resistance device.

The results presented in this report indicate that further investigations are warranted, using the present sample preparation method and other methods that might prove faster and better.

Washington, D. C. January 1963

DETERMINING FIBER-LENGTH DISTRIBUTION OF COTTON BY ELECTRICAL RESISTANCE MEASUREMENTS

Albert W. Hartstack, Jr.[1]

INTRODUCTION

The basic importance of length measurement of cotton fibers has never been greater than it is today, according to the National Cotton Council.[2] In particular, there has been an increasing need for precise determination of the distribution of fiber lengths within a sample of cotton. These determinations allow cotton-mill operators and merchants to select the best length of cotton available for their particular needs. Length-distribution data are also of great importance for studies in genetics, breeding, and cultural practices related to the cotton plant.

Mechanically harvested cotton requires additional cleaning to produce samples equal in appearance to samples of handpicked cotton. This additional cleaning increases the risk of fiber damage such as fiber breakage, especially if accompanied by excessive drying. The detection of such damage is becoming increasingly important to farmers and buyers, as well as to spinners and researchers.

For many years, the cotton industry has depended upon the accurate, but tedious, Suter-Webb array[3] for precise determinations of length distribution. Only a small percentage of the total cotton crop can be evaluated by this slow method.

The Fibrograph[4], developed over 20 years ago, was designed to give length information much faster than the Suter-Webb array. This was a major step forward. Over the next 15 years, many improvements were made in the Fibrograph, resulting in the familiar Servo instrument, and more recently the development of the Digital Fibrograph. However, many cotton bales go to market without objective measurements of the length distribution of the fibers comprising the bale.

The purpose of this report is to present a method of detecting differences in the fiber-length distribution patterns between bales, and a method of analysis that would enable the interpretation of these differences if desired.

PROCEDURE

Basic Theory

The measuring instrument is an electrical resistance device[5,6], developed by the U. S. Department of Agriculture, which employs the electrical properties of cotton fibers in measuring their length.

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[1] Agricultural Engineer, Field Crops and Animal Products Branch, Market Quality Research Division, Agricultural Marketing Service, U. S. Department of Agriculture, College Station, Tex. The Texas Agricultural Experiment Station cooperated in the study.

[2] Johnson, Burt. Cotton Fiber and Spinning Tests. National Cotton Council. Sept. 1956.

[3] Webb, R. W. The Suter-Webb Cotton Fiber Duplex Sorter and the Resulting Method of Length-Variability Measurements. American Society for Testing Materials. Proc. 35. 32: 764-74. 1932.

[4] Mention of specific instruments or trade names is made for the purpose of identification and does not imply an endorsement by the U. S. Government. Also, see Hertel, K. L., and Zervigon, M. C. An Optical Method for the Length Analysis of Cotton Fibers. Textile Res. Jour. 6: 331-39. May 1936.

[5] See: Hartstack, A. W., Jr. An Electrical Resistance Method of Measuring Cotton Fiber-Length Distribution. 1959 Winter Meeting, American Society of Agricultural Engineers, Chicago, Ill. Paper No. 59-908. December 15-18, 1959.

[6] See: Hartstack, A. W., Jr. An Electrical Resistance Method for Determining the Fiber Length Distribution of Cotton Lint. A thesis. A & M College of Texas. January 1961.

This device is designed to measure the length and the relative numbers of cotton fibers of each length protruding from a metal clamp. The relative electrical conductance of these fibers, as a group, is measured at 1/8-inch intervals from the clamp, commencing at 1/8 inch and continuing until the longest fibers have been measured.

If environmental conditions and specimen preparation are satisfactory, the basic formula for the resistance of any material will apply to a cotton specimen containing a large number of fibers:

$$(1) \quad R_x = C \frac{L}{AN}$$

where:

C = Resistivity
L = Length
A = Cross-sectional area of a single fiber
N = Total number of fibers

Environmental Conditions

Satisfactory environmental conditions are 70° F. and 65 percent relative humidity. These should be maintained as closely as possible within a tolerance of a plus or minus 1 degree of temperature and 1 percent of relative humidity.

Sample Preparation

The most difficult problem encountered in measuring the electrical resistance or conductance of a cotton specimen with fibers of various lengths was a method of preparing the specimen. The ideal way would be to aline all fibers on one end and then arrange them to be parallel. If these fibers were clamped at the alined end, each fiber would protrude from the clamp in accordance with its length. The time involved in preparing a specimen in this manner for routine testing is prohibitive.

The next best method of preparing the specimen, seemingly, would be to have the fibers parallel, with their ends positioned at random. A number of machines used in the spinning of cotton prepare this type of sample material. These machines make the fibers parallel to each other and form a rope, or sliver, of these fibers. This sliver could be clamped at random, and, with a minimum of preparation, a sample of fibers as described could be formed. However, the forming of the rope, or sliver, is a time-consuming process and probably would not be fast enough for assembly-line cotton grading practices.

The samples presented to the resistance device, described in this report, were prepared by blending 3 grams of raw cotton with a USDA laboratory blender. After three blendings, the bat was taken from the blender, divided into eight equal parts, and combined to form two samples, each made up of four thicknesses of the bat. Each of these composite samples was clamped in the clamp of the resistance device, combed manually to remove loose fibers, and measured with the instrument. They were then reoriented 180 degrees in the clamp, and recombed and again measured, providing four replications. This type of sample preparation did not arrange the fibers in the manner necessary to enable the plotting of a doubly cumulated curve of the original data; however, the distribution in the clamped samples is relative to the distribution in the original bulk sample.

Circuit for Measuring

The circuit designed to measure the changes in conductance of the cotton fibers is shown in figure 1. In order to derive the relationships for that circuit, an equivalent circuit as shown below figure 1 may be drawn.

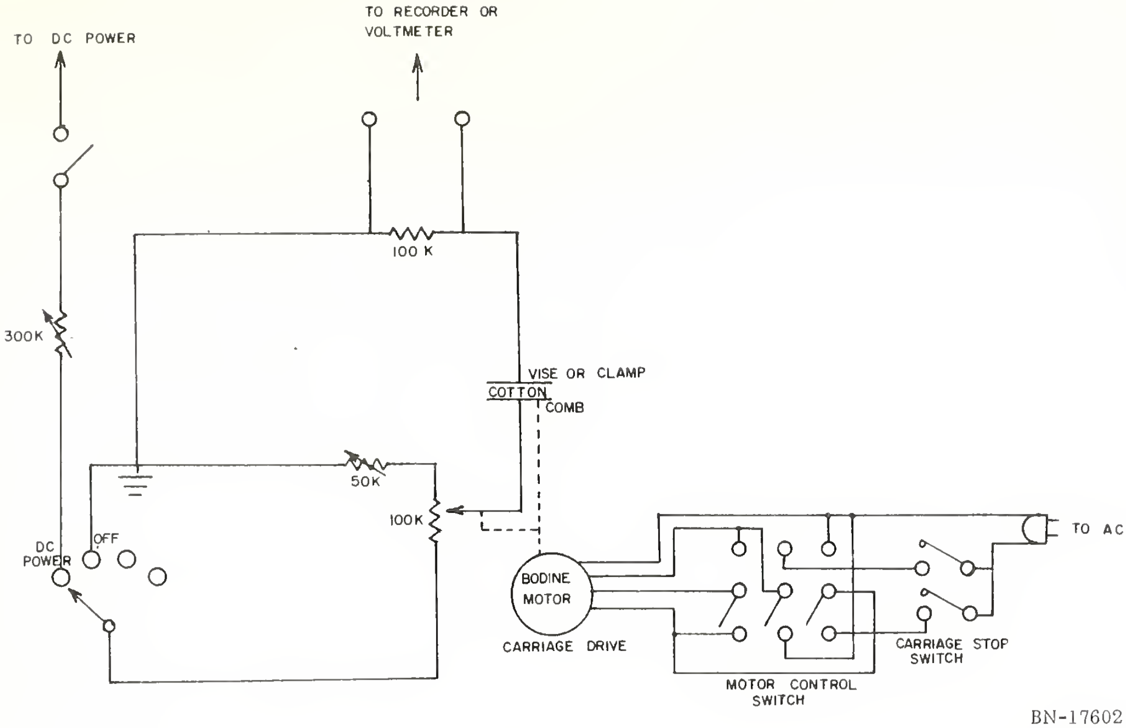
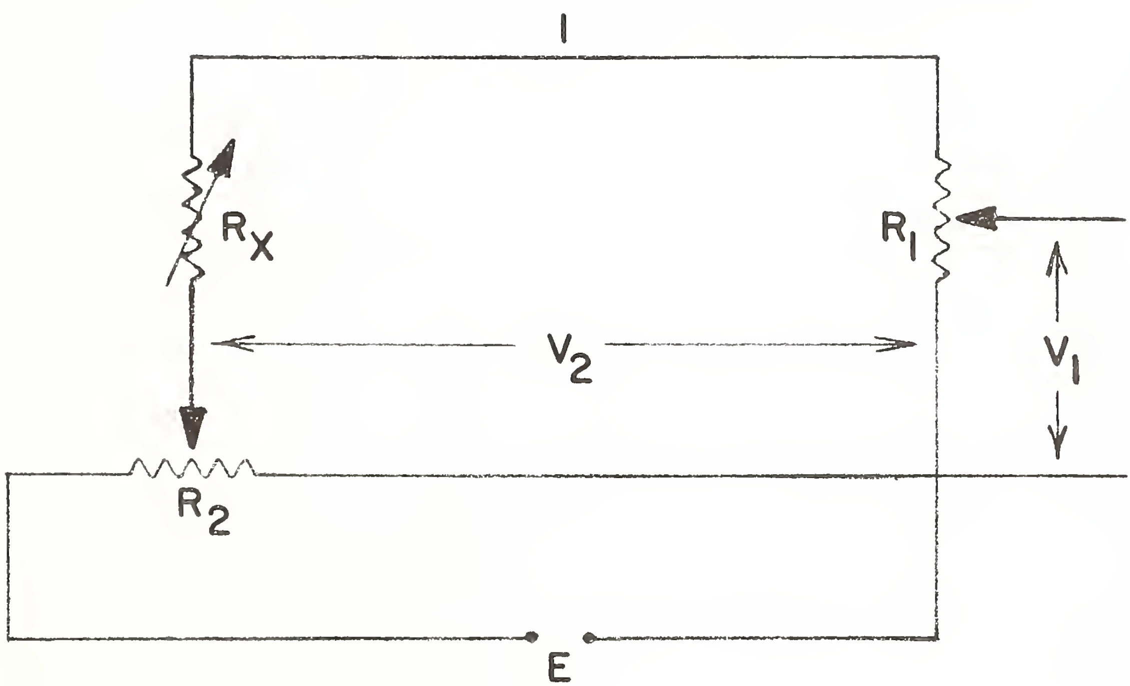


Figure 1. --Circuit designed to measure the number of fibers at intervals along the clamped beard.



In the equivalent circuit:

R_x = Resistance of cotton
R_1 = 100,000 ohms
R_2 = 150,000 ohms = 10-turn 100K potentiometer plus 50K potentiometer
I = Current
E = Direct-current power supply
V_1 = Voltage to Digital Voltmeter
V_2 = Voltage across cotton and R_1

From the above circuit, the following loop equations can be written:

(2) $V_1 = C_1 I R_1$ — C_1 = Constant set by potentiometer R_1

(3) $V_2 = C_2 L_1 E$ — L_1 = Distance from comb to clamp

(4) $R_x = \frac{V_2 - IR_1}{I} = \frac{V_2}{I} - R_1$ — C_2 = Constant set by potentiometer R_2

Equation 2 is readily seen since V_1 is a percentage of the voltage across $R_1 I$. This percentage, or constant, for any one test can be represented by C_1.

C_2 in equation 3 is a constant or the percentage of R_2 that is added for each unit length. L_1 is the number of units of length that the comb has traveled from the clamp.

Substituting for V_2 and I in equation 4,

(5)
$$R_x = \frac{C_2 L_1 E}{\frac{V_1}{C_1 R_1}} - R_1 = R_1\left(\frac{C_1 C_2 L_1 E}{V_1} - 1\right)$$

To simplify the further development of the relationship, the "1" can be dropped from equation 5. This can be done because typical values substituted for $\frac{C_1 C_2 L_1 E}{V_1}$ give values of 500 or larger, causing errors of only 0.2 percent or less. For this research, errors of this magnitude will be considered as negligible, since the equipment and operator may be responsible for errors of greater magnitude.

Substituting the basic formula, equation 1, into equation 5 gives:

(6)
$$R_x = \frac{C_1 C_2 L_1 E R_1}{V_1} = \frac{CL}{AN}$$

C, C_1, C_2, E, and R_1 are constants during any one test. L equals L_1 in all cases.

Solving for N,

(7)
$$N = \frac{CLV_1}{C_1 C_2 L_1 E R_1 A} = \frac{CV_1}{C_1 C_2 E R_1 A}$$

(8)
$$N = \frac{KV_1}{A} \qquad \text{Where } K = \frac{C}{C_1 C_2 E R_1}$$

To obtain the percentage of fibers of a given length within the specimen,

(9)
$$\frac{\Delta n}{N} = \frac{\frac{K}{A}\Delta v_1}{\frac{K}{A} V_1} = \frac{\Delta v1}{V_1}$$

Instrumentation

Figure 2 is a picture of the complete instrument developed for measuring, computing, and recording the length of the cotton fibers. A Varian Model G-10 Graphic Recorder serves as the recording instrument. This recorder fulfills the need for a flexible, compact instrument to record direct-current signals in the 10-millivolt range.

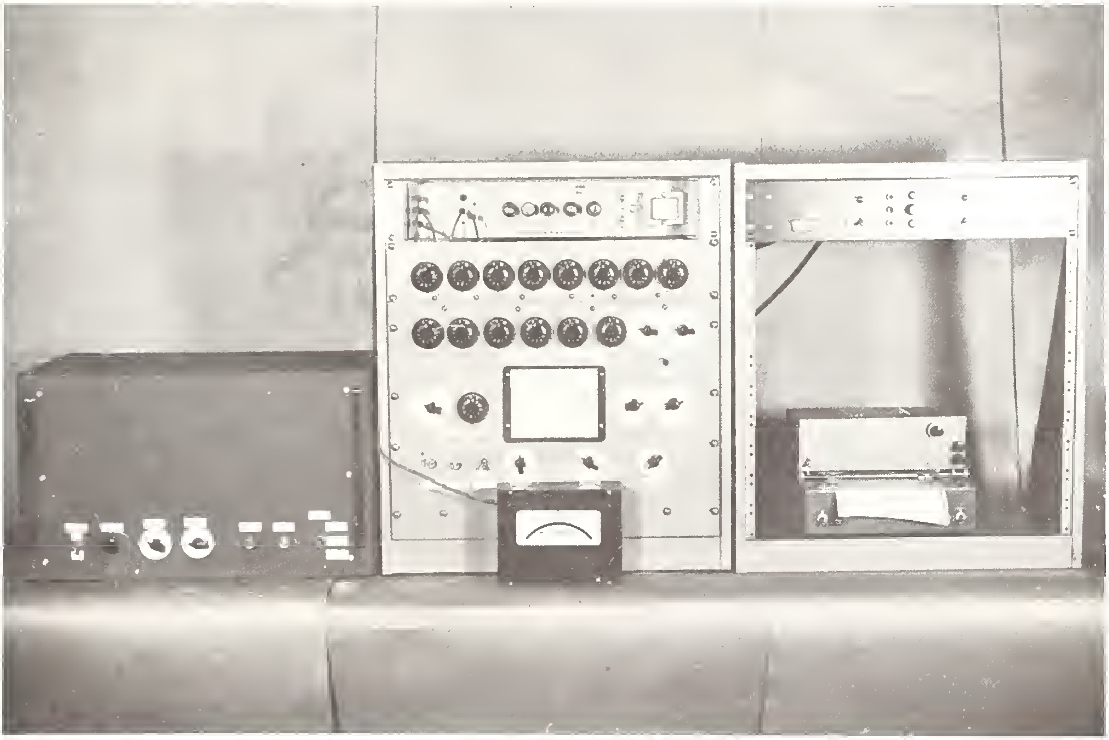


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Figure 2. --Instrument for measuring, computing, and recording cotton fiber length.

Figure 3 presents a closeup of the internal mechanism of the specimen-measuring instrument.

A plastic stand holds a metallic specimen clamp in position during a given test. This electrically conductive clamp, holding the cotton test specimen, forms the fixed electrode of the measuring device.

A Fibrograph steel-needle comb, attached to a movable carriage for drawing the comb through the cotton test specimen, forms the movable electrode of the measuring device. The needles of this comb are alined parallel to the jaws of the clamp. The comb carriage is driven by a Bodine Type NS1-12RH, 1/50-horsepower, 43-rpm reversible motor.

A cam-actuated micro switch connected into the measuring circuit serves as an event marker to indicate, on the trace drawn by the recorder, each 1/8-inch distance traveled by the comb carriage.

A Philbrick Model R-100B regulated power supply is used as a source of from 0 to 300 volts direct-current supply for the measuring circuit.

The motor that operates the carriage also rotates a 10-turn 100K-ohm precision potentiometer of 0.1-percent linearity. The wiper arm of this potentiometer is attached to

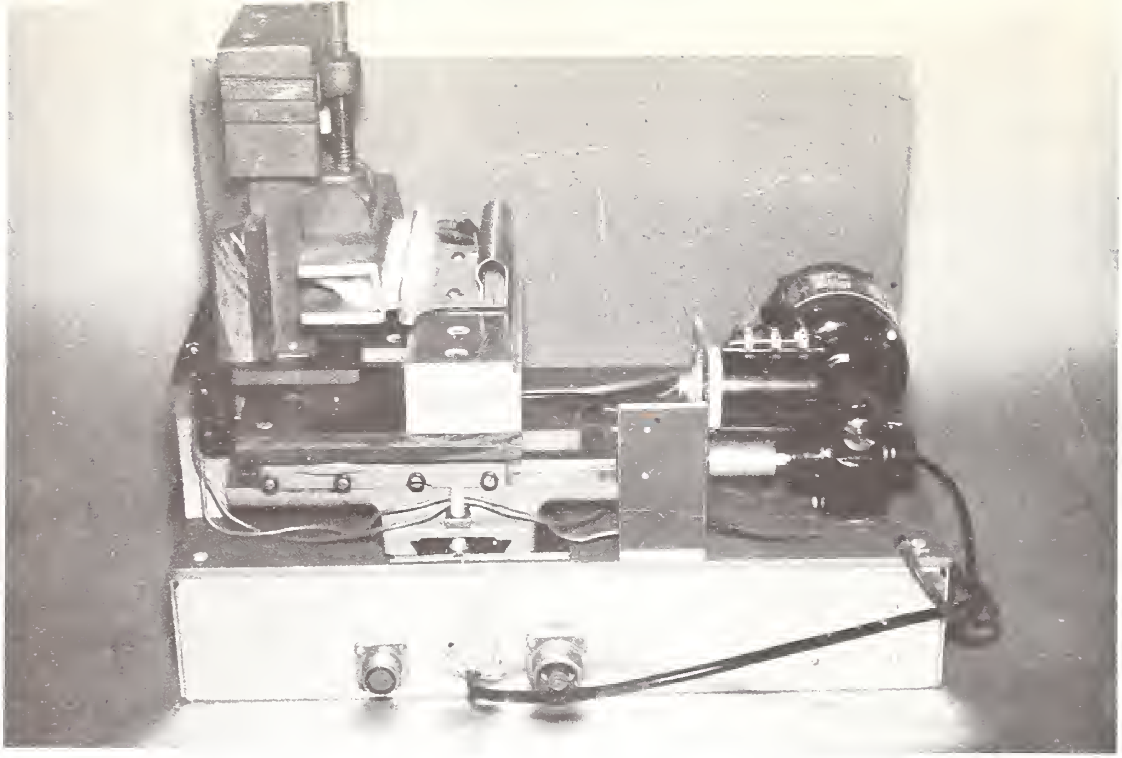

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Figure 3. --Internal mechanism of the measuring instrument.

the comb to permit the voltage across the cotton to be increased proportionally to the distance of the comb from the clamp. The resultant changes in the signal voltage to the voltmeter, or recorder, are due to changes in electrical resistance relative to the number of fibers at each length interval being measured.

A 50,000-ohm potentiometer in series with the 10-turn potentiometer serves as a zero control to provide the necessary voltage across the cotton at the beginning of each test, or for calibration of the instrument.

Test Procedure

The procedure used to measure the clamped cotton fibers follows:

1. The test sample is prepared as described previously.

2. The clamp with the sample is placed into the clamp holder. The substantially paralleled fibers are engaged with the needles of the comb. The comb, attached to the carriage, is set 1/8-inch from the clamp jaws.

3. The voltage from the power supply is applied and increased until an approximately full-scale reading on the recorder is obtained.

4. The recorder chart drive is started. A few seconds later, the carriage drive is started and the measurement of the conductance of the fibers begun.

5. The relative number of fibers at any specific distance from the clamp is determined from the values indicated by the recorder.

EXPERIMENTS AND RESULTS

A group of cotton samples of known history was selected for this experiment. This group consisted of 4 samples drawn from each of 12 bales of medium-staple-length cotton containing varying amounts of short fibers, making a total of 48 samples[7].

Each of the 48 samples was prepared and presented to the resistance device for measurement.

Figure 4 presents the four length-frequency curves of the clamped beards recorded by the resistance instrument. These include two length-frequency curves of the cotton ginned at high moisture, and two of the cotton ginned at low moisture. The rest of the curves fall between the two extremes, as plotted, of their respective moisture groups. These are an average of four replications on each four samples drawn from each bale. Also shown in the figure is the gin treatment which each of these cottons received, which was referred to previously when speaking of high- and low-moisture cottons. Table 1 presents the data from all 12 curves.

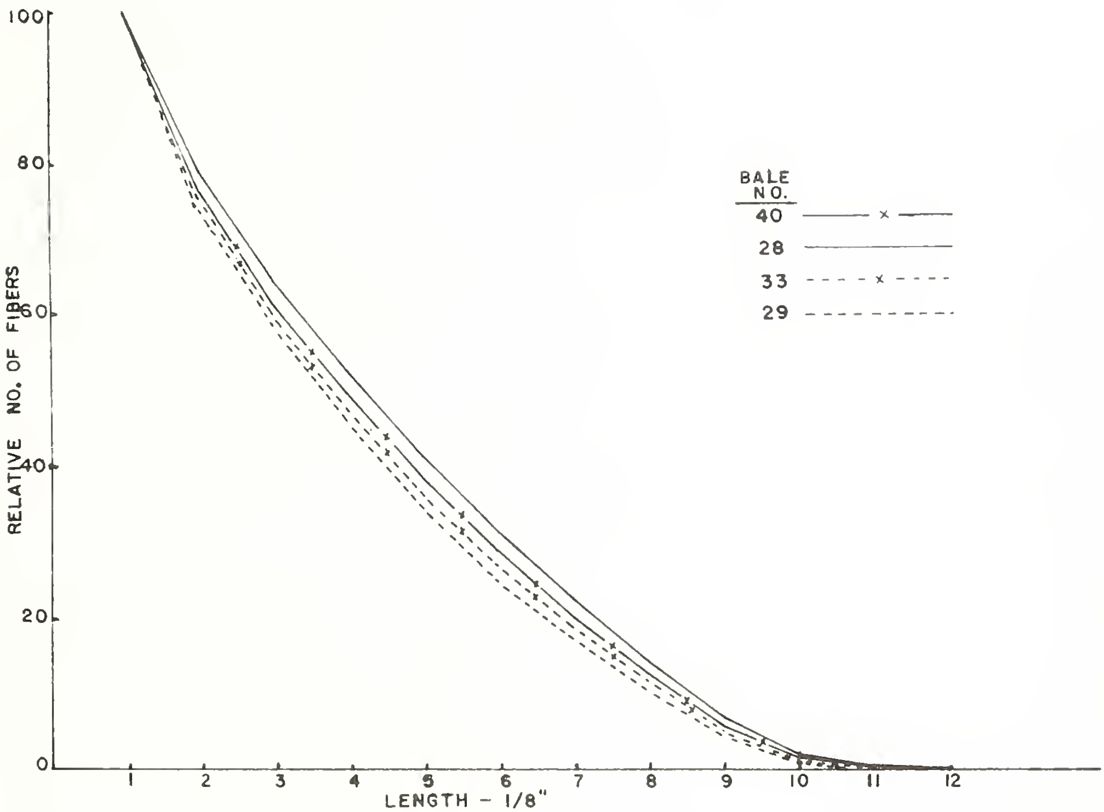

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Figure 4. --Length frequency curves of the beards protruding from clamp, measured by resistance.

The resistance device detected a definite difference between high- and low-moisture cottons. The length-frequency curves of the high-moisture cotton are all above the curves of the low-moisture cotton. The other gin treatments had an insignificant effect on the shape of the curves. This difference as detected by the resistance method was explained and confirmed by the Suter-Webb array method. Table 2 shows the average Suter-Webb array results of three replications on each of four samples drawn from each bale.

7 These bale samples pertain to a study of the effects of cotton ginning practices on the market quality of a variety of Mississippi Delta cotton, season 1958-59. Laboratory and spinning test data related to the study have been compiled for a forthcoming publication.

TABLE 1.--Relative percents of fibers protruding from the clamp at 1/8-inch intervals commencing 1/8 inch from clamp (each reading is an average of 16 tests)

	Gin treatments											
Lint moisture	High level						Low level					
Seed cotton cleaning	Moderate			Elaborate			Moderate			Elaborate		
Lint cleaners	0	1	2	0	1	2	0	1	2	0	1	2
Bale No.	40	39	28	38	36	37	33	34	35	29	32	30
Distance from clamp: 1/8" points	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	76.1	76.8	78.7	76.9	77.7	77.5	75.0	75.3	74.3	74.1	75.1	74.5
3	60.7	61.9	64.3	62.1	62.3	62.6	59.1	59.7	59.5	58.2	59.1	58.1
4	48.9	50.2	52.4	49.7	51.0	50.1	47.0	47.5	45.9	45.4	46.9	45.6
5	38.1	39.0	41.1	38.2	40.0	39.2	36.1	36.6	35.5	34.4	36.0	34.6
6	28.4	29.3	31.2	28.5	30.2	29.3	26.8	27.0	25.3	24.8	26.5	25.3
7	20.0	20.7	22.1	19.8	21.4	20.5	18.8	18.7	17.5	17.0	18.4	17.4
8	12.4	13.0	14.0	12.1	13.4	12.7	11.5	11.5	10.4	10.1	11.2	10.4
9	5.7	6.1	6.9	5.6	6.2	5.8	4.8	5.2	4.4	4.1	4.9	4.4
10	1.3	1.6	1.9	1.5	1.6	1.5	1.1	1.3	1.0	0.7	1.2	0.8
11	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 2.--Percent of fibers by weight in each 1/8-inch length group obtained by the Suter-Webb array (each reading is an average of 12 tests)

	Gin treatments											
Lint moisture	High level						Low level					
Seed cotton cleaning	Moderate			Elaborate			Moderate			Elaborate		
Lint cleaners	0	1	2	0	1	2	0	1	2	0	1	2
Bale No.	40	39	28	38	36	37	33	34	35	29	32	30
Fiber distribution:	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
1-1/2" to 1-5/8"	0.4	0.4	1.0	0.8	0.9	1.0	0.8	0.2	0.2	0.3	0.4	0.2
1-3/8" to 1-1/2"	6.0	6.5	8.5	6.3	6.7	5.5	4.8	5.6	4.3	6.2	4.7	4.4
1-1/4" to 1-3/8"	18.3	17.0	17.8	19.0	19.0	16.8	16.0	16.2	16.7	15.8	16.7	13.6
1-1/8" to 1-1/4"	26.2	26.8	22.8	26.4	24.7	25.2	25.1	22.2	21.8	23.3	24.9	23.5
1" to 1-1/8"	15.0	17.0	16.0	16.8	18.1	16.7	15.2	16.9	17.5	15.3	15.5	16.0
7/8" to 1"	10.0	9.3	10.1	9.4	9.0	10.1	11.4	11.0	10.2	10.6	10.3	11.7
3/4" to 7/8"	6.8	6.3	6.4	6.2	5.7	6.8	6.8	7.2	8.0	7.5	6.6	7.6
5/8" to 3/4"	4.4	4.7	4.2	4.3	4.2	4.6	4.6	5.1	5.2	5.2	5.5	5.6
1/2" to 5/8"	3.4	3.4	3.7	2.9	3.3	3.6	4.0	4.0	4.2	4.2	4.0	4.6
3/8" to 1/2"	3.4	3.2	3.1	2.8	2.9	3.4	3.6	4.0	4.0	4.1	3.9	4.0
1/4" to 3/8"	3.2	2.9	3.2	2.6	2.7	3.1	3.6	3.8	3.9	3.8	3.6	4.6
1/8" to 1/4"	1.8	1.6	2.1	1.4	1.5	1.9	2.4	2.0	2.0	2.4	2.4	2.6
Shorter than 1/8"	1.2	1.0	1.2	1.1	1.2	1.2	1.6	1.7	1.6	1.6	1.6	1.5

Table 3 shows the relative number of fibers measured at the 1/2-inch point for each individual specimen presented to the resistance device. An analysis of variance was run on these data to determine the effect of gin treatments and the standard error that could be expected in readings of this type.

TABLE 3.--Relative percent of fibers at 1/2-inch point of beard extending from clamp

		Gin treatments											
Lint moisture		High level						Low level					
Seed cotton cleaning		Moderate			Elaborate			Moderate			Elaborate		
Lint cleaners		0	1	2	0	1	2	0	1	2	0	1	2
Bale No.		40	39	28	38	36	37	33	34	35	29	32	30
Subsample	Specimen	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
1	1	49.3	50.0	51.3	49.9	50.7	47.8	46.5	46.9	42.5	44.6	48.2	47.6
	2	47.5	48.1	51.5	50.0	54.8	50.6	47.3	50.6	46.2	47.7	50.1	43.6
	3	49.9	53.4	53.4	50.7	54.0	49.2	49.0	49.5	49.1	48.1	48.4	46.2
	4	47.3	50.7	49.6	49.1	50.2	48.5	46.1	44.0	46.6	42.6	52.4	43.0
2	1	46.1	48.8	53.9	43.0	48.3	47.7	47.6	43.4	42.3	42.9	45.6	41.6
	2	45.0	49.3	55.3	46.5	49.0	48.6	48.6	42.6	42.6	44.6	45.6	46.3
	3	48.2	55.2	55.7	47.4	53.2	51.5	47.3	49.4	44.0	45.9	47.9	46.5
	4	49.5	51.1	51.7	47.2	48.1	51.7	48.4	43.9	39.4	45.2	45.7	45.5
3	1	48.5	48.6	49.6	50.4	48.0	50.0	42.1	48.2	46.5	48.8	44.8	45.2
	2	51.0	49.2	52.8	51.9	46.4	53.0	48.9	47.1	48.3	45.6	49.2	46.6
	3	50.5	53.3	53.0	52.4	51.8	57.1	45.3	46.1	48.9	45.0	46.2	50.5
	4	47.9	45.7	51.2	50.9	48.0	49.4	43.3	48.0	47.8	45.1	42.8	47.0
4	1	48.4	50.7	49.1	51.5	52.9	49.1	44.8	49.4	48.0	43.2	43.4	46.5
	2	51.8	50.1	51.4	54.0	52.2	48.3	49.4	51.5	45.8	44.0	48.4	46.1
	3	50.0	50.3	55.5	54.5	54.2	48.2	49.0	50.0	49.2	47.3	47.8	45.0
	4	51.8	48.3	52.9	46.7	51.8	51.4	47.5	49.4	47.4	45.5	43.5	44.2
Grand average		48.9	50.2	52.4	49.7	51.0	50.1	47.0	47.5	45.9	45.4	46.9	45.6

Table 4 presents the statistical analysis of the gin-treatment effects on the relative percent of fibers at the 1/2-inch point of the beard extending from the clamp. Moisture of cotton during ginning had a highly significant effect on the reading at 1/2 inch, whereas the other treatment effects were insignificant. There was a significant difference between samples taken from different parts of the bale.

TABLE 4.--Statistical analysis of gin-treatment effects on relative percent of fibers at 1/2-inch point of beard extending from clamp

Sources of variation	Degrees of freedom	Sum of squares	Mean Square	F value
Total	191	1985.44		
Treatments	11	924.53		
Lint moisture (LM)	1	760.02	760.02	62.00**
Seed cotton cleaning (SCC)	1	12.92	12.92	1.05
Lint cleaners (LC)	2	41.00	20.50	1.67
LM x LCC	1	3.68	3.68	0.30
LM x LC	2	51.22	25.61	2.08
SCC x LC	2	12.96	6.48	0.53
LM x LC x SCC	2	42.73	21.36	1.74 (Calculated from "between subsamples within treatments" mean square.)
Between subsample with treatments	36	441.55	12.26	2.85** (Calculated from "within subsamples" mean square.)
Within subsamples	144	619.36	4.30	

**Significant at the 1-percent level.

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