USING OBJECTIVE FIBER PROPERTY MEASUREMENTS AT ALTERNATIVE PROCESSING STAGES TO PREDICT YARN QUALITY

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Introduction

The use of fiber property measurements in statistically based quality control programs for yarn manufacturing has become common during the past fifteen years. Movement of this approach into the management mainstream has been based largely on the availability of high volume instrument (HVI) data, which was designed and primarily used for raw cotton; i.e., ginned and baled cotton lint. Since HVI measurements are based on bundles of fibers, they are sensitive to sample preparation and technique. Therefore, using HVI measurements at any stage beyond the raw fiber state raises questions of measurement errors and the relative utility of the measurements [Duckett, et. al. 1993; Fryer and Rust 1996; Fryer, et. al. 1994; Lord and Rust 1994; Suh, et. al. 1993].

The development of the Advanced Fiber Information System (AFIS) provided the first commercial capability to focus automated measurements on individual fibers. This focus brought with it a greatly enhanced capability to get comparable measurements on raw versus partially processed fibers. Indeed, current uses of AFIS generally involve monitoring the effectiveness of the processing machinery and impacts on the fibers up through the finisher drawing [Oxenham, et. al. 1995].

Under controlled conditions within the spinning laboratories of the International Textile Center (ITC), the usefulness of alternative fiber property measurements at different stages may be authoritatively examined. The information obtained will enable progress toward (1) understanding the sampling and measurement effects on fiber property data and (2) improving the application of fiber property data to quality control management.

Results reported here come from 156 samples of cotton from all over the world; 106 of the samples are from Upland cotton varieties and 50 samples are from extra long staple (ELS) cotton varieties. Since the research encompasses both Upland and ELS cottons, results were obtained for: (1) carded Upland and ELS cottons that were ring spun into Ne 36 yarns, (2) combed ELS cottons that were ring spun into Ne 50 and Ne 80 yarns,(3) carded Upland cottons that were ring spun into Ne 24 yarns, (4) carded Upland cottons that were rotor spun into Ne 18 and Ne 36 yarns, and (5) carded ELS cottons that were rotor spun into Ne 36 yarns.

This report deals only with results for Upland and ELS cottons combined. Therefore, results are limited to the first category given above; i.e., carded cotton spun on the ring system to make Ne 36 yarns. This approach maximizes the range of data collected on objective fiber properties, which strengthens the statistical basis for drawing conclusions about the influence of these properties on spinning performance and yarn quality.

Results specific to ELS cottons have previously been reported [Ethridge and Zhu, 1997; Zhu and Ethridge, 1997]. The research for these previous reports, as for this one, has been funded by an Advanced Technology Program project administered by the Texas Higher Education Coordinating Board.

Experimental Procedures

The cotton samples contained approximately 20 kg of ginned lint, in order to perform both fiber and spinning tests. The fiber tests used for this report are summarized in Table 1, where symbols used for each fiber property are also given. The fiber tests are consistent with the commercially available HVI and AFIS instruments; however, the HVI leaf measurement is omitted in favor of the AFIS trash measurement.

The yarn quality tests used for this report are the following:

- Count-strength product (CSP = lb x Ne), measured by the Scot Pendulum Tester
- Non-uniformity (CV%), measured by the Uster Tester 3

The fiber tests were done at the following stages:

- Prior to opening and cleaning (on the ginned lint)
- After opening and cleaning but prior to carding (at the chute feeder)
- After carding (on the card sliver)

The processing steps and machinery used are shown in Figure 1. Some critical machine parameters are given in Table 2. These machinery and settings were used throughout, in order that processing conditions be held constant in every test.

Data and Analysis

A statistical summary of all fiber property measurements taken on the 156 samples <u>prior to processing</u> is given in Table 3. Since the samples came from all over the world, the properties should be spread over the full population distribution. However, the cottons used were generally good specimens of their varieties, so occurrences of deteriorated properties (from insects, weather stress, ginning, etc.) would not be expected.

It is generally agreed that:

1. Both the central tendencies and the dispersions of the fiber properties are altered by further processing.
2. The measurements of the properties are likely to be affected by the processing stages; especially for those measurements taken on fiber bundles, as with the HVI.

The impacts on average values of each of the eleven fiber properties are summarized in Table 4, comparing the values of raw cotton with those at the chute and at the card. It may be observed that:

- Several fiber property measurements deteriorated at the chute; i.e., strength, elongation, length, length uniformity, micronaire, short fiber content, and neps. The only measurement that was clearly improved by the opening and cleaning process was trash content.
- The carding machine restored most of the fiber property measurements to a level near the measurements recorded on the ginned lint. Five of the measurements at the card are noteworthy for being the best of the three measurements taken; namely, strength, elongation, short fiber content, neps, and trash.

The uncomfortable fact is that it is virtually impossible to interpret the meaning of any changes in color–i.e., in reflectance and yellowness–as further processing is done. Unless color is related to other aspects (e.g., type and variety, weathering, bacterial damage, etc.), it is of limited use in managing the mechanical aspects of textile processing of cotton fibers.

Based on an examination of statistical indicators, along with *a priori* knowledge of fiber property measurements, four of the fiber properties were excluded from the variables used to predict yarn strength and non-uniformity. There were the following:

- **Elongation (E)** - This measurement is highly autocorrelated with several other fiber property measurements, rendering it useless in statistical prediction.
- **Trash (T)** - This is a contaminant and its impact on yarn quality is going to depend largely on the efficiency of the textile processing machinery in removing it from the lint. In this experiment the machinery performance was held virtually constant; therefore, the trash variable was not useful.
- **Reflectance (R)** - Across the range of cotton types and varieties examined here, the reflectance of the fibers is impossible to interpret. Furthermore, the impacts on fiber properties were inconsistent and/or

statistically insignificant.
- **Yellowness (Y)** - The same conclusions apply to yellowness that apply to reflectance.

The remaining seven fiber property variables were used in multiple linear regression equations to explain the count strength product (CSP) and the non-uniformity (CV%) of the yarns produced. Stepwise regression was used to screen fiber variables for both correlation with yarn variables and autocorrelation with other fiber variables. The resulting "best-fitting" equations are shown in Table 5. In this table, only the coefficients which were significantly different from zero at the 95% confidence level are kept in the regression equations. Table 6 shows the sequence of selection of each fiber property variable for each of the stepwise regressions. The order of their selection is based on statistical significance; therefore, it ranks the explanatory power of each variable. For example, in the regression of CSP on raw fiber properties, in the fifth step (or iteration) micronaire (M) barely exceeded the threshold for being included in the equation.

Conclusions

The results in Table 5 are remarkable for the "goodness of fit" in a statistical sense. Thus, all of the coefficient of determination (R^2) values are at 0.9 or higher, which means that all of the regression equations explain 90% or more of the changes in yarn properties. Such strong explanatory power is made possible by the combination of a large number of fiber samples and a wide range of fiber properties.

The results are made more remarkable by the fact that all of the variables are linear. The inclusion of non-linear forms of the fiber property variables did not significantly improve the fit of the regression equations. Furthermore, examination of the distributions of the error terms resulting from the linear regressions did not reveal significant departures from randomness. This result has to be taken as somewhat unexpected; *a priori*, it seemed likely that some non-linearity would occur over the wide range of fiber properties covered. The fact that it did not occur increases confidence that linear specification of prediction equations are adequate for quality control in textile mills.

Major conclusions for CSP include the following:

- Fiber property measurements at the chute feeder going into the card machine provide the best statistical fit for predicting CSP; this is clearly revealed by the very large value for the F statistic (Table 5). Measurements on the card sliver are second best, while measurements on the raw fiber are third.
- All three of the R^2 values are very high, assuring that measurements at any of these stages may be used with confidence.
- The useful fiber variables for explaining yarn CSP are strength (s), length (l), short fiber content (sf), and diameter (d). It is noteworthy that length was selected first in the raw fiber regression, but was selected last in the chute and card fiber regressions (Table 6). Meanwhile, strength moved from third to first in the order of selection.
- Measures of fiber uniformity and neps were not useful for explaining CSP values; they were not included in any of the regression equations.
- Measures of micronaire were of little use; this variable was included in the regression on raw fibers but was excluded from the regressions on chute and card fibers.
- The regression coefficient for micronaire must be interpreted as a <u>residual</u> effect, which is detected <u>after</u> the impact of fiber diameter is determined. Micronaire was the last fiber property selected in the regression on raw fibers (Table 6). Furthermore, the positive sign of its coefficient (Table 5) must be interpreted as an impact of fiber maturity, with the diameter measurement having already captured the influence of fiber fineness.
- All of the signs of the coefficients in all equations are consistent with *a priori* expectations.

Major conclusions for CV% include the following:

- By a small margin, fiber property measurements on the raw fiber provide the best statistical fit for predicting CV%. A close second is the chute measurements and a close third is the card measurements (Table

5). Measurements on the card sliver are second best, while measurements on the raw fiber are third.

- The dominant fiber variables for explaining yarn CV% are short fiber content (SF), length (L), diameter (D), and neps (N). The most dominant variable is SF, which was selected first in all regressions (Table 6). L was selected in the regression on chute fiber; however, after the impacts of D and U were incorporated, L failed to make a significant contribution and was removed from the equation. In fact, L managed to survive only in the regression on raw fibers; it was replaced by U in the other two equations (Table 4).
- Measures of fiber strength were not useful for explaining the CV%; they were not included in any of the regression equations.
- As with the CSP, The regression coefficient for M must be interpreted as a <u>residual</u> effect in the equations for CV%. It is always selected after D and the negative sign of its coefficients makes sense only if interpreted as an impact of fiber maturity (with the diameter measurement having already captured the influence of fiber fineness).
- All of the signs of the coefficients in all equations are consistent with *a priori* expectations.

A high degree of processing control and a wide range of objective fiber properties have been combined here to provide authoritative guidance on the use of fiber properties to control yarn quality indicators like CSP and CV%. Other areas where this methodology needs to be applied include blends of diverse cotton fibers and other yarn and fabric qualities.

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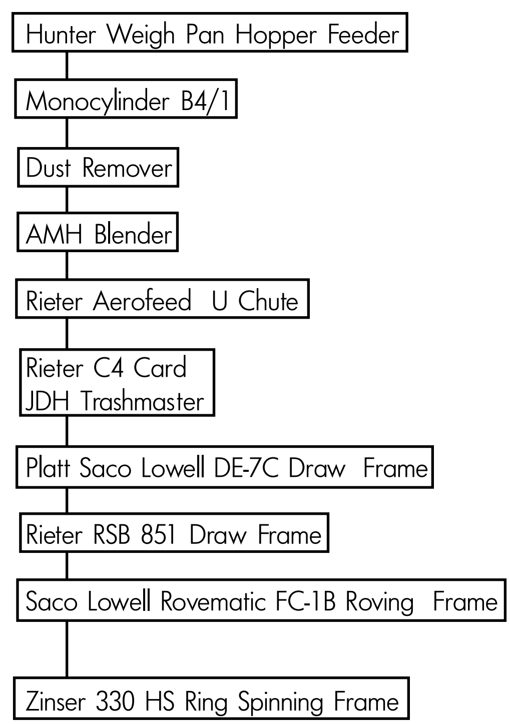

Figure 1: Processing Flow

Table 1. Fiber Property Measurements

Instrument	Measurement	Symbol
Spinlab HVI	1/8 in Gauge Strength (g/tex) (g/tex)	S
	Elongation (%)	E
	Length (in)	L
	Uniformity Ratio (%)	U
	Micronaire Value (μg/in)	M
	Reflectance (Rd)	R
	Yellowness (+b)	Y
Uster AFIS	Short Fiber Content (% by weight)	SF
	Diameter (μm)	D
	Trash (no/g)	T
	Neps (no/g)	N

Table 2. Machine Operating Parameters

Machine	Operating Parameters
Monocylinder Cleaner	Roll Speed = 750 rpm
Card	Production Rate = 60 lb/hr Sliver Weight = 60 gr/yd
Opening Draw Frame	Delivery Speed = 570 ft/min Sliver Weight = 55 gr/yd
Finishing Draw Frame	Delivery Speed = 990 ft/min Sliver Weight = 55 gr/yd
Ring Spinning Frame	Spindle Speed = 18,000 rpm Ring Diameter = 36 mm

Table 3. Statistical Measures of Raw Fiber Properties

Property	Mean	Std. Dev.	Min.	Max.
S	33.4	4.94	24.3	44.4
E	6.3	0.67	4.8	7.9
L	1.2	0.13	0.99	1.50
U	83.8	1.94	80.3	88.3
M	4.0	0.57	2.3	5.4
R	73.8	4.99	63.4	81.8
Y	9.6	1.44	6.8	14.1
SF	6.5	2.27	2.9	12.1
D	12.3	1.22	9.5	14.9
T	775.3	838.94	24	8,174
N	270.1	128.52	80	725

Table 4. Average Fiber Property Values at Different Stages

Property	Raw	Chute	Card
S	33.4	32.4	34.1
E	6.3	6.2	6.5
L	1.2	1.2	1.2
U	83.8	82.9	83.6
M	4.0	4.0	4.0
R	73.8	74.8	77.1
Y	9.6	10.5	10.7
SF	6.5	6.5	6.2
D	12.3	12.3	12.2
T	775.3	470.8	136.1
N	270.1	413.1	196.1

Table 5. Stepwise Multiple Regression of Ne 36 Ring Spun Yarn Properties on Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP			
Stage:	Raw	Chute	Card
F Value:	596.21	1,175.66	895.49
R^2:	0.96	0.97	0.96
Independent Variables			
S	49.96	65.24	55.30
L	806.71	419.07	435.29
U			
M	47.42		
SF	-39.94	-55.66	-46.97
D	-221.68	-209.80	-230.12
N			
Constant	3,331.37	3,495.62	3,861.41

Dependent Yarn Variable: CV%			
Stage:	Raw	Chute	Card
F Value:	292.61	287.62	281.44
R^2:	0.92	0.91	0.90
Independent Variables			
S			
L	-2.73		
U		-0.22	-0.17
M	-0.36	-0.26	-0.70
SF	0.25	0.41	0.27
D	0.56	0.51	0.92
N	0.003	0.0007	0.001
Constant	11.81	26.55	20.38

Table 6. Sequence of Selection of Fiber Property Variables in Stepwise Regressions

Stage	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
			Dependent Yarn Variable: CSP				
Raw	L	D	S	SF	M		
Chute	S	D	SF	L			
Card	S	D	SF	L			
			Dependent Yarn Variable: CV%				
Raw	SF	L	N	D	M		
Chute	SF	L	D	U	(L)	N	M
Card	SF	D	M	N	U		

Note: Parentheses denote that a variable was removed.

ITC Cotton Fiber Properties Seminar Participants

front row: Felix Schilling, Delta & Pine Land International; M'Lys Lloyd, Vance Publications; Cyndy Bhattacharya, Pillowtex Corp.; Laura Decanini, Texas A&M Univ.; Peggy Burden, J.G. Boswell Co.; Angie Goodman, ACG Cotton Marketing; Ann Johnson, USDA, ARS, SRRC.
back row: Dean Ethridge, ITC; Mike Grunder, Mount Vernon Mill (Brentex); Mike Bragdon, Fieldcrest Cannon; Tony Pastori, Fieldcrest Cannon; Ted Wallace, Mississippi State Univ.; Brett Anderhub, Rikerdres & Sons Insurance; Bryant Rayngay, Rainbow Organic Mill; Bill Sheehan, Lands End; Richard Dennard, Pillowtex Corp.; Richard Johnson, USDA, ARS, SRRC; Randy Boman, Tx Ag Extension Service, Lubbock; Howard Mills, Pillowtex Corp. The ITC will offer the seminar at least one time in 1998.