FAVIMAT ANALYSIS OF FIBER FINENESS DISTRIBUTIONS

C. D. Delhom
X. Cui
US Department of Agriculture, Agricultural Research Service
New Orleans, Louisiana
D. P. Thibodeaux
US Department of Agriculture, Agricultural Research Service
Clemson, South Carolina
J. E. Rodgers
US Department of Agriculture, Agricultural Research Service
New Orleans, Louisiana

Abstract

Fiber length, strength, and micronaire are the most commonly studied properties of cotton. Cotton fineness is also understood to be an important property of cotton and to affect how fibers perform when converted into yarn. Cotton is a natural material and, as such, has variable properties. In recent years it has become well understood that the distribution of properties, such as length, within a cotton sample provides more useful information that just a single average value. Until recently, it has not been practical to examine the distribution of fiber fineness throughout a cotton sample. The Favimat single fiber tester allows for the distribution of fiber fineness to be studied. The distribution of fiber fineness, as measured by the Favimat, is compared to the fineness distribution provided by the AFIS. Appropriate parameters for testing cotton on the Favimat are discussed and sources of error are identified. Single fiber testing requires a large number of observations to accurately represent a cotton sample's true properties. Work on identifying necessary sample size is reported.

Introduction

The Favimat (Textechno, Mönchengladbach, Germany) single fiber testing machine is capable of measuring single fiber properties such as tenacity, elongation, and linear density. The Favimat uses a constant rate of extension crosshead to measure fiber breaking strength and elongation. The Favimat utilizes the vibroscopic principle to measure linear density, or fiber fineness (Montgomery, 1952). Cotton is a natural material and its properties are heterogeneous. Most cotton testing instruments measure fiber properties in bulk. High Volume Instrument (HVI) measures the length, strength, and elongation of cotton fibers in a bundle. An average value of the bundle is reported for strength and elongation. The fineness of cotton is measured indirectly by the HVI through the measurement of micronaire. Laboratory instruments, such as the AFIS, are able to measure the length of individual fibers but not the strength. Fineness of individual fibers is measured by the AFIS; however this is done through a system of optics which measures the fiber shape at two different angles.

A number of attempts have been made to relate yarn properties to single fiber properties (Ramey et al., 1982 and Sasser et al., 1991). Yarn strength is a result of processing parameters and fiber properties. Fiber strength, length, and fineness all have a role in determining yarn strength. Finer fibers allow more fibers in a given cross-section of yarn. A better understanding of fiber fineness and the relationship of fiber fineness with other fiber properties can help produce better quality textile goods and better predict fiber damage. Understanding the distribution of fiber properties leads to a better understanding of how fiber properties interact and lead to textile properties.

Single fiber testing has evolved from the Dewey single fiber testes to the Mantis (Uster Technologies, Charlotte, NC) and currently the Favimat (Foulk, 2001). The automated loading of the Favimat allows for the possibility of single fiber testing becoming practical. Single fiber testing faces many challenges; in addition to the challenges of selecting and handling individual fibers, the number of fibers that must be observed to accurately represent the fiber properties as distributed throughout a bale of cotton is unknown. The objective of this study was to evaluate the feasibility of the Favimat as a cotton testing instrument, examine the distribution of fiber fineness that exists in cotton samples, and to begin to determine an acceptable number of observations necessary to characterize a cotton sample.

Materials and Methods

The Favimat instrument was setup according to the manufacturer representative's specifications (Measured Solutions, Greenville, SC). Testing of synthetic fibers is the standard application for the Favimat and a gauge length of 13 mm is suggested for standard testing. Due to the shorter length of cotton fibers, the manufacturer recommended a 10 mm gauge length. Tests were performed at both gauge lengths. The fibers were loaded into 25 fiber capacity magazines with a 100 mg weight clipped to the end of the fiber to allow the fiber to hang vertically to aid the Favimat Robot2 in transferring the fibers from the magazine to the test instrument. The test instrument pre-tensioned the fibers to 0.5 cN/tex and performed testing at a cross-head speed of 10 mm/min. The same cross-head speed was used for both gauge lengths. The Favimat was equipped with 2 mm upper and lower clamps in place of the standard 4 mm clamps to better enable the testing of cotton fibers. The Favimat requires that an approximate linear density be provided for the material being tested which allows the vibroscopic measuring unit to begin to determine the exact linear density. Testing of the cottons on an AFIS Pro (Uster Technologies, Charlotte, NC) was used to determine a value which would suffice for cotton. A value of 1.7 dtex was used for all of the cottons in this study; this value is the same average linear density as found in previous testing by Sasser, et al (1991).

A set of cottons used for the U.S. Department of Agriculture's Agricultural Marketing Service's 8x8 HVI test were chosen for use in this study. The 8x8 cottons are a set of eight cottons which collectively cover a wide range of upland cotton fiber properties. Three of the eight cottons were tested for the study being reported (Table 1 and 2). The three cottons were tested at both 10 and 13 mm gauge length. Approximately 1000 fibers were tested for each cotton at a given gauge length.

Table 1. Select HVI values for the selected 8x8 cottons

ID	Micronaire	Strength (cN/tex)	UHML (mm)	Uniformity Index
38 (31594)	4.55	32.7	30.2	84.2
37 (32422)	4.05	31.1	29.7	83.2
36 (31334)	4.52	26.9	28.8	82.8

Table 2. Select AFIS values for the selected 8x8 cottons

ID	Fineness (mtex)	UQL(w) (mm)	SFC(w) (%)	Maturity Ratio
38 (31594)	177.6	32.5	6.0	0.92
37 (32422)	160.4	32.0	7.1	0.90
36 (31334)	177.2	31.0	6.2	0.91

Testing was performed by selecting a fiber from a tuft of cotton using forceps. The fiber was laid on a velvet board to aid the operator in attaching the 100 mg weight clip. The operator visually assessed the fiber to ensure that the fiber was most-likely long enough to be successfully tested. Operators were encouraged to only discard fibers which were obviously too short to be tested. Four operators were used to randomly prepare fibers for testing in order to eliminate any operator bias. Although 13 mm, or 10 mm, of fiber length was needed for the gauge length, additional fiber length is needed for the weight clip, the fiber clamps on the Favimat, the magazine, and the robot fiber transport arm resulting in the need for an addition 8-9 mm in length, at a minimum.

Results and Discussion

The Favimat was initially set up to test cotton fibers using a 10 mm gauge length. Approximately 1000 fibers were successfully tested of each of three cotton samples utilizing this setup. Testing was only successfully on ~75% of the fibers mounted in the magazines. In order to obtain 1000 good test results, over 1300 fibers had to be selected and loaded into the magazines. The unsuccessful tests included tests in which the fiber was too short to load properly, the weight clip fell off the fiber, fiber slippage in the clamp, and instrument malfunctions. Table 3 shows the results for the three cottons tested at 10 mm.

Table 3. Favimat results at 10 mm gauge length

ID	n	Elongation (%)		Tenacity (cN/tex)		Linear Density	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
38	1014	9.44	3.41	24.8	11.7	2.47	0.86
37	1012	8.50	3.24	22.5	11.6	2.43	0.86
36	999	9.36	3.58	18.2	9.0	2.47	0.70

The standard deviations for tenacity were observed to be quite high. The linear density results for the cottons were consistent with each other, but were considerably different than the AFIS fineness results. Figures 1-3 show the fineness distributions as measured by the AFIS and the Favimat. The plots reveal a bimodal distribution for the Favimat results. The AFIS plot for cottons 38 and 37 reveal a bimodal distribution near the mean, however it does not show up for cotton 36, nor does it seem to relate to the bimodal distribution observed in the Favimat data. The bimodal distribution in the AFIS data for cottons 38 and 37 relate to the inflection observed in the Favimat data between 1.4 and 2.0 dtex. The bimodal distributions account for the significantly higher mean value observed for the linear density on the Favimat compared to the AFIS.

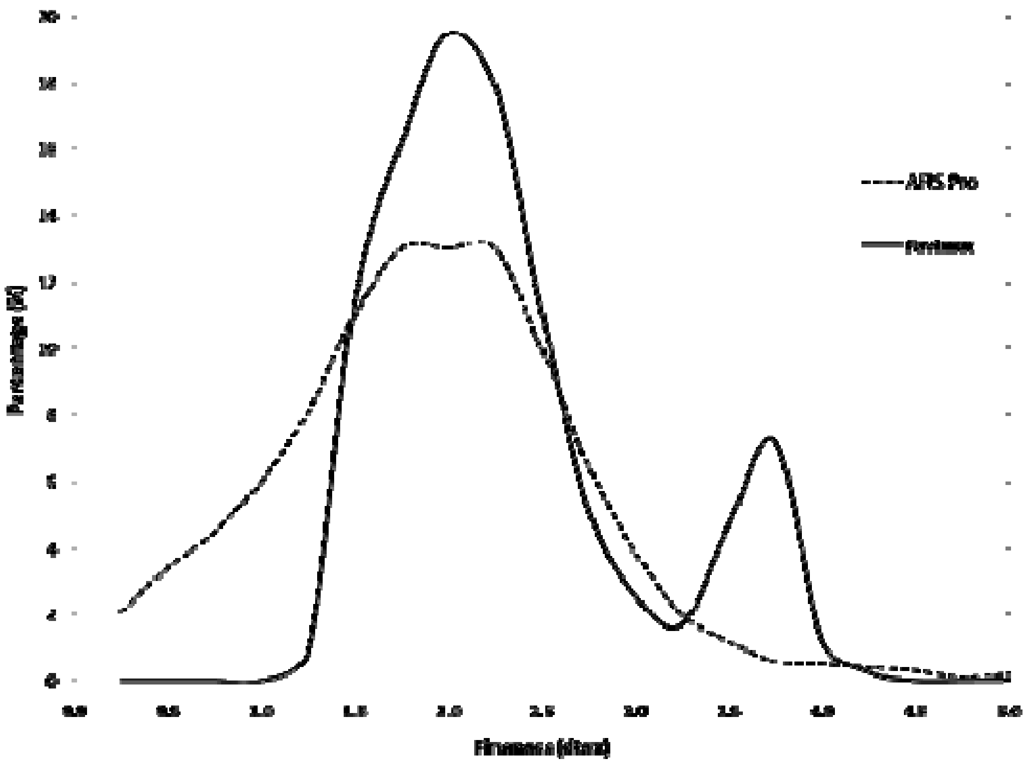

Figure 1. AFIS and Favimat fineness distribution plots for cotton 38 at 10 mm gauge length

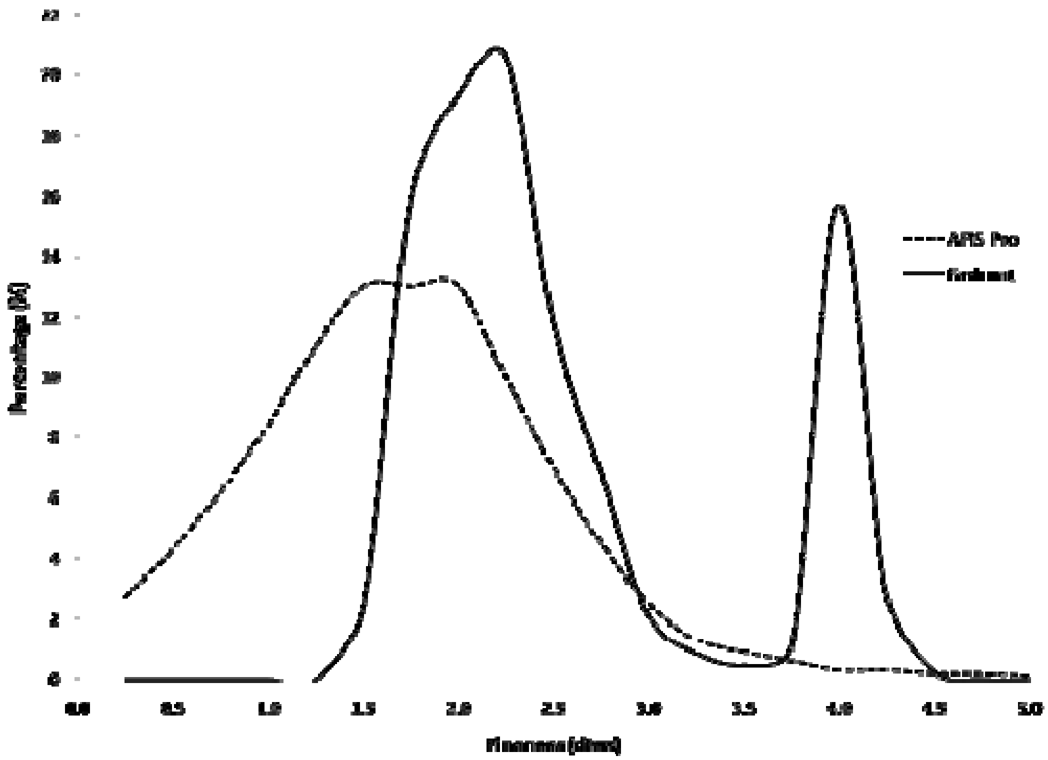

Figure 2. AFIS and Favimat fineness distribution plots for cotton 37 at 10 mm gauge length

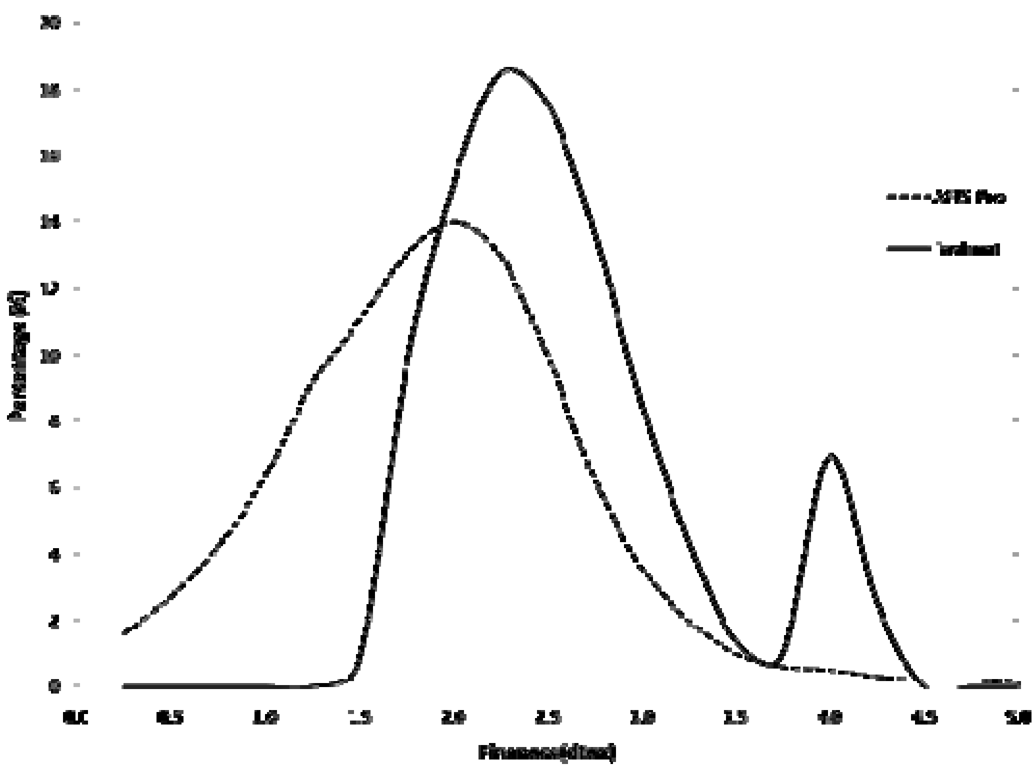

Figure 3. AFIS and Favimat fineness distribution plots for cotton 36 at 10 mm gauge length

The smaller distribution in the bimodal distribution always appears on the right side of the distribution, indicating coarser fibers. The amount of material registering in this region varies from 11.9% for cotton 36 to 21.1% for cotton 37. Literature searches did not reveal any references to a bimodal distribution being observed for cotton fiber fineness. The accuracy and validity of the data come into question when reviewing this data. Further testing was conducted using synthetic fibers of known linear density values. The results of this additional investigation are not presented here, however the conclusion was to retest the cottons using 13 mm gauge length, as the instrument is normally operated.

The results from retesting the three cottons using 13 mm gauge length provide a significantly lower average linear density along with a standard deviation approximately 50% smaller than the results at 10 mm. The linear density measurements do not match the fineness values from the AFIS but they follow the same trend, with cotton 37 being the lowest linear density and most fine fiber. Figures 4-6 show the fineness distributions as measured by the AFIS and the Favimat, utilizing 13 mm gauge length.

Table 4. Favimat results at 13 mm gauge length

ID	n	Elongation (%)		Tenacity (cN/tex)		Linear Density	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
38	1012	8.57	3.07	24.6	9.6	2.18	0.39
37	998	7.47	2.84	22.2	9.6	2.03	0.39
36	1040	8.32	3.34	18.0	8.4	2.11	0.38

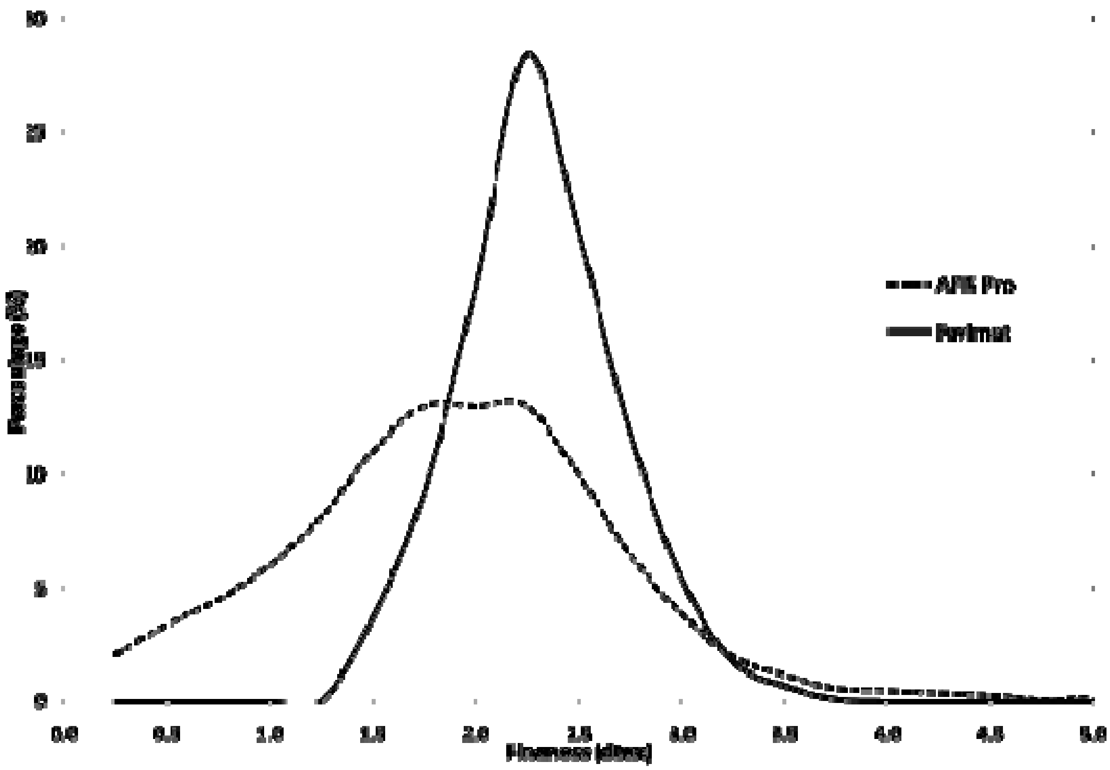

Figure 4. AFIS and Favimat fineness distribution plots for cotton 38 at 13 mm gauge length

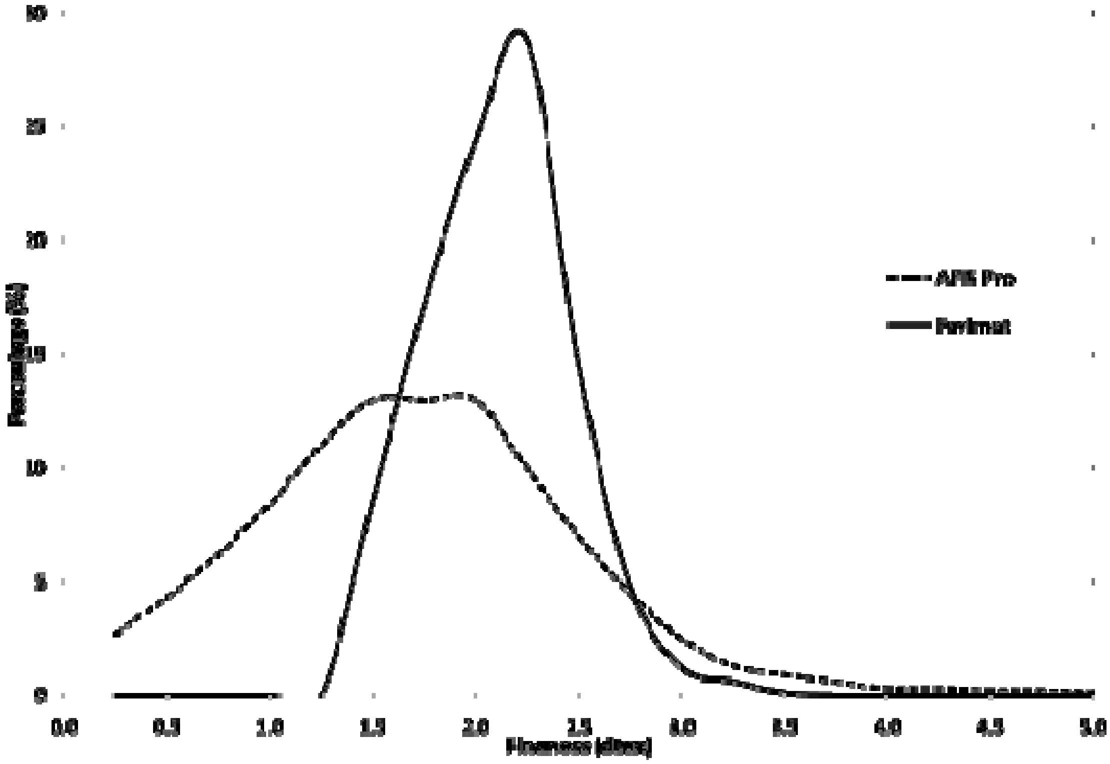

Figure 5. AFIS and Favimat fineness distribution plots for cotton 37 at 13 mm gauge length

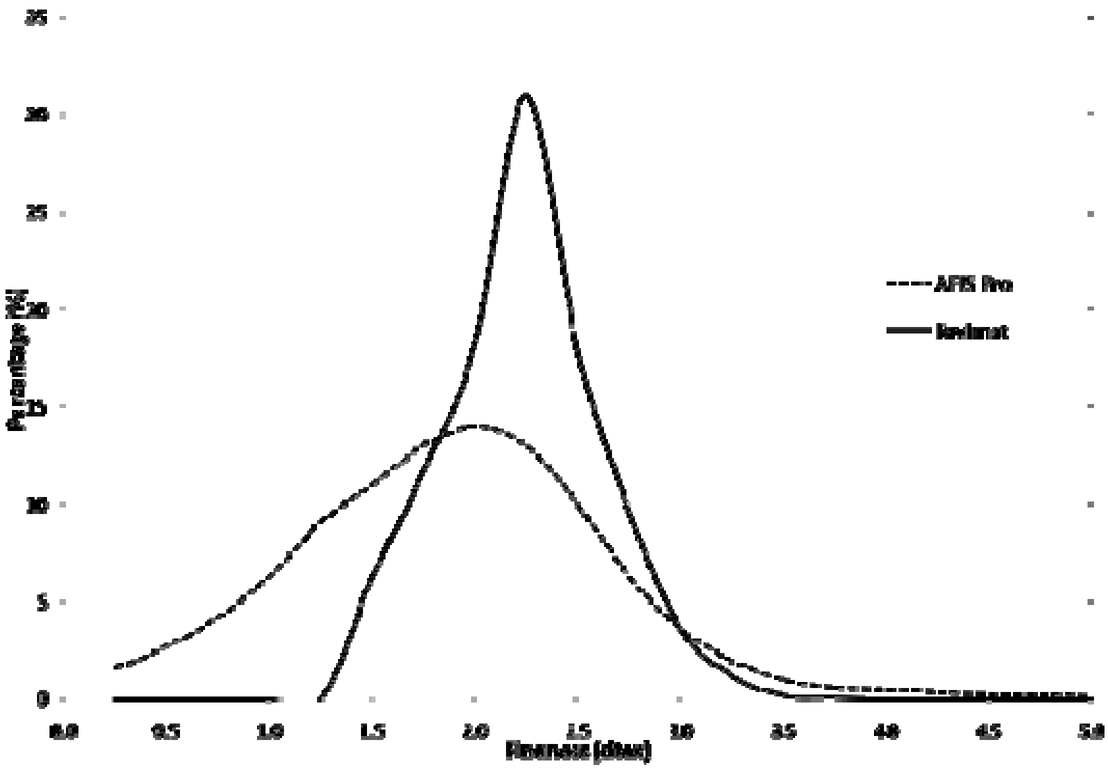

Figure 6. AFIS and Favimat fineness distribution plots for cotton 36 at 13 mm gauge length

The use of 13 mm gauge length completely eliminates the bimodal distribution observed in the first set of data. The mean and overall distribution of fineness is higher for Favimat data rather than AFIS data. The AFIS data shown is based on the average of five repetitions of 5000 fibers each. The AFIS is able to assess the fineness of fibers of all lengths which pass through the sensors. The Favimat data is strictly based on observations of fibers 20 mm and longer due to limitations in the handling and mounting of specimens. Additional work is needed to determine if the difference is due to this length bias or other causes.

The data clearly illustrates that 10 mm is not an acceptable gauge length for fineness testing of cotton fiber using the Favimat. The vibroscopic method determines fiber fineness using well-known laws of physics governing fundament frequencies. The fundamental frequency of an object is the lowest natural frequency for the object. The Favimat utilizes an audio oscillator to emit a sound at a range of frequencies while an optical sensor determines when the fundamental frequency of the fiber has been reached. The audio oscillator allows the Favimat to vibrate the fiber without the oscillator being in direct contact with the fiber. The vibration takes place while the fiber is clamped in the jaws of the Favimat at a constant pre-tension, 0.5 cN/tex. The Favimat calculates the linear density of the fiber using equation 1, where T is the linear density, F is the pretension force, f is the natural frequency, and L is the gauge length.

$$T = F / (4 f^2 L^2) \qquad (1)$$

It is necessary that the gauge length be long enough to allow the stiffness of the fiber to be overcome, and the fiber to vibrate. The stiffness of a fiber is related to the Young's modulus, E, and moment of inertia, I. The cross-sectional area of a fiber is approximated as a circle. The moment of inertia for a circular cross-section is given by equation 2, where d is the diameter of the circle.

$$I = \pi d^4 / 64 \qquad (2)$$

As reported by Montgomery (1952), there is a dimensionless stiffness factor, α, that governs the vibration of the fiber. The stiffness factor is defined in equation 3.

$$\alpha = (4 E I / L^2 F)^{1/2} \qquad (3)$$

Equations 1-3 show how the interaction of the natural properties of the material (modulus and moment of inertia) interact with the gauge length and pre-tension of the instrument to determine the components of the natural system that allow the fiber to vibrate freely at that system's natural frequency. The assumptions of the principle are that a cotton fiber has a cross-section which is circular on average and that the modulus of the material is uniform along the gauge length being tested. Neither of these assumptions are perfect and are both sources of error.

The results shown clearly demonstrate that the Favimat has potential as a cotton fiber testing instrument. The results also hint at new information being discovered with the help of the Favimat, or similar instruments, which may help to improve the assessment of the quality of cotton fiber. Single fiber testing is tedious and requires considerable time to accomplish. The tediousness of single fiber testing usually makes it an impractical approach. The addition of the Robot2 to the Favimat increases the production rate of the tester. The use of multiple magazines allows for multiple operators to prepare and mount fibers which the instrument can test automatically, including being operated unsupervised. A lingering question about single cotton fiber testing is the number of observations that must be conducted to properly and adequately represent a cotton sample. The length bias of the instrument has been discussed. The above data consists of approximately 1000 fiber observations for each sample studied.

A mathematical model was used to randomly sample 250, 300, and 500 fibers from the original population of approximately 1000 fibers. This model was run 10 times for each sampled cotton. The average of the mean and standard deviation for the 10 random samplings is shown in table 5 for each simulated population. The simulations, when compared to the results for the full population (Table 4) show that it may be feasible to perform single fiber testing using a smaller sample size than previously believed. More extensive testing is needed to confirm what these three cotton samples indicate. The three cottons shown in this report have relatively high uniformity which would allow for a smaller sample size to represent the population as a whole. Less uniform cottons will need to be studied in order to confirm an acceptable population size.

Table 5. Favimat results with varying modeled number of observations at 13 mm gauge length

ID	n	Elongation (%)		Tenacity (cN/tex)		Linear Density	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
38	250	8.55	3.10	24.7	9.6	2.18	0.38
38	300	8.64	3.08	24.6	9.6	2.18	0.38
38	500	8.47	3.02	24.5	9.6	2.18	0.38
37	250	7.41	2.77	22.4	9.4	1.98	0.36
37	300	7.43	2.79	22.6	9.9	2.00	0.38
37	500	7.48	2.84	22.5	9.6	2.00	0.39
36	250	8.34	3.39	18.1	8.4	2.11	0.38
36	300	8.30	3.30	18.0	8.4	2.11	0.38
36	500	8.35	3.37	18.0	8.3	2.11	0.38

Summary

The Favimat instrument has shown potential for practical use in cotton fiber testing. The acceptable number of fibers to accurately represent a complete sample of fiber is still under examination; however it appears possible to accurately represent a cotton sample without testing tens of thousands of fibers individually. The fineness distribution data presented will help to better understand the role fineness plays in predicting yarn and fabric properties from fiber properties. There are several assumptions used in the vibroscopic method that are not ideal and more testing is needed to determine the level of error in the data from these assumptions.

The Favimat instrument is capable of examining single fiber properties in addition to linear density, which is the focus of this report, more research is needed to examine the usefulness of all of the data generated by the Favimat. Work is ongoing to measure the remaining five cottons from the 8x8 cotton set. Additional data is currently being analyzed to determine optimal settings for gauge length and pretension to accurately measure cotton fineness. Future work is planned to examine the relationship of fiber length to fiber fineness.

Disclaimer

The use of a company or product name is solely for the purpose of providing specific information and does not imply approval or recommendation by the United States Department of Agriculture to the exclusion of others.

Acknowledgements

The authors are grateful for the help of the technicians in the Materials Testing Laboratory at the U.S. Department of Agriculture's Southern Regional Research Center in New Orleans, Louisiana, without the dedication and attention of these technicians the data presented in this report would not have been possible.

References

Foulk, J. and McAlister, D. 2001. Favimat analysis of single cotton fibers. In *Proc of the Beltwide Cotton Conference*. 1261-1267. Memphis, TN.

Montgomery, D.J. and Milloway, W.T. 1952. The vibroscopic method for determination of fiber cross-sectional area. Textile Res. J., 22:729-735.

Ramey, H. 1982. The meaning and assessment of cotton fibre fineness. International Institute for Cotton, Technical Research Division. Manchester, UK. 19 pp.

Sasser, P.E., Shofner, F.M., Chu, Y.T., Shofner, C.K., and Townes, M.G. 1991. Interpretations of single fiber, bundle, and yarn tenacity data. Textile Res. J., 61:681-690.