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QUALITY MEASUREMENTS

Improved High Volume Instrument Elongation Measurements

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INTERPRETIVE SUMMARY

How can the elongation measurement of the high volume instrument (HVI) be improved? A paper index card is clamped by the HVI breaker system and used to measure the system deflection as a function of load. This measured response is then used to correct the stress-strain response of cotton bundle breaks. The elongation of the cotton fibers at the peak of the curve is calculated from the corrected curve. A test group of 18 cottons was measured and compared to Mantis® single-fiber data. The USDA crop samples from 1990 to 1994 were also measured using the modified HVI method, and the new results compared to standard HVI measurements.

The modified analysis of the stress-strain curve based on the index card deflection produced a measurement for elongation that was more precise and had a lower standard deviation, compared to standard measurements on the HVI. Comparisons with simulated curves generated from Mantis® single-fiber data showed similar levels of elongation. However, both the modified HVI and Mantis® results were almost double stelometer elongation values. Correlations with stelometer data give a slope of approximately one with an offset of approximately 5%.

In all cases when measurements made on the 1990 to 1994 USDA crop samples were incorporated as predictors in yarn models, the new HVI elongation measurement proved to be a better predictor of yarn properties than were stelometer elongation data.

ABSTRACT

Cotton fiber elongation (extensibility, elongation at breaking load) is one of the least utilized measurements from the high volume instrument (HVI). This may be due, in part, to the large standard deviation of this HVI measurement. In addition, the correlation of fiber elongation with yarn elongation is not as high as the physical theory of yarn strength suggests. Thus, an improved method for deriving elongation from HVI stress-strain data was needed. The response of the HVI breaker system was characterized by clamping an index card in the jaws and measuring the tensional force applied to the non-rupturing card. This measured response was then used to correct the raw HVI stress-strain curves. A modified analysis of this corrected stress-strain curve resulted in improved measurements of fiber elongation and crimp. A set of 18 cottons was broken at 10 different break amounts to test the validity of the curve correction and modified analysis. Comparisons of these modified measurements with bundle stress-strain curves generated from Mantis® single-fiber data showed similar levels of elongation (approximately 5% higher than traditional stelometer values). Measurements were also made on samples from the 1990 through 1994 crops in order to investigate the correlations of the modified elongation data with stelometer data and to determine the utility of the modified elongation measurements as predictors in yarn strength and elongation models.

Materials, including cotton fibers, change shape or deform when external *stress* (force per unit area) is applied. This deformation normally occurs almost instantaneously and is quantified as *strain* (the ratio of the change in size to the initial size). Deformational strain in response to stress may be extensional (e.g. a change in length of a column) or shear (e.g. as in the bending of a beam) (Mintzer et al., 1957; Preston, 1974). The ratio of stress to strain is referred to as a modulus – the bulk modulus for compressive stress, Young's modulus for tensile stress, and shear modulus for shearing stress. As long as the elastic limit of the stressed material is not exceeded, the mechanical system returns to the original form when the stress load is removed. In

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Abbreviations: HVI, high volume instrument; ICC, International Calibration Cotton.

such ideally elastic materials, the modulus is constant. This is referred to as Hooke's law, and materials obeying Hooke’s law are referred to as Hookean solids [Reiner, 1966]. However, the strains for which Hooke’s law holds are quite small, and the elastic limit of cotton fiber cell walls is exceeded after only very small strains [Preston, 1974]. Moreover, the value of Young’s modulus is time-dependent in that the precise value depends on the rate of application of stress and is history-dependent in that repeated stretching, even within the elastic limit, changes fiber structure and, hence, the modulus [Preston, 1974].

In addition to the natural deviations of cotton fibers from the Hooke’s law ideal [Preston, 1974], deformations within the mechanical system used to produce strength and corresponding elongation measurements also create errors in measurements of the elongation of the fiber beard as the beard is broken [Taylor, 1986; 1995]. The basic mechanism for breaking a fiber beard in a Spinlab high volume instrument (HVI) is shown in Figure 1. When a fiber beard is analyzed, the comb first moves to the right, measuring the fiber length by Fibrograph [ASTM D 4605-86, 1993, ASTM D 1447-89, 1994; Taylor, 1995]. The comb is then moved to the left so that the desired ‘break amount’ of fiber is positioned over the leading edge of the rear jaw. The jaws clamp the beard; and the breaker step motor rotates, causing the rear jaws to move to the right at constant velocity. Force and displacement voltage signals are recorded at every second step of the breaker step motor [ASTM 4605-86, 1993].

The force exerted on the jaws by the fiber beard causes the breaker system to deform. As load is applied to the jaws by the fiber beard, the jaws deflect, the force transducer and mounting brass screws stretch, and the main beam coupling the motor to the force transducer at the rear deflects. Since the traditional method for measuring stress or displacement is the rotation of the motor, these deformations in the mechanical system create errors in measurements of the stress-strain curve for the fiber beard.

When considering the deflection of the breaker system, it is important to consider the relative magnitude of the distances involved in fiber elongation and the breaking of the fiber beard. If the elongation is 10% and the break gage is 3.175 mm, the total travel to the peak of the stress-strain curve is only 0.3175 mm. Thus, even small deflections are important in measuring elongation. A total deflection of only 0.0381 mm represents a 20% error in a 6% elongation measurement.

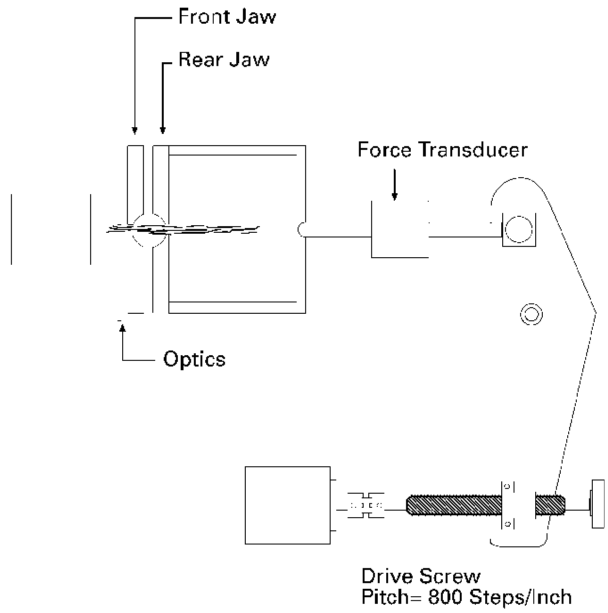

Fig. 1. HVI breaker mechanism diagram.

Displacement transducers mounted near the jaws have been used to measure the motion of jaws directly. However, the mechanical design of the HVI prevents direct attachment of transducers to the jaws at the clamp point without compromising the mechanical integrity of the breaker system. This limitation, the small displacements involved in elongation measurements, and the signal-to-noise ratio of the transducers have limited the success of this approach [Riley, 1996].

Further, the pitch of the screw coupled with the step angle of the step motor produces 25.4 mm of travel for the ball-nut assembly with every 800 steps [Riley, 1996]. As the step motor rotates, a reading of the force transducer is made at every two steps, which is equivalent to 0.0635 mm of travel of the ball-nut assembly on the breaker motor. The lever arm ratio is 3:1, which corresponds to a reading after every 0.0212 mm of travel of the rear jaw, assuming that there is no deformation deflection in the system. Since the break gage is 3.175 mm, this travel increment for each increment in the index corresponds to an elongation increment of 0.67%.

As a graphic example, a force and displacement curve for a strong cotton plotted against this index is shown in Figure 2. If there were no deflection, the displacement curve would have been a straight line.

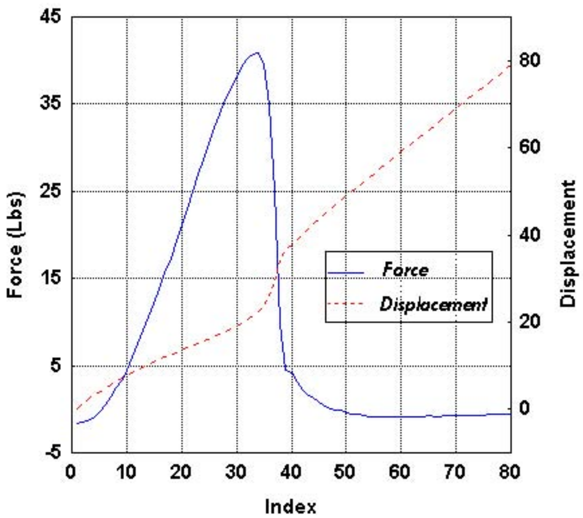

Fig. 2. Force and jaw displacement *vs.* motion of step motor.

Deviations from a straight line represent the deformation within the system. As the load on the system increases, the curve deflection becomes greater. At the peak of the curve for a strong cotton, the deflection represents about 30% of the total travel. (In offered example, the fibers used were from a D-6 cotton, one of the strongest cottons tested with a strength of about 34 g tex^{-1} on the International Calibration Cotton (ICC) scale.)

The maximum deflections of the HVI breaker system depend on both the strength of the cotton and the selected break mass [Taylor, 1995]. The range of deflections encountered in cotton fiber force/displacement curves is from approximately 6% to 35% [Riley, 1996].

The most successful stress-strain curves plot the force for the motion of the rear jaw at equidistant points. Since the curves in Figure 2 can be represented by a pair of parametric equations with a common variable of index, the index variable can be eliminated from the two equations and a composite 'corrected' curve plotted. An example of the raw curve measured by the HVI and the same curve corrected for deflection is shown for staple type 37 in Figure 3. In this way, the mechanical displacement error problem may be resolved by obtaining the curve representing the travel distance of the rear jaw as a function of the index variable for each sample.

In addition to the correction calculations described above, a direct measurement of HVI jaw deformation and the resulting stress-strain curve

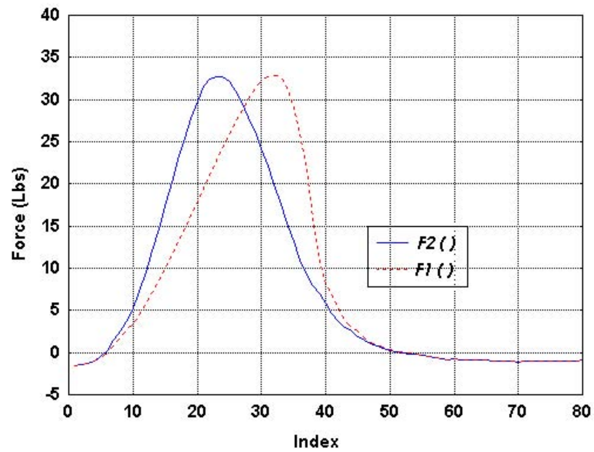

Fig. 3. Raw and corrected force on HVI for staple 37.

deflection was needed. Such direct measurements were made, using a 3x5 inch paper index card. This report describes the applicability of correction factors obtained with this inexpensive, simple, near-Hookean material, which does not elongate significantly under loads typical of the HVI, and which can be clamped between the HVI jaws without damage to the jaws.

MATERIALS AND METHODS

Fiber Samples Tested

Verification of the HVI elongation correction involved 18 cotton samples, including the current 8x8 cotton standards used to evaluate new high volume instruments, six USDA-Clemson test cotton standards used with the Universal Strength Tester, and four International Calibration Cottons (ICC) in Table 1. An independent study of the elongation measurement correction was obtained by testing 119 USDA crop samples from 1990 through 1994.

Fiber Tests

The group of 18 cottons was tested on an HVI at ten different break amounts [ASTM D 4605-89, 1993]. Single-fiber strength and elongation data were obtained with Mantis® for the six USDA-Clemson cotton standards [Cui, 1994a, b; Suh et al., 1996]. The 119 USDA crop samples were assayed on three different high volume instruments calibrated in both HVI and ICC modes. A total of five repetitions were made for each mode, resulting in 30 tests of each sample. Stelometer elongation data

Table 1. Standard HVI values of 18 test cottons

Sample	Micronaire	Length (in)	Strength (g/tex)	Elongation (%)
A-19	5.56	1.05	19.0	6.5
C-37 †	3.56	1.15	22.4	6.1
D-6 †	3.80	1.33	33.3	6.2
G-19 †	2.78	0.95	17.1	8.4
30 ‡	4.16	0.942	24.0	
32 ‡	4.69	1.002	25.4	
33‡	4.79	1.042	27.6	
34‡	2.83	1.070	27.8	
35‡	4.88	1.095	29.4	
36‡	4.61	1.134	26.6	
37‡	4.15	1.159	32.0	
38‡	4.19	1.182	32.7	
27992	3.83			
28020	2.83			
27742	5.41			
28463	4.41			
28671	4.84			
E-5	3.04			

† ICC standard values

‡ HVI standard values

were also available from USDA for these crop samples [ASTM D 1445-90].

System Deflection/Deformation Measurements

An HVI software modification program was written so the jaws could be clamped with no material spanning them. The breaker motor was rotated, and the HVI measured the tare force over the standard breaking distance (80 readings for a total travel of 1.693 mm). The jaws were then returned to the starting position and opened. Following a prompt on the instrument monitor, the operator inserted a standard paper index card between the jaws which then clamped the card as if it were a fiber sample. The HVI sensors read and recorded the force and the HVI then stepped the breaker. This process continued until a maximum of 36.3 kg (80 pounds) was reached. This upper limit was set to avoid excessive loading on the system.

It is imperative that the index card not elongate significantly during stress application. The amount of elongation of the index card during this process was ascertained by using a 200 mm ‘C’ clamp to physically clamp the jaws together. Also, aluminum bars (approximately 25 mm thick) were used to bridge the front optics system as the HVI lens system proved to be fairly flexible. (See Figure 1.) The force applied was monitored during measurement to avoid a preload on the system. The resulting curve had lower slope which indicated a greater deflection for the same force. This was attributed to deflection of the bars used to bridge the optics.

Stress-strain Curve Analysis

Stress-strain curves were corrected and analyzed with the following procedure.

1. The uncorrected stress-strain curve was defined as F1(j). The displacement in index units at the j force reading without any loading was then j. The actual displacement at the j force reading was labeled X(j) and was calculated by subtracting the calculated deflection from the unloaded displacement.

$$X(j) = j - \frac{k * \mathrm{F1}(j)}{2}$$

   Note that the factor of 2 was necessary because the force readings were taken every *second* step for a normal fiber stress-strain curve, but the index-card readings used to obtain k were taken at every step.

2. The X(j) and F1(j) *arrays* represented the force and displacement at each measurement point. However, these data points were not uniformly separated. For purposes of graphing and further analysis, a force array with equal separation of data points was required. Simple interpolation was used to generate this array F2(j).

3. The F2(i) array was scanned to locate the peak of the curve and the value at the peak. The array was again scanned to locate the points on either side of the maximum representing 70% of the maximum value.

4. This region of the F2() array between these points was fitted with a parabola. The maximum value and position of the maximum value (X3) were calculated from the fitted curve.

Variations observed at the beginning of the stress-strain curves were attributed to the use of several different high volume instruments. It appeared that some high volumes instruments preloaded the sample slightly so that the starting force was 0.5 to 2 kg above the tare force. This preloading might be due to several factors which are currently under investigation. In order to obtain a more consistent starting point for the curves, the HVI software program was modified to read the force immediately after jaws clamped the test material. If the force exceeded the tare force by more than 0.25 kg, the rear jaw was stepped back until this limit was satisfied.

Sample Breaking Procedure

The normal bundle breaking procedure follows.

1. The true starting point of the curve was determined when the F2(i) array was scanned again to locate the last point prior to the peak of the curve that was less than 30% of the maximum. The region of the F2() array between the start of the curve and this point was then fitted with a parabola. The minimum value and the position of the minimum value (X1) were calculated from the fitted curve. The position of this minimum was then used as the true starting point of the curve.

2. The F2() array was again scanned to locate the point before the maximum representing 50% of the maximum value. A straight line was fitted to the curve through this point and two points to either side of the point. This section of the curve was the most linear section of the curve and represents almost all of the fibers in a stretching mode. The slope of this curve represents the Young's modulus for the cotton fibers.

3. The intercept of this line with the tare force (X2) was determined. This divided the elongation axis into two sections. The region from X1 to X2 represented the stretching of fibers that were partially crimped. As all of the crimp was removed, a linear region in which all fibers were stretching was entered. Gradually, some of the fibers began to break and the curvature reversed to the maximum at X3. This region from X2 to X3 represented the *true* elongation of the fibers.

RESULTS AND DISCUSSION

The results of an index card deformation/deflection test are shown in Figure 4. Note that the 'tare' stroke, which involved no clamped card or fiber, is flat over the total length of travel within the resolution of the 12-bit analog-to-digital converter used for the measurement (96.4 grams). Following an initial curl, the deflection curve is straight, indicating an elastic deflection of the system. The slope, *k*, of this line, which is the effective modulus of the mechanical system, can be calculated in the linear region and stored as a correction factor for HVI stress-strain curves.

One important benefit of this technique is that the curve fitting techniques involve many more data points than would a simple peak selection. This has proved to be a more stable method of estimating the peak value of the force. The precision of the elongation value is also increased as a non-integer position is calculated. In addition, the highest force reading may be a variable distance from the actual peak. As a result, a slightly improved strength

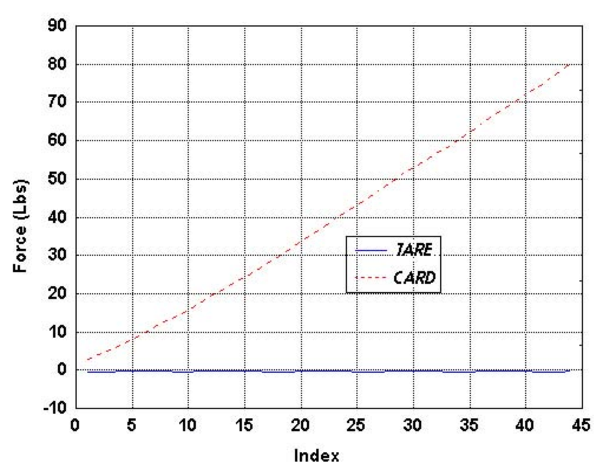

Fig. 4. Index card deflection on HVI.

reading has resulted in combination with an elongation measurement that is more precise and has a much lower standard deviation, compared to standard HVI measurements. The USDA crop samples from 1990 to 1994 were tested on HVIs using this algorithm. The coefficients of variation for the modified elongation measurement ranged from 2% to 4%. This range compares well with the range of 8% to 15% from standard programs.

Experimental Verification of Modified Elongation Measurement Using 18 Characterized Cottons

The standard testing values of micronaire, length, strength, and elongation percentage for the 18 test cottons analyzed are summarized in Table 1. These cottons were tested on an HVI at ten different break amounts. An example of the raw curves collected is shown in Figure 5. The method outlined above was used to correct the raw curve, and the corresponding ‘corrected’ curve is shown in Figure 6. If the correction method is valid, the position of the peak for the corrected curves should be the same, regardless of the break amount. In addition, the breaking force should be a linear function of the break amount. The elongation and breaking force as a function of break amount is shown for sample 28463 in Figures 7 and 8. The results were similar for the remaining cotton fiber lots. The correlation between the breaking force and break amount in each case is $ 0.99. These results are summarized in Table 2.

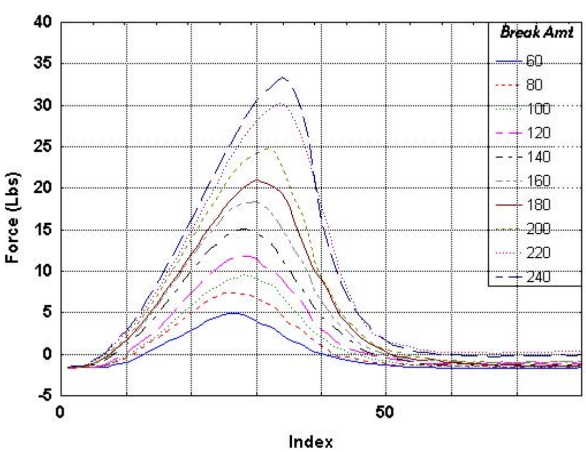

Fig. 5. Uncorrected force for cotton 28463 at break amounts from 60 to 240.

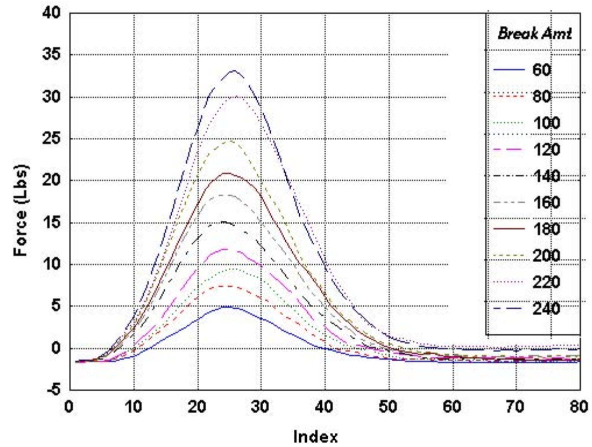

Fig. 6. Corrected force for cotton 28463 at break amounts from 60 to 240.

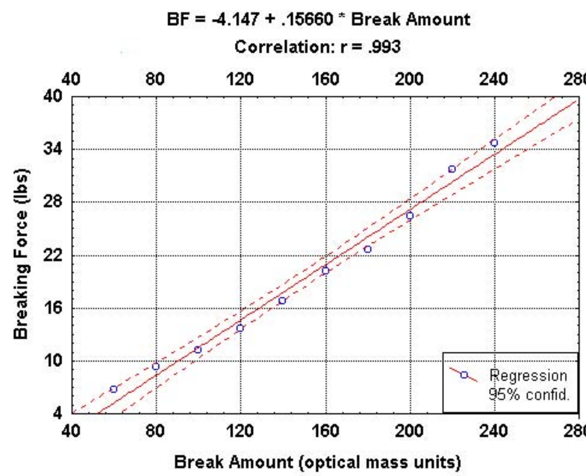

Fig. 7. Break force *vs*. break amount for cotton 28463.

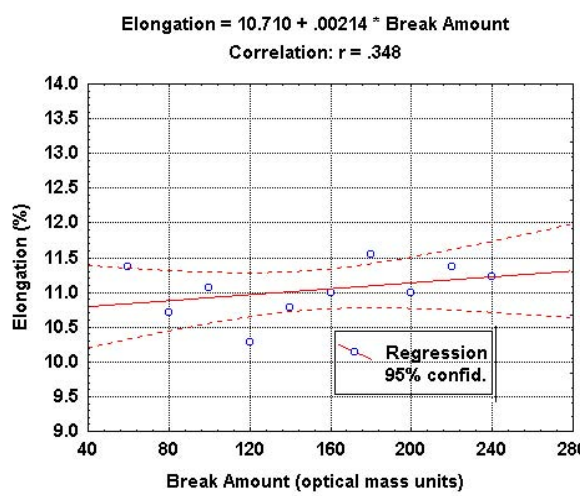

Fig. 8. Elongation *vs*. break amount for cotton 28463.

Table 2. Simple regression coefficients for breaking force and elongation *vs*. break mass for 18 test cottons.

	Breaking force			Elongation		
Sample	**Offset**	**Slope**	**Correlation**	**Offset**	**Slope**	**Correlation**
C-37	**-3.236**	**0.13365**	**0.996**	**11.121**	**-0.00027**	**-0.038**
D-6	**-5.313**	**0.20955**	**0.995**	**8.863**	**0.00450**	**0.681**
G-9	**-2.276**	**0.09460**	**0.998**	**15.322**	**-0.00233**	**-0.398**
30	**-2.299**	**0.11494**	**0.997**	**11.869**	**-0.00116**	**-0.157**
32	**-2.391**	**0.11943**	**0.991**	**12.663**	**-0.00846**	**-0.561**
33	**-3.533**	**0.13278**	**0.996**	**12.208**	**-0.00011**	**-0.019**
34	**-2.793**	**0.11479**	**0.994**	**12.900**	**-0.00014**	**-0.023**
35	**-4.081**	**0.15532**	**0.992**	**11.615**	**0.00433**	**0.515**
36	**-4.094**	**0.13592**	**0.998**	**11.617**	**0.00128**	**0.228**
37	**-3.507**	**0.15867**	**0.998**	**10.128**	**0.00229**	**0.419**
38	**-2.790**	**0.14454**	**0.999**	**9.884**	**0.00418**	**0.820**
27992	**-2.332**	**0.10332**	**0.996**	**13.836**	**0.00700**	**-0.598**
28020	**-2.619**	**0.11614**	**0.998**	**12.644**	**0.00112**	**0.213**
27742	**-3.894**	**0.16175**	**0.992**	**11.231**	**0.00174**	**0.296**
28643	**-4.354**	**0.15677**	**0.992**	**10.706**	**0.00215**	**0.348**
28671	**-3.212**	**0.13277**	**0.997**	**12.269**	**0.00130**	**0.418**
E-5	**-3.180**	**0.15718**	**0.997**	**9.646**	**0.00368**	**0.643**

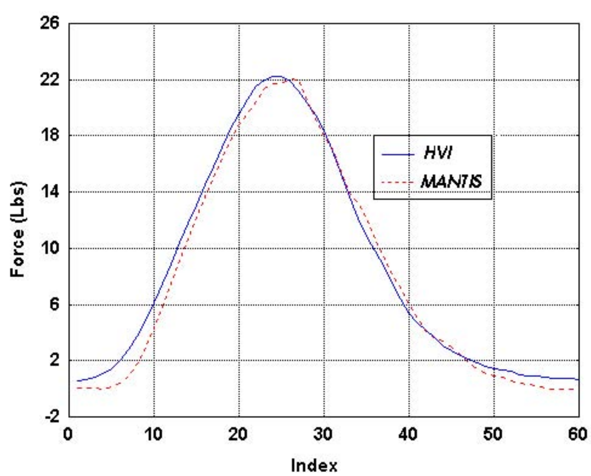

Fig. 9. HVI and Mantis® simulated stress-strain curves for cotton 27742.

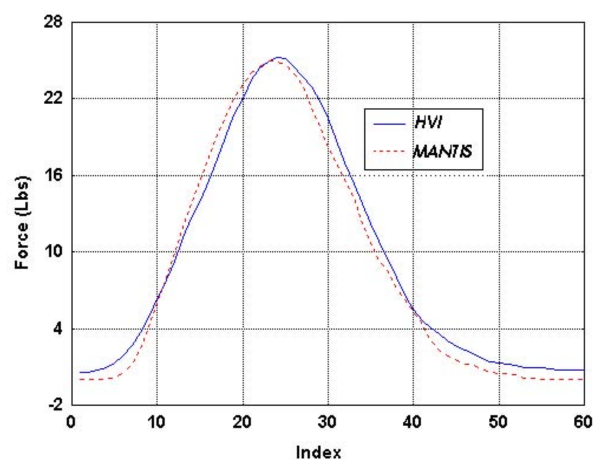

Fig. 10. HVI and Mantis® simulated stress-strain curves for cotton 28463.

Comparison with Mantis Single Fiber Data

The elongations measured by HVI using this correction method were better correlated with elongations measured by stelometer than with standard HVI elongation measurements. However, the corrected elongation values were significantly higher. By including the six Clemson cottons in the

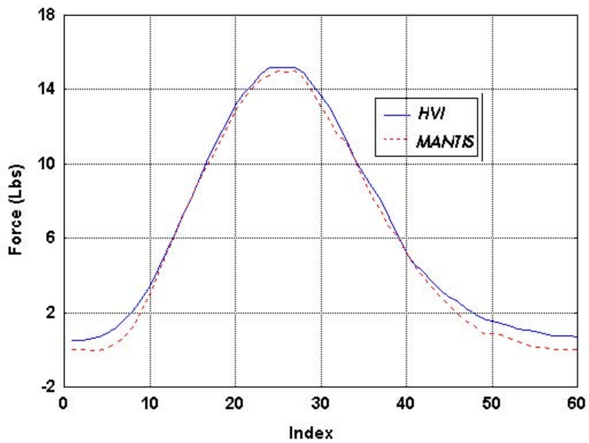

Fig. 11. HVI and Mantis® simulated stress-strain curves for cotton 28671.

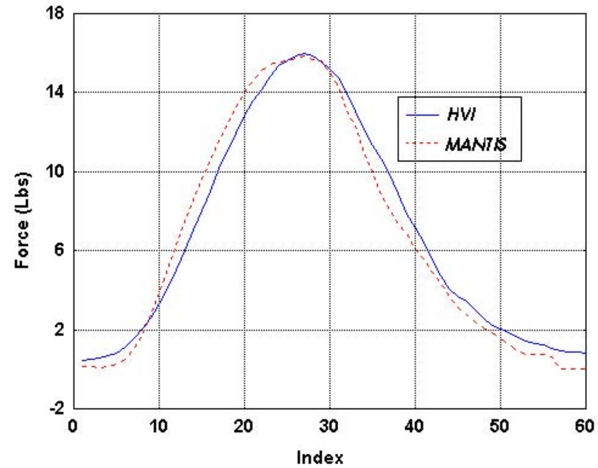

Fig. 12. HVI and Mantis® simulated stress-strain curves for cotton 28080.

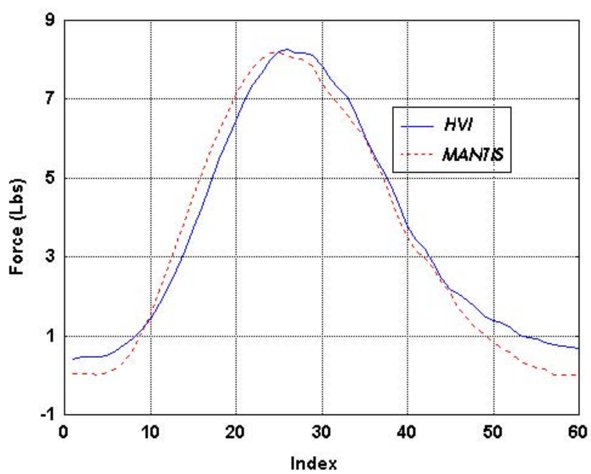

Fig. 13. HVI and Mantis simulated stress-strain curves for cotton 27992.

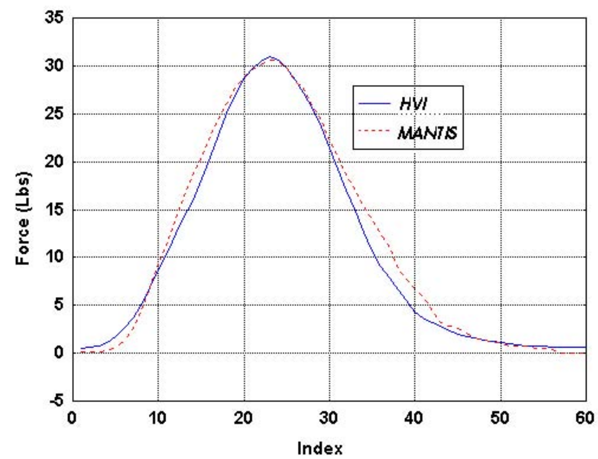

Fig. 14. HVI and Mantis® simulated stress-strain curves for cotton E-5.

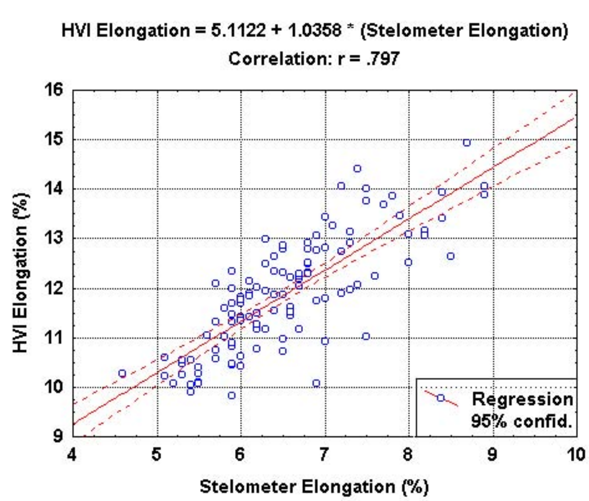

Fig. 15. HVI elongation *vs*. stelometer elongation for 1990 to 1994 USDA crop samples.

Table 3. Simple correlation coefficients of yarn elongation with fiber elongation (measured by stelometer and the HVI using the new algorithm). Fiber is from the 1990 to 1994 USDA crop samples.

	Yarn count					
	Open-end spun			Ring-spun		
	10's	22's	30's	22's	36's	50's
Stelo-meter	0.45	0.59	0.41	0.33	0.30	0.49
HVI	0.63	0.68	0.57	0.61	0.58	0.66

original group of 18 cottons, advantage could be taken of the large single-fiber strength and elongation available from Mantis® analyses.

These data, obtained from USDA, were used to simulate time-aligned bundle breaks. All starting points of the Mantis® curves are aligned, simulating a distribution of crimp in the fibers. Comparisons of the simulated bundle break and actual stress-strain curves from HVI for the six Clemson cottons are found in Figures 9, 10, 11, 12, 13 and 14. These figures indicate similar elongation values for all six of the cottons. However, both Mantis® and the modified HVI elongations are much higher than those obtained with the stelometer.

In reality, better agreement between the two curves would be questionable, considering the differences in crimp and crimp distributions due to sample preparation. The stress-strain curve depends upon both the distributions of strength and elongation for the fibers that are broken and the distributions of crimp. Since the brushing force in the HVI is changed, the stress-strain changes slightly. It is extremely difficult at this time to duplicate or model the distribution of crimp in the HVI with Mantis® data.

Bundle-to-Yarn Strength and Elongation Correlations

As an independent study of the validity of the modified HVI elongation measurement, the USDA crop samples from 1990 through 1994 were obtained. A total of 119 samples were tested on three different high volume instruments calibrated in both the HVI and International Calibration Cotton calibration modes. The correlation of HVI elongation with stelometer elongation reported by USDA is shown in Figure 15. The correlation coefficient of $r = 0.80$ compares well to $r = 0.69$ for the HVI elongation data published by USDA (Motion Control, Inc. HVI data). The simple correlation of the USDA and HVI elongation with yarn elongation data for ring-spun 22's is shown in Figures 16 and 17. The linear correlation of yarn elongation with fiber elongation increases from $r = 0.33$ to $r = 0.61$. Test of other yarn counts from

Table 4. Stepwise multiple correlation model† for yarn strength (CSP) expressed in terms of standard HVI measurements [micronaire (MIC), length (L), uniformity index (UI), reflectance (Rd), and brightness (+b)] along with two trial variables [El (associated with elongation) and S1 (associated with strength)] where E1 may represent stelometer, standard HVI, or new HVI elongation and S1 may represent stelometer, standard HVI, or new HVI strength.

Variables	Open end counts			Ring counts		
E1 and S1	10's	22's	30's	22's	36's	50's
Stelometer elongation, stelometer strength	0.786	0.785	0.779	0.832	0.839	0.848
Standard HVI elongation, standard HVI strength	0.831	0.794	0.768	0.830	0.821	0.802
Stelometer elongation, standard HVI strength	0.794	0.798	0.766	0.840	0.836	0.821
New HVI elongation, new HVI strength	0.850	0.863	0.843	0.875	0.886	0.879
New HVI elongation, new HVI strength	0.882	0.889	0.871	0.903	0.911	0.903

† Model is of the form: CSP = a * MIC + b * L + c * UI + d * Rd + e (+b) + f * E1 + g * S1 + constant.

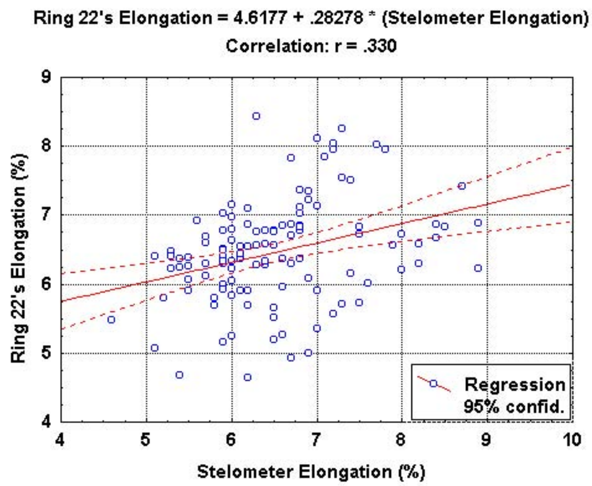

Fig. 16. Ring-spun 22's yarn elongation compared to stelometer elongation for 1990 to 1994 USDA crop samples.

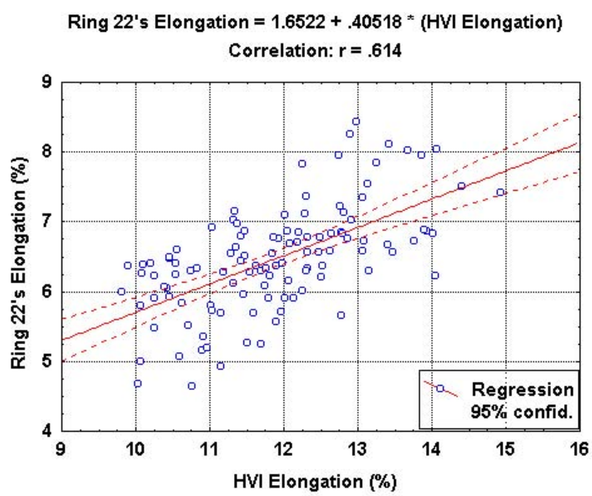

Fig. 17. Ring-spun 22's yarn elongation compared to HVI elongation for 1990 to 1994 USDA crop samples.

open-end and ring spinning showed similar increases and are summarized in Table 3.

Stepwise regression analyses were used to model yarn count strength product (CSP), using USDA HVI test results (micronaire, length, uniformity index, Rd, and +b), plus strength and elongation measurements from both USDA databases and Zellweger tests. The results are summarized in Table 4. Substituting the modified HVI strength measurement significantly improved all models. When the modified HVI elongation measurements were added, the models were further improved.

CONCLUSIONS

The use of the index card method provided an accurate measurement of the deflection in the breaker system of an HVI. When this measured deflection was used to correct raw stress-strain curves, elongation was found to be independent of breaking force, as it should be. A modified analysis of the corrected stress-strain curves produced a measurement of fiber elongation that was more precise and had a lower standard deviation, compared to the variability of standard HVI measurements. Comparisons of simulated curves generated from Mantis® single-fiber data showed similar levels of elongation from the two methods. However, both the modified HVI and Mantis® results were almost double the corresponding stelometer elongation values. For example, in Figure 15, the slope was approximately one with an offset of approximately 5%. This suggested that the modified HVI elongation data or simulated Mantis data gave elongation values that were 5% higher than the stelometer data. Further, this suggested that the zero on the elongation scale of the stelometer might be incorrect. This error could conceivably arise from pretensioning of the fibers in the stelometer clamp.

Measurements obtained from the new HVI strength/elongation method were compared to those obtained from the stelometer on the 1990 to 1994 USDA crop samples. In all cases, the new HVI elongation measurement proved to be a better predictor of yarn properties than were models based on stelometer elongation data.

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