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A COMPARATIVE STUDY OF THE DEGREE OF PERFECTION OF COTTON YARNS

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A COMPARATIVE STUDY OF THE DEGREE OF PERFECTION OF COTTON YARNS

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PREFACE

Until fairly recent times the field of textiles has been primarily an art. Few attempts have been made to develop basic chemical, physical or engineering concepts in order to establish general laws for textiles. Today the development of many different man-made fibers, each having individual properties, has served to awaken the interest of researchers in textiles. Perhaps in the near future the consumer will be able to specify exactly the properties desired and the manufacturer will be able to design and engineer a textile product to meet these specific requirements. However, at present the textile industry must still rely primarily on empirical relationships in the manufacture of its products.

It is hoped that this thesis will be a contribution, however small, to efforts to transform the field of textiles from an art to a science. This thesis is concerned with the problem of analyzing cotton yarn variation for the purposes of quality control comparisons. The techniques discussed and compared are not new, but their use is not universally accepted. It is hoped that this work will encourage a wider use of the methods discussed. Controlled laboratory techniques are interesting, but their value can only be adequately assessed under actual mill manufacturing conditions.

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ABSTRACT

In yarn manufacturing there appears to be no generally accepted method or technique for comparing yarns of varying counts for the purposes of quality control. Many textile researchers have done considerable work in an effort to solve this problem. The object of this thesis is to review the factors affecting cotton yarn irregularity; to discuss and compare various methods of determining the Degree of Perfection of cotton yarns; and, to investigate the possibility of using the Degree of Perfection as a useful quality control measure. The factors affecting cotton yarn irregularity are shown to be the variation in the number of fibers per cross section of the yarn and the variation of individual fibers themselves. The Degree of Perfection is defined as the ratio of the actual yarn variation to the minimum or inherent yarn variation. The inherent yarn variation is not constant but increases as the yarn count increases.

The experimental portion of this work tested fifteen cotton yarns distributed representatively over a range of counts from coarse to fine. The Uster Evenness Tester and yarn single-strand-break-strength variation were used to determine actual yarn variation. When a yarn is perfect the value of the Degree of Perfection ratio is one. It was found that the Duerst method for determining inherent yarn variation

gave higher values than the Enrick method. The break-test method for determining actual yarn variation gave erroneous results for the Degree of Perfection ratio even when yarns approximately at maximum twist as defined by Mr. Duerst were tested. Theoretically the break-test values should give the same results as the Uster variation values for yarns near maximum twist. The use of the Degree of Perfection ratio appears to be satisfactory for comparing yarns of different counts. If a desired ratio is selected for all yarns made in a mill, a formula can be evolved to compare actual yarn variation directly with a standard value. The formula includes the factor of inherent variation and a sample derivation is explained. This would appear to be a useful quality control measure.

The author felt that both Duerst and Enrick in their respective methods for determining inherent yarn variation neglected the factor of the variation of individual fibers themselves. The statistical derivation of minimum yarn variation by Dr. Martindale shows that this factor mathematically cannot be ignored. It is recommended that further research be conducted to determine if this factor of yarn irregularity can be disregarded practically in determining the minimum possible yarn variation for cotton yarns.

CHAPTER I

INTRODUCTION

In the period of continually increasing competition among textile mills since the close of the easy profit days of World War II, the problems of quality control have become paramount. Many mills are finding it necessary to use more scientific quality control methods in the manufacture of their products. To successfully compete many textile mills will require more adequate laboratory testing facilities and others must utilize the facilities they have to better advantage.

This thesis will be concerned with only one, but an important one, of the myriad of problems in cotton yarn manufacturing. It should be the continuing goal of yarn mills to produce a yarn that can be made cheaper without lowering quality, or that can be made of higher quality, thus commanding a premium price. In yarn manufacturing there appears to be no generally accepted method or technique for comparing yarns of varying counts for the purposes of quality control. It would be of great benefit to a yarn mill if a convenient and accurate system or method were available for comparing the processing efficiency of the various yarns being produced. The use of quality control is of little value if an accurate means of measuring quality is lacking. The ultimate aim in yarn manufacturing is to produce the most nearly perfect yarn possible with due regard for the costs of production. There are available accurate means of determining the costs of production. What means are available to determine the degree of perfection of the product? In other words, how regular or uniform is one yarn being produced as compared to some other yarn of a different count? A comparison of different count yarns by a direct comparison of the results of strength, diameter, evenness or similar tests is not a valid comparison of their degrees of perfection.

Assume a fine count yarn with a hundred fibers per cross section and a coarser count yarn with five hundred fibers per cross section. It is obvious that a variation of ten fibers per cross section will be a greater (five times greater) variation in the 100-fiber yarn than the 500-fiber yarn. However, the probability of a specific per cent variation in the number of fibers per cross section is greater for the 100-fiber yarn. Therefore, a direct comparison of strength, diameter, number of fibers, or weight-per-unit-length variations between two different counts of yarn is not valid unless a measure of the varying probability of the occurrence of this measured variation is considered.

In order for a yarn manufacturer to utilize quality control measures in production there must be a valid method for quality comparison between yarns of varying counts. To make a valid quality comparison, the above-mentioned probability factor must be considered. Many textile researchers, such as

Dr. J. G. Martindale and Mr. John Duerst, have done considerable theoretical analysis and practical experimentation in an effort to arrive at a solution to this problem.

The object of this thesis is to review the factors affecting cotton yarn irregularity; to discuss and compare various methods of determining the degree of perfection of cotton yarns; and, to investigate the possibility of using the degree of perfection as a useful quality control measure.

Factors Affecting Yarn Irregularity.--Before attempting to arrive at a solution to the problem of measuring yarn uniformity, the factors that affect the evenness properties of yarns must be determined. What is cotton yarn irregularity and what are the factors that affect this irregularity? Cotton yarn irregularity means that the yarn is not uniform, but is uneven or variable in some manner or degree. This irregularity is manifested by a variation in the appearance of the yarn in the cloth; by a variation in the color or shade of the dyed yarn; by a variation in the breaking strength, elongation, diameter, yarn number, turns-per-inch, or weight-per-unit-length of the yarn.

It is essential for an understanding of yarn irregularity that these various manifestations of irregularity are not confused with the factors causing the irregularity. The above mentioned manifestations are the effect or the result of variation in the factors affecting or causing the yarn irregularity. These manifestations are the visible means by which yarn irregularity is usually denoted and they are not the factors or causes of the irregularity itself. Thus, the methods or techniques of comparing yarns of varying counts solely on the basis of some physical test of variation are invalid. In other words, it is incorrect to say that a 100's yarn with some physical variation measurement of 75% is a poorer yarn comparatively than a 10's yarn with a variation of 25%.

If an absolutely perfect staple yarn could be produced, it would have to have certain essential characteristics. Assume that the individual staple fibers were all exactly alike in every respect. Assume further that a hypothetical processing system was capable of producing a yarn so that at any point along its length where an individual fiber ended, another fiber exactly took its place. If this perfection could be achieved, the final yarn would have exactly the same number of fibers per cross section at any point along the yarn. This perfect yarn would have no variation in weight per unit length; turns per inch, diameter, or strength. Of course this perfect yarn could never be achieved as nature has yet to produce perfectly identical staple fibers and the textile machinery manufacturers will probably never achieve the hypothetically perfect processing system.

The very manner in which the fibers are presented to a mechanical yarn processing system prevents the manufacture of a hypothetically perfect yarn. The fibers are presented to the processing system in a random manner, and this random distribution can only be impaired, not improved, by the processing. This means that each fiber has an equal chance to be selected at a given moment to begin the yarn manufacturing process. In actuality the properties of the staple fibers vary, and regardless of the perfection of the machinery the yarn must vary. This yarn variation at a minimum will be a measure of the random variation of the fibers initially.

Therefore, it can be seen that fundamentally there are only two factors affecting cotton yarn irregularity: the variation in the number of fibers per cross section of the yarn, and the variation of individual fibers themselves. This statement has been determined and verified many times by the experimental work and theoretical analysis of researchers in the textile field. The peculiarities of nature are responsible for the variation in the individual fibers. The peculiarities of the mechanical processing system used are responsible for the variation in the number of fibers per cross section of the yarn.

Random Fiber Arrangement Theory.--Now that the two basic factors affecting yarn irregularity have been established, it is important to enlarge the discussion to a brief consideration of the manner in which these factors vary at a minimum. The variation in the number of fibers per cross section of the yarn is one of the two basic factors of yarn irregularity. It has just been stated that this variation is due to the peculiarities of the mechanical processing system used. Regardless of the mechanical design, use, or condition of the equipment in a yarn processing system, there will always be an inherent variation in the number of fibers per yarn cross section, or in other words, a minimum variation caused by the random arrangement of the fibers in a yarn.

Martindale (1) has shown that "with any preparation, drawing, or spinning machinery in use at the present time, the best that can be done is to arrange the fibre ends in a random order in the sliver, roving, or yarn." This is because the original presentation of the fibers to the first machine in the yarn manufacturing process is a random presentation, i.e., any fiber in the total lot is equally likely to appear at any point of a sample cross section, and no matter how perfect the succeeding machinery, this random presentation can not be improved. The best that machines can do is to preserve the same fiber order in delivery as was fed initially. This assumes that the machines will have complete control over each fiber during the drafting processes. This perfect control is not obtainable, and thus the random variation will in practice be impaired rather than improved.

At this point a question might arise concerning the effect of doubling on yarn variation. Doubling will decrease the overall yarn variation, i.e., the actual total yarn variation value. However, doubling will not decrease the random variation, i.e., the minimum possible yarn variation value.

To decrease the random variation the doubling procedure would require a theoretical power of selectivity that is presently impossible. Such selective doubling would require the matching of cross sections of sliver and roving so that the resultant sum of the fibers in each cross section would be constant or at least less than the random variation.

Assuming that there is no variation among the individual fibers, Martindale (2) has statistically calculated the variation due to random variation of the number of fibers per yarn cross section, using the theory of probability as follows:

> The probability of a fibre crossing a given section in a yarn is proportional to the length of the fibre. Consider first therefore, a yarn made from N fibres all of the same length. Each fibre has the same chance of crossing any section of the yarn and although in a large bulk of yarn this chance will be small, it still exists as the fibre must appear somewhere in the length of yarn made. If p is the probability of a given fibre crossing a certain section, and q is the probability of its failing to do so, $p + q = 1$, where p is very small compared to q. If the average number of fibres per cross-section of yarn equals n, then $p = n/N$.
>
> The probabilities of N, (N-1), (N-2) ...3, 2, 1 fibres all of the same length crossing a given section of the yarn are given respectively by the successive terms in the Binomial expansion of $(p + q)^n$. When p is very small, this is the well-known Poisson distribution. The distribution of fibre number between the various cross-sections of the yarn is described by this distribution which therefore determines the irregularity of a yarn made up of a random arrangement of fibres of equal lengths. From the known characteristics of a Poisson distribution it can be stated that if the average number of fibres per cross section = n, the standard deviation of the number per cross section $\sigma_n = \sqrt{n}$.
>
> (Writer's note: The Poisson distribution is a special case of the binomial distribution. Statistical theory shows that an important property of the Poisson distribution is that its variance is equal to its mean, or in other words, standard deviation equals the square root of the mean.)

Suppose, now, that the fibres in the yarn are not all of the same length but that fibres of lengths l_1, l_2, l_3, ...l_r, ...l_m all occur and that the average number of these per cross section is respectively n_1, n_2, n_3, ...n_r ...n_m, then the average total number of all fibres per cross section $n = \sum n_r$.

If each group of fibres of the same length is regarded as forming a separate tenuous yarn and these yarns have standard deviations of fibre number per cross section σ_1, σ_2, σ_3 ... σ_r ... σ_m respectively, then

$$\sigma_1^2 = n_1, \quad \sigma_2^2 = n_2, \quad \sigma_3^2 = n_3 \; \ldots \; \sigma_r^2 = n_r \; \ldots \; \sigma_m^2 = n_m$$

If these are imagined as being randomly doubled together to form the complete yarn with standard deviation σ_n then $\sigma_n^2 = \sum \sigma_r^2 = \sum n_r = n$

$$\therefore \quad \sigma_n = \sqrt{n} \tag{1}$$

Thus the standard deviation of the number of fibres per cross section is still $\sqrt{n}$ and is unaffected by the length characteristics of the fibres.

Equation (1) therefore holds for a yarn made up of fibers randomly arranged regardless of fiber length or distribution, provided that measurement is made at points separated by a distance greater than the length of the longest fiber.

It has been previously stated that the only two fundamental factors affecting yarn cross section variation or irregularity are the variation in the number of fibers per yarn cross section and the variation of individual fibers. Weight-per-unit-length has been selected as the term to express the measurement of these variations. In the case of cotton fiber variation the weight-per-unit-length is a better measure than cross section area or diameter because the latter are not necessarily definite quantities. The same reasoning holds true for the yarn variation.

As a means of verification, Martindale (2) has written:

> It is well known that any product of drawing or spinning machinery varies in weight per unit length from one point to another. In the case of yarns this causes variation in turns per inch of twist, variation in diameter and variations in strength, but these are all somewhat secondary effects brought about by variations in weight per unit length due to the irregular arrangement of the fibres composing the yarn.

Spencer-Smith (3) stated:

> The levelness or regularity of a yarn depends to a great extent upon the characteristics of the system by which it was produced, but...no matter how perfect the system may be, yarn produced by the standard methods of doubling and drafting slivers cannot be more regular than a similar yarn in which the fibres are arranged at random along its length. The irregularity of weight of such a yarn was shown to depend only upon the mean number of fibres in a cross section of the yarn.

Also, Townsend (4) has reported that:

> For fundamental analysis of yarns and drafting processes...the most important property of a yarn is the number of fibres per cross section, and the variation of this number along the yarn is the most fundamental measure of irregularity. Moreover, assuming uniform density and diameter of the fibres, the variation in the number of fibres per cross section is equal to the variation of weight per unit length, which is much more easily determined in practice than the variation in the number of fibres per cross section...In view of the importance of this factor for theoretical reasons, and also because it seems likely that variation of fibre number will be closely related to the appearance of irregularity of a yarn in fabric form, the variation of fibre number, or the associated variation of weight per unit length is a convenient and basic measure of yarn irregularity with which other methods of measuring irregularity can be compared.

It has been shown that the standard deviation of the number of fibers per yarn cross section area due to a random arrangement is: $\sigma_n = \sqrt{n}$, where n is the mean number of fibers per yarn cross section. Now it remains to apply this information to determine the minimum variation of the yarn per cross section, i.e., the variation due to random fiber arrangement. Let:

$\bar{a}$ = yarn mean weight per unit length
σ_a = yarn standard deviation
CV_a = yarn coefficient of variation
$\bar{w}$ = fiber mean weight per unit length
σ_w = fiber standard deviation
CV_w = fiber coefficient of variation
n = mean number of fibers per yarn cross section
σ_n = standard deviation of the number of fibers per yarn cross section

Consider the effect of the two yarn variables separately. Assume that the fibers were uniform and had a mean weight value W. Then the yarn standard deviation would be due entirely to the variation in the number of fibers and would be:

$$\sigma_a = \sigma_n \bar{w}$$

Therefore the variance of the yarn weight-per-unit-length would be:

$$\sigma_a^2 = \sigma_n^2 \bar{w}^2$$

By definition variance is the square of the standard deviation.

Now assume that the number of fibers-per-unit-length of yarn is constant and equals n. Then the variance of fiber weight-per-unit-length is σ_w^2, and n of these fibers form a yarn unit length with variance:

$$\sigma_{\bar{a}}^2 = n\,\sigma_w^2$$

By statistical definition when independent variable factors operate simultaneously the resultant variance is equal to the sum of the variances of each of the factors operating separately. Therefore, the summation of the variances of the two factors affecting yarn irregularity is the resultant yarn variance and is:

$$\sigma_{\bar{a}}^2 = \sigma_n^2\,\bar{w}^2 + n\,\sigma_w^2 \tag{2}$$

$$\sigma_n^2 = n \qquad \bar{a} = n\bar{w} \qquad CV_a^2 = \frac{\sigma_{\bar{a}}^2 \cdot 100^2}{\bar{a}^2} \qquad CV_w^2 = \frac{\sigma_w^2 \cdot 100^2}{\bar{w}^2}$$

By substitution

$$CV_a^2 = \frac{100^2}{n} + \frac{CV_w^2}{n} \tag{3}$$

CV_a is the coefficient of variation of the most perfect yarn that can be made on perfect machines which do not perform any operations which tend to decrease random variation. All doubling and drafting operations do not selectively double every thick place with every thin place or draft every thick place more than every thin place. Therefore, the irregularity due to random variation is the minimum possible irregularity and the coefficient of the limit or minimum variation per unit length according to Martindale (2) will be:

$$\text{CV(limit)} = \sqrt{\frac{100^2}{n} + \frac{CV_w^2}{n}} \tag{4}$$

Degree of Perfection.--The implications of formula (4) are important. The number of fibers per yarn cross section decreases as the cotton yarn counts increase, and thus the coefficient of random variation will increase as the counts increase. The actual yarn variation always includes the variation due to random fiber arrangement. To directly compare the actual variation of a fine count yarn with a coarser yarn is to neglect the fact that the inherent or random yarn variation is a varying quantity.

Various textile researchers such as Temmerman and Hermanne (5), Enrick (6), Duerst (7), and others have offered solutions to the problem of comparing yarns of various counts. In general the various solutions agree that yarn variation comparisons should be based on the Degree of Perfection of the yarn. The Degree of Perfection is defined as the ratio of the actual yarn variation to the minimum or inherent yarn variation. Therefore, it can be said that:

$$\text{Degree of Perfection} = \frac{CV(\text{actual})}{CV(\text{limit})} \qquad (5)$$

If yarns of varying counts are compared on the basis of formula (5), the comparison is valid.

Now that the factors affecting yarn irregularity have been determined and a formula evolved for a valid comparison of varying count yarns for the purposes of quality control, the problem remains to determine a suitable means for measuring the actual and inherent yarn variation. Enrick (6) has proposed the following method to measure yarn variation.

By definition the count of a yarn on the cotton system is the reciprocal of the weight in pounds of 840 yards of the yarn. The count of a given yarn will vary in inverse proportion to the variation in weight-per-unit-length along the yarn. It is obvious that the weight-per-unit-length of a yarn will be the sum of the weights of the individual fibers in that length. Assuming that there is no variation in the weights of the individual fibers, then the variation in weight-per-unit-length of a given yarn is directly proportional to the number of fibers in that length. Mean fiber weight-per-unit-length (average linear density) is usually expressed in micrograms-per-inch. Convert the units of the cotton counts to grams and inches and:

$$\text{Counts} = \frac{\text{L(yards)} \times 1}{\text{W(lbs)} \times 840} = \frac{\text{L(inches)} \times 453.6}{\text{W(grams)} \times 36 \times 840}$$

Then the weight-per-unit-length of a given count yarn is:

$$\text{W/L(grams/inch)} = \frac{0.0150}{\text{counts}}$$

The mean number of fibers-per-unit-length of yarn is:

$$n = \frac{\text{W/L(grams/inch) of the yarn}}{\text{W/L(grams/inch) of the fibers}}$$

$$n = \frac{15{,}000}{\text{yarn count} \times \text{fiber weight (micrograms)}} \qquad (6)$$

Continuing the assumption that there is no significant variation in mean fiber weight, formula (4) for the coefficient of minimum yarn variation becomes:

$$\text{CV(limit)} = \frac{100}{\sqrt{n}} \tag{7}$$

Combining equations (6) and (7):

$$\text{CV(limit)} = 0.82\sqrt{\text{yarn count x fiber weight (micrograms)}} \tag{8}$$

The Sheffield Micronaire fiber "fineness" value is used by Enrick (6) to determine the mean fiber weight. Unless certain limitations on the applicability of the Micronaire readings are observed, the use of these readings in formula (8) will not necessarily be a valid measure of the mean fiber weight although the readings may be satisfactory for practical use. These limitations will be explained later. The actual yarn variation, CV(actual), is measured by any electronic tester such as the Uster Evenness Tester which measures yarn weight-per-unit-length variation. Therefore, Enrick's (6) solution to measuring the Degree of Perfection of cotton yarns is:

$$\text{Degree of Perfection} = \frac{\text{CV(actual)}}{0.82\sqrt{\text{cts x F}}} \tag{9}$$

where:

cts = yarn counts (cotton system)

F = Micronaire fiber fineness reading

CV(actual) = Variation value from electronic tester

Fiber Fineness.--Before proceeding further some of the limitations of the Micronaire readings should be discussed. Fiber fineness may be determined either by fiber diameter or fiber weight-per-unit-length measurements. To determine cotton fiber fineness by diameter measurement is of little value because cotton is a hollow fiber and its properties depend not only on its diameter (which is not circular) but on its wall thickness compared to lumen (the hole) thickness. Therefore, cotton fiber fineness is usually determined by the fiber mean weight-per-unit-length (expressed in micrograms-per-inch) which is a more definite quantity.

The fiber weight-per-unit-length (array method) (8) using an instrument such as the Suter-Webb Duplex Cotton Fiber Sorter is probably the most accurate means of determining fiber fineness directly. However, this method is extremely time consuming and except for research is not suitable for production control measurements. The Sheffield Micronaire measures fiber fineness by employing the air-permeability principle. Its use is rapid, simple, and suitable for quality control procedures. As a result of research by the U. S. Department of Agriculture (9) (10) (11) special scales for the

Micronaire have been developed to give readings directly in micrograms per inch (mean fiber weight-per-unit-length). Only two scales have been developed so far and they are for American Upland and American Egyptian cottons. If fineness of other botanical types of cotton is to be measured on the Micronaire, the use of the Causticaire scale and method is recommended. The use of the proper scale on the Micronaire is important because the relationship between air permeability testing and actual mean fiber weight-per-unit-length is curvilinear. Whenever mean fiber weight-per-unit-length (fiber fineness) is determined using the Micronaire, the above limitations should be considered for their effect upon the accuracy of the results.

Hexagonal Fiber Pattern Theory.--John Duerst, research engineer for Coats & Clark, Inc., has worked for about twenty years on his Hexagonal Fiber Pattern Theory in an effort to explain all of the many peculiarities of yarn manufacturing in terms of a single theory. Duerst has also arrived at a solution to the problem of comparing yarns of various counts for the purposes of quality control. The writer will attempt to explain here only those portions of the Hexagonal Fiber Pattern Theory that have a direct bearing upon yarn variation comparisons.

Duerst's (12) ideal yarn cross section assumes cotton fibers of circular cross sections forming concentric circular layers about an imaginary yarn center. This will form a hexagonal yarn cross section of "n" concentric fiber layers. When twist is imparted to the yarn, its cross section approaches a circular shape, but the basic hexagonal distribution of fibers remains. It is realized that cotton fibers are not all perfect cylinders, but Duerst has theorized that the practical yarn cross section will have a negligible variation from the ideal cross section in its effect upon the practical yarn calculation formulas that he develops from this basic assumption.

By the law of arithmetic progression the number of fibers per yarn cross section can be calculated from the hexagonal fiber pattern arrangement. A hexagon is composed of six equal triangles. The sum of the fibers in one triangular segment of the hexagon is:

$$\frac{n\ (n + 1)}{2} \qquad (10)$$

where: n = number of concentric fiber layers

one fiber = equivalent number of fibers in the first layer of the triangle

one fiber = common difference between concentric fiber layers of the triangle

therefore, the total number of fibers in a yarn cross section is:

$$S = \frac{6n\ (n + 1)}{2} \qquad (11)$$

where: S = total fibers per yarn cross section

Duerst (12) then states that, "In the past it was commonly accepted that an average grade of American cotton would show approximately 3000 fibers per cross section of a

No. 1.0 yarn. Egyptian cottons being much finer were accepted to count 3200 fibers per cross-section of a No. 1.0 yarn." The writer found this statement to be concurred in by Locher (13). Also, from the above information the average fiber weight in micrograms per inch can be calculated as 5.0 for American and 4.7 for Egyptian cottons. Then it can be said that the fiber weights are inversely proportional to the fibers per cross section of No. 1.0 yarn.

However, it has been found that the average Micronaire value (F) for American cottons is about 4.0, and for Egyptian cottons about 3.5. Assuming an expotential relationship be-between fiber weight and number of fibers per yarn cross section and using Micronaire (F) values:

$$\frac{3200}{3000} = \left(\frac{4.0}{3.5}\right)^n = \left(\frac{F_A}{F_E}\right)^n \qquad (12)$$

where: F_A = Micronaire reading average American cotton

F_E = Micronaire reading average Egyptian cotton

which gives a value for the expotential constant of approximately one-half (0.5). Then: 3000 $\sqrt{F}$ equals 6000 for a No. 1 yarn when F equals four, and as the total number of fibers per yarn cross-section (S) decreases linearly as the cotton counts increase:

$$S = \frac{6000}{\sqrt{F} \text{ x cts}} \qquad (13)$$

where: S = total number of fibers per yarn cross-section

F = Micronaire reading

cts = Average cotton yarn counts

Combining formulas (11) and (13):

$$n = \frac{1}{2}\left(\sqrt{1 - \frac{8000}{\sqrt{F}\,\text{cts}}} - 1\right) \qquad (14)$$

Now if "u" is the number of fibers per yarn cross-section diameter, then "u" equals "2n" and formula (14) becomes

$$u = \sqrt{1 - \frac{8000}{\sqrt{F}\,\text{cts}}} - 1 \qquad (15)$$

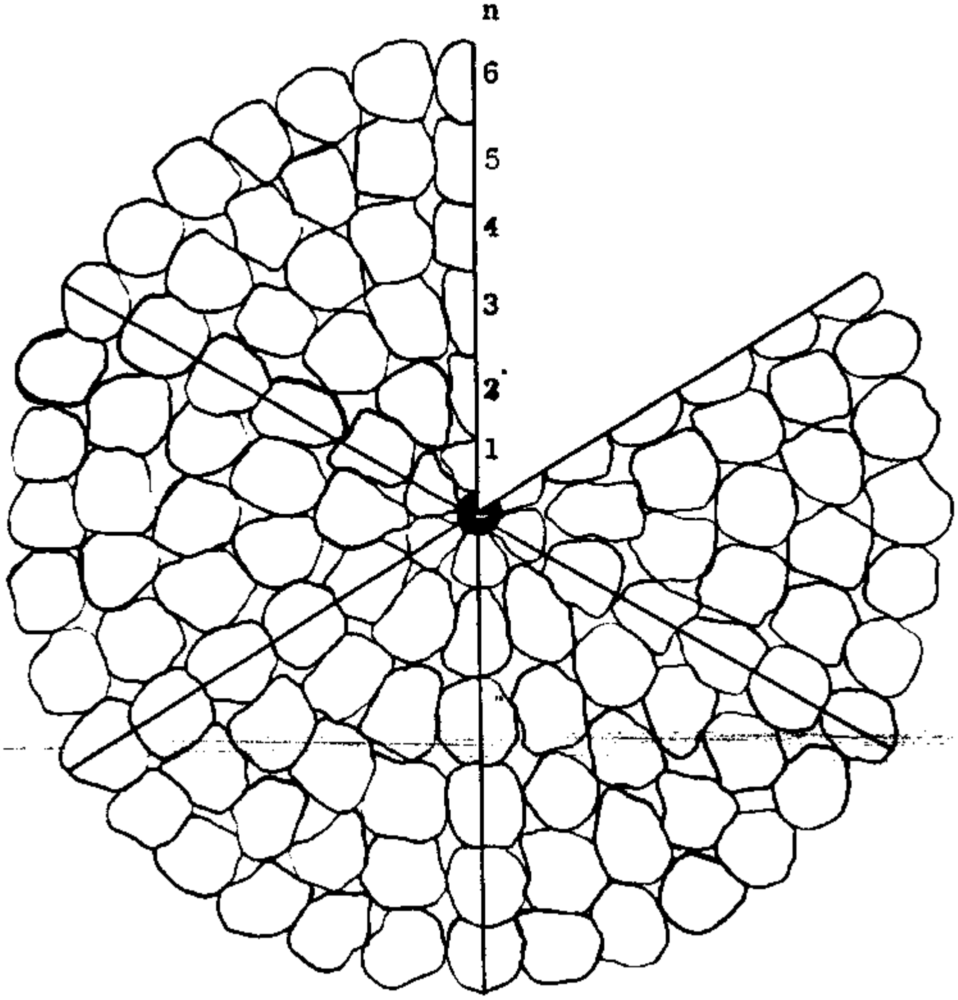
where F = Micronaire scale reading

cts = Average cotton yarn counts

Figure 1 is a sketch of Duerst's idealized yarn cross-section and formula (15) is the "common denominator" of all Duerst's subsequent yarn calculations.

For yarn variation evaluation Duerst (7) states that the limit of perfection of a hypothetically perfect yarn consists of one fiber variation per cross section diameter.

> This one fiber difference between high mean and low mean cross section diameters is the limit of perfection in any fibrous strand of sliver, roving, yarn, or thread. One fiber after all is the smallest unit of change. While this one fiber difference is good for diameters only, we will readily understand that this fiber per cross section diameter means the difference of a whole layer of periphery fibers of a strand.



Idealized Shape of a Yarn Cross Section

Number of Concentric Layers = n

Figure 1. Duerst's Hexagonal Fiber Pattern

Therefore:

$$CV = \frac{(\bar{u}_1 - \bar{u}_2)}{u} 100 \qquad (16)$$

where: CV = coefficient of variation of yarn

u_1 = high mean number of fibers per cross section diameter

u_2 = low mean number of fibers per cross section diameter

u = average number of fibers per cross section diameter

The Degree of Perfection was previously defined as the ratio of the coefficient of actual yarn variation to the coefficient of the limit of perfection. From Duerst's definition CV equals CV(limit) when $(\bar{u}_1 - \bar{u}_2)$ equals one. Therefore, formula (5) becomes:

$$\text{Degree of Perfection} = (\bar{u}_1 - \bar{u}_2) \qquad (17)$$

and:

$$CV(\text{limit}) = \frac{100}{u} \qquad (18)$$

In discussing the subject of yarn variation with the writer, Mr. Duerst has proposed that any mill could determine the actual coefficient of yarn variation from simple single strand break-tests without the need for elaborate electronic testing equipment by using his theories, and the formulas derived therefrom. Then by calculating the coefficient of the limit of perfection as described above, the Degree of Perfection can be determined and the result used for quality control determinations.

Duerst(14) has written that there are four main factors responsible for yarn strength: individual fiber strength, fiber surface frictional strength, number of fibers per cross section, and the degree of intertwining force imparted to the yarn by twisting. For a yarn to break when tension is applied, one of two things must happen. Either the individual fibers at the point of break will slip past each other or the fibers themselves will break. Uusually both things will occur simultaneously in varying degrees.

Staple yarn would not exist if there were no frictional forces active and latent to hold the fibers together to form a yarn or to resist an applied force attempting to break a yarn. Also, it is an accepted fact that when a yarn is broken in many places along its length the individual break strength values vary. The theoretical strength of a yarn is obtained when the fibers in a given cross section all break when tension is applied to the yarn and none of the fibers slip. Assuming each fiber develops equal frictional force, the absolute break strength of a yarn would occur when the sum of the developed fiber frictional forces at the yarn-break cross section is equal to or greater than the sum of the individual fiber strengths in the cross section. Absolute yarn strength can never be achieved because all the cross section fibers can not develop their full potential frictional forces. Duerst (15) has shown that those fibers on the periphery of the strand which are partially exposed develop only about one-sixth of their potential frictional force.

Brandt (16) has experimented on the effect on yarn strength of varying twist at varying yarn counts. The results showed that yarn strength varies approximately parabolically as twist increases for a given count yarn. For coarse yarns the strength increases rapidly as twist increases to a point of maximum strength and then decreases gradually in strength as twist continues to increase. The reverse is true with fine yarns.

Now assume a yarn spun at maximum twist, i.e., the point of maximum strength. With this condition the yarn break-strength will be directly proportional to the number of fibers per cross section. If the yarn is spun at other than maximum twist, the relationship between the number of fibers per cross section and the yarn strength becomes more complicated and will have to include some factor for the parabolic-shaped relationship between twist and strength.

The experimental portion of this thesis is concerned with comparing the various methods of determining the Degree of Perfection of cotton yarn manufactured with a quality characteristic of maximum strength. Thus, the experimental yarns used should be at or near maximum twist. Gregory (17) states:

> The question of whether or not the weakest places in a yarn are the thinnest will obviously depend upon the average twist of the yarn. For a fully twisted yarn, the influence of twist is secondary in importance to that of weight in defining the strength of yarn elements...It is therefore highly probable that the thick places, although not developing their full strength, are considerably stronger than the thin places.

If actual yarn variation is directly proportional to yarn break-strength variation for yarns spun at or near maximum twist, then the Degree of Perfection could be calculated using the coefficient of variation of yarn break-strength as CV(actual) and dividing it by formula (18) as advocated by Chang (18), and the result should be the same as that obtained from an electronic tester such as the Uster for measuring yarn variation.

Summary.--The factors affecting cotton yarn irregularity have been reviewed and shown to be in the final analysis the variation in the number of fibers per cross section of the yarn and the variation of individual fibers themselves. The meaning, derivations, and methods of measuring the Degree of Perfection of cotton yarns have been discussed.

The experimental portion of this thesis is concerned with a comparison of these various methods of determining the Degree of Perfection. First, it will be determined from

Martindale's random fiber arrangement theory with Enrick's method for determining the CV(limit) and the Uster electronic evenness tester for determining the CV(actual). Then the Degree of Perfection will be determined from Duerst's hexagonal fiber pattern theory using single-strand breaking-strength variation values to determine CV(actual) and Duerst's method for determining CV(limit). Finally, the results will be compared.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

The experimental portion of this work utilized two major pieces of standard textile testing equipment: the Suter Single Strand Tester and the Uster Evenness Tester (Model B). In addition, a standard cotton yarn reel and a Christian Becker Chainomatic Balance were used.

Suter Single Strand Tester.--This instrument is a low capacity vertical pendulum type machine for testing yarns, and is a standard item of equipment in most yarn testing laboratories. The machine simply determines the elongation and breaking strength of the yarn between the jaws, and does not have an autographic attachment. Haven's "Industrial Fabrics Handbook" (19) gives a complete description of the machine.

> In the single strand test...the jaws of the machine may be flat grip, capstan, drum, or any other device which does not have more than 25% of the specimens breaking within ⅛ inch of the jaw; specimens which break within ⅛ inch of the jaw are discarded. The speed of the lower jaw is 12 ± 1/16 inches-per-minute. (20)

The capacity of the single strand tester used is up to twelve pounds. If no additional weight is attached to the pendulum, the breaking strength is read in grams (up to 500 grams). If a greater capacity is desired, the two-pound or twelve-pound weight may be attached to the pendulum. The allowable capacity of the machine is considered to be the dial readings included between a nine to forty-five degree swing of the pendulum. If these precautions are observed in operating the single strand tester, the breaking strength results will be as accurate as can be obtained on this type of machine.

Uster Evenness Tester.--The Uster Evenness Tester is a completely electronic instrument for measuring variation in uniformity of sliver, roving, or yarn. The tester is manufactured by Zellweger, Ltd., a Swiss firm, and sold and serviced in the United States by the Uster Corporation.

The Uster Evenness Tester consists of three separate basic units. These are the Tester itself, the Integrator, and the Recorder. The Tester is a cabinet-enclosed unit that contains a complete electronic system for measuring the amount of variation in weight-per-unit-length of yarn, roving, and sliver. It is equipped with a sensitive meter that visually indicates instantaneously and directly the percentage variation from the mean. There is an eight-slot measuring head on the Tester, and each slot contains the plates of an electrical capacitor whose dielectric is partly air and partly the material passing through the plates. The capacitor plates in the measuring head are connected to one of two oscillators in the electronic system. One oscillator operates at a fixed frequency and the other varies in accordance with the variation in the mass of material passing through one of the slots in the measuring head. The electronic system in the Tester then detects, converts, and suitably amplifies the outputs of the two oscillators to give a direct and instantaneous linear percentage variation reading on the meter on the face of the Tester. The Tester is a direct indicating instrument and contains no averaging circuits. It is extremely difficult to take accurate readings from the Tester meter because of the difficulty of setting the meter reading initially to zero percentage variation.

To overcome this difficulty the other two basic units are furnished with the Tester and are connected to it and to each other by electrical cables. The Recorder graphically records the linear percentage variation continuously and the charted results may be manually analyzed to determine the average percentage linear variation. The third basic unit, the Integrator, permits direct readings of the average variation. There are two types of Integrators and either one may be used in conjunction with the Tester. The Linear Integrator determines the average percentage linear unevenness, and the Quadratic Integrator indicates the percentage coefficient of variation of the material tested. Both of these Integrators have an unvarying time constant of two and one-half minutes. This means that any Integrator reading, properly corrected, is the average linear percentage unevenness or the coefficient of variation for the preceding two and one-half minutes of material that passed through the Tester. The Tester is equipped to provide material speeds of 2, 4, 8, 25, 50, and 100 feet per minute. The speed of the material through the Tester determines the test length of the material corresponding to the Integrator reading.

> The Integrator consists of two scales, the Unevenness scale and the Average Value scale. For any section of material tested, the Unevenness scale represents only the magnitude of the variations in weight; the Average Value scale represents the average weight. To get the per cent unevenness, therefore, the amount of variation must be divided by the average weight. The Unevenness scale is so calibrated that whenever the Average Value scale reading is "0" the value read from the Unevenness scale is identical with the per cent unevenness.
>
> However, whenever the average weight results in a plus or minus Average Value scale reading, the value read from the Unevenness scale must be divided by that average weight before a true percentage value can be obtained. (21)

A knowledge of the actual values represented by the various divisions on the two scales of the Integrator is required to perform the calculations necessary for determining the true percentage variation. To obtain this value with the least amount of calculation, the Uster Corporation has prepared a table of correction factors. This is merely a table of reciprocal values corresponding to the various average weights. The Integrator operator reads the division of the Unevenness Scale on the Integrator corresponding to the setting of the scale selector control knob on the Tester. At the same time, the Average Value scale on the Integrator is read. These two values are used to determine the correction factor to use from the table. The unevenness value read multiplied by the correction factor gives the true percentage variation value.

For the experimental work of this thesis the Model B Uster Tester with the Linear Integrator was used. The Linear Integrator essentially determines the mean deviation (sometimes called the average deviation) of the yarn weight-per-unit-length expressed as a percentage of the mean weight. From statistics it is known that the mean deviation value is only 0.7979 as large as the standard deviation value for a normal distribution. (22) Therefore, the CV(actual) values required for determining the Degree of Perfection will be 1.25 times as large as the Linear Integrator Values (U%). This explains the difference in the values obtained by the Uster Linear and Quadratic Integrators. The Uster Corporation (23) states that the Quadratic Integrator value is approximately twenty-five per cent greater than the Linear Integrator value.

The instructions for properly operating the Uster Evenness Tester and the Linear Integrator are contained in the Uster Corporation "Instruction Book for the Uster Evenness Tester Model A, B" (23), and the Zellweger Uster "Operating Instructions for the Uster Integrator, Type 1TGL." (24) Both manuals contain the operating instructions in detailed form and are furnished with the instruments. Testing must be conducted in a laboratory maintained at standard conditions. The dielectric constant of the material passing through the external capacitor plates must remain constant for all tests run or the values obtained will not be valid. A wide variation in the moisture in the yarn tested will vary the dielectric constant and introduce an error into the results.

CHAPTER III

PROCEDURE

Determining the Number of Tests Necessary.--At the beginning of any experimental work the question of the number of samples to be tested always arises. The experimental work of this thesis is concerned with estimating some characteristic such as the average breaking strength of a given count yarn. It is definitely impractical and frequently impossible to determine the actual value of the characteristic. Instead, a limited number of tests are conducted (in this case on a bobbin of a given count yarn) and the value of the characteristic is estimated within certain limits. It is obvious that such a procedure will not necessarily give the desired answer every time. Therefore, when experimental work is conducted it is essential to determine the probability that the value of the tested characteristic will be within certain limits of the true value, and how many tests should be made to determine this estimated value.

The use of statistics will solve this problem once the engineer or researcher decides at what probability level he wishes to estimate that the mean of the test values will not differ from the true mean by more than some allowable sampling error. In this work a probability factor of 95 per cent was selected as being accurate enough for most practical purposes. The allowable sampling error or percentage accuracy of the mean was selected as six per cent. Then from statistics (25) (26) (27) the number of tests to be made is determined by the formula:

$$n = \left(\frac{1.96\ CV}{P}\right)^2 \tag{19}$$

where: n = number of tests

CV = coefficient of variation percentage

P = percent accuracy

To determine the number of tests from this formula it is necessary to know the coefficient of variation percentage. Partial preliminary testing plus any known information concerning the material under test will provide a rough estimation of the coefficient of variation. This estimate can then be substituted in formula (19) and the approximate number of tests determined. By this method the tested value obtained should be within six per cent of the true value approximately 95 times in 100.

Materials Used.--The testing materials used in the experimental work were manufactured by Coats and Clark, Inc., in their Georgia mills. The yarns were all combed cotton and ranged in size from 10's to 110's distributed representatively over a range of counts from coarse to fine. The yarns before manufacture were blended by Micronaire fiber fineness readings

(Upland Scale) with a mean fiber fineness value (Micronaire) of 3.5 for Egyptian Cotton, and 4.5 for American cotton.

The tests were conducted on only one bobbin of each count yarn and therefore the variation values determined apply only to the bobbin tested. This was done purposely so that the variation values used in comparing the different methods of determining the Degree of Perfection would not be influenced by any variation that might exist between bobbins of the same count yarn. The description of these yarns is given in Table 1.

Table 1. Description of Yarns Tested

Sample	Count	Type of Cotton	Staple (in.)	Twist Multiple
1	10's	Egyptian	1-7/16	3.4
2	23's	American	1-1/8	3.6
3	26's	American	1-1/8	3.6
4	30's	Egyptian	1-13/32	3.4
5	38's	Egyptian	1-13/32	3.4
6	44's	Egyptian	1-13/32	3.4
7	48's	Egyptian	1-13/32	3.4
8	56's	Egyptian	1-13/32	3.4
9	60's	Egyptian	1-13/32	3.4
10	66's	Egyptian	1-13/32	3.4
11	76's	Egyptian	1-13/32	3.4
12	80's	Egyptian	1-13/32	3.38
13	80's	American	1-5/16	3.38
14	100's	Egyptian	1-13/32	3.4
15	110's	Egyptian	1-13/32	3.5

<u>Experimental Method</u>.--All testing was conducted in an air-conditioned laboratory having standard atmosphere of 65 per cent relative humidity at 70 degrees Fahrenheit. The sample bobbins of yarn were first conditioned for two weeks (which

should insure equilibrium). Each bobbin of yarn was sized to determine the average yarn count by reeling 120-yard skeins and weighing the skeins on an analytical balance. A minimum of three sizings was made for each bobbin sample.

Each yarn was then broken using a Suter Single Strand Tester described in Chapter II with a ten-inch jaw distance for all break-tests. Approximately one yard of yarn was removed from the bobbin between individual break-tests. The testing precautions listed in Chapter II for single strand break-tests were observed. A minimum of forty break-tests was made on each bobbin.

Each yarn sample was then tested on the Uster Evenness Tester equipped with the Linear Integrator as described in Chapter II. The testing procedures followed were as described in the "Instruction Book for the Uster Evenness Tester." (23) A material speed of four yards per minute was selected based on a consideration of the variance-length curve relationship in testing yarn irregularity. (27) Ten Integrator readings at 30-second intervals were taken per bobbin tested for a total minimum of 28 yards of yarn tested per bobbin as recommended by the Uster Corporation. (27)

For each of the tests outlined above the mean value was determined from the minimum number of tests specified. The percentage coefficient of variation was then calculated for the count determination and the break-strength tests, and the value obtained in each case was substituted in formula (19) to estimate the correct number of tests to be made. The number of tests run in each case was then adjusted if necessary so that the mean value used in subsequent calculations should be at least within six per cent of the true value 95 times in 100.

Calculations.--The following statistical symbols and relationships used are defined as:

$$\bar{x} = \text{arithmetic mean} = \frac{\sum x}{n} \tag{20}$$

$$\sigma^2 = \text{squared standard deviation} = \frac{\sum(x^2) - \frac{(\sum x)^2}{n}}{n-1} \tag{21}$$

$$CV = \text{coefficient of variation} = \left(\frac{\sigma}{\bar{x}}\right) 100 \tag{22}$$

where:

x = observed or measured value

n = number of observations

$\sum$ = summation or sum of

These symbols and relationships have been used throughout the experimental procedure.

From formula (19) the coefficient of variation percentages of the observed values must exceed the following values in each case before the minimum number of tests previously specified would be increased:

CV(sized counts): 5.3

CV(break tests) : 19.4

As specified in Chapter II the following relationship was used in determining the CV(actual) from the Uster Linear Integrator values:

$$CV(actual) = 1.25\ U\% \tag{23}$$

where U% is the Uster corrected mean linear unevenness value.

As discussed in Chapter I the Degree of Perfection was calculated first utilizing the theoretical work of Martindale, and then utilizing the theoretical work of Duerst. By definition from formula (5):

$$\text{Degree of Perfection} = \frac{CV(actual)}{CV(limit)} \tag{5}$$

The following formula was used to determine CV(limit) by Enrick's method:

$$CV(limit) = 0.82\ \sqrt{\text{yarn count} \times \text{fiber weight}} \tag{8}$$

where fiber weight is taken as the average Micronaire reading for the particular type of cotton being considered. The CV(actual) was determined from the Uster Evenness Tester.

Using Duerst's hexagonal fiber pattern theory the CV(limit) was defined as:

$$CV(limit) = \frac{100}{u} \tag{18}$$

where "u" equals the average number of fibers per cross section diameter. Formula (18) was solved using formula (15) to determine the CV(limit) as:

$$\mathrm{CV(limit)} = \frac{100}{\sqrt{1 + \frac{8000}{\sqrt{F}\ \mathrm{cts}}} - 1} \qquad (24)$$

Also using Duerst's theory the CV(actual) was determined from the single strand break-tests as:

$$\mathrm{CV(actual)} = \mathrm{CV(break\text{-}tests)} \qquad (25)$$

In the following chapter the calculations are summarized for comparison of the two different approaches to determining the Degree of Perfection of cotton yarns.

CHAPTER IV

RESULTS

The sample number assigned to each different manufactured yarn count in Table 1 (page 34) has been used in all the other tables as the identifying symbol for the different tests and calculations made. The manufactured count of Sample 8 is less than Sample 9, but the actual yarn count determinations summarized in Table 2 show the reverse to be true. Also, the manufactured counts of Samples 12 and 13 are equal, but Table 2 shows that the actual count of Sample 13 is less than Sample 12.

Table 2. Summary of Yarn Count and Actual Yarn Variation Determinations

Sample Number	Sized Counts	CV(actual) by Single Strand Break-Tests	CV(actual) by Uster Tester
1	9.3	5.53	9.59
2	22.3	9.50	16.24
3	26.6	9.70	15.06
4	29.2	7.65	16.93
5	37.6	9.56	17.21
6	43.4	9.55	16.57
7	46.9	7.28	17.62
8	58.6	9.18	21.06
9	56.2	11.87	19.00
10	63.6	13.44	19.87
11	70.2	13.19	20.74
12	76.4	18.03	25.97
13	70.7	12.98	22.26
14	95.9	14.28	22.46
15	111.0	17.51	25.74

The sample numbers increase as the manufactured yarn counts increase as listed in Table 1. In addition, it should be remembered that Samples 2, 3, and 13 were yarns made from American Upland cotton, while all the other samples were made from Egyptian cotton. As the fiber fineness values of these two types of cotton are not the same, a comparison of Samples 2, 3, and 13 with the other samples tested requires consideration of this difference. These points of distinction are emphasized as they may not be readily apparent in the interpretation of the experimental results. The tables in the Appendix contain the individual sample results of the various tests conducted. The tables and figures in this chapter summarize the results of all tests in appropriate groups. The formulas used in the calculations are summarized in Chapter III and further explained in previous chapters.

The actual yarn variation values determined from single strand break-tests and from the Uster Tester are summarized in Table 2 and graphically represented in Figure 2. The variation values derived from the break-tests are lower in all cases than the values determined from the Uster Tester. Table 3 shows that the Degree of Perfection value calculated from the break-test variation values in the majority of cases is less than one. By definition the Degree of Perfection can not be less than one. This inconsistency appears to be significant and is further discussed in Chapter V. Table 3 also includes a comparison of the Degree of Perfection values

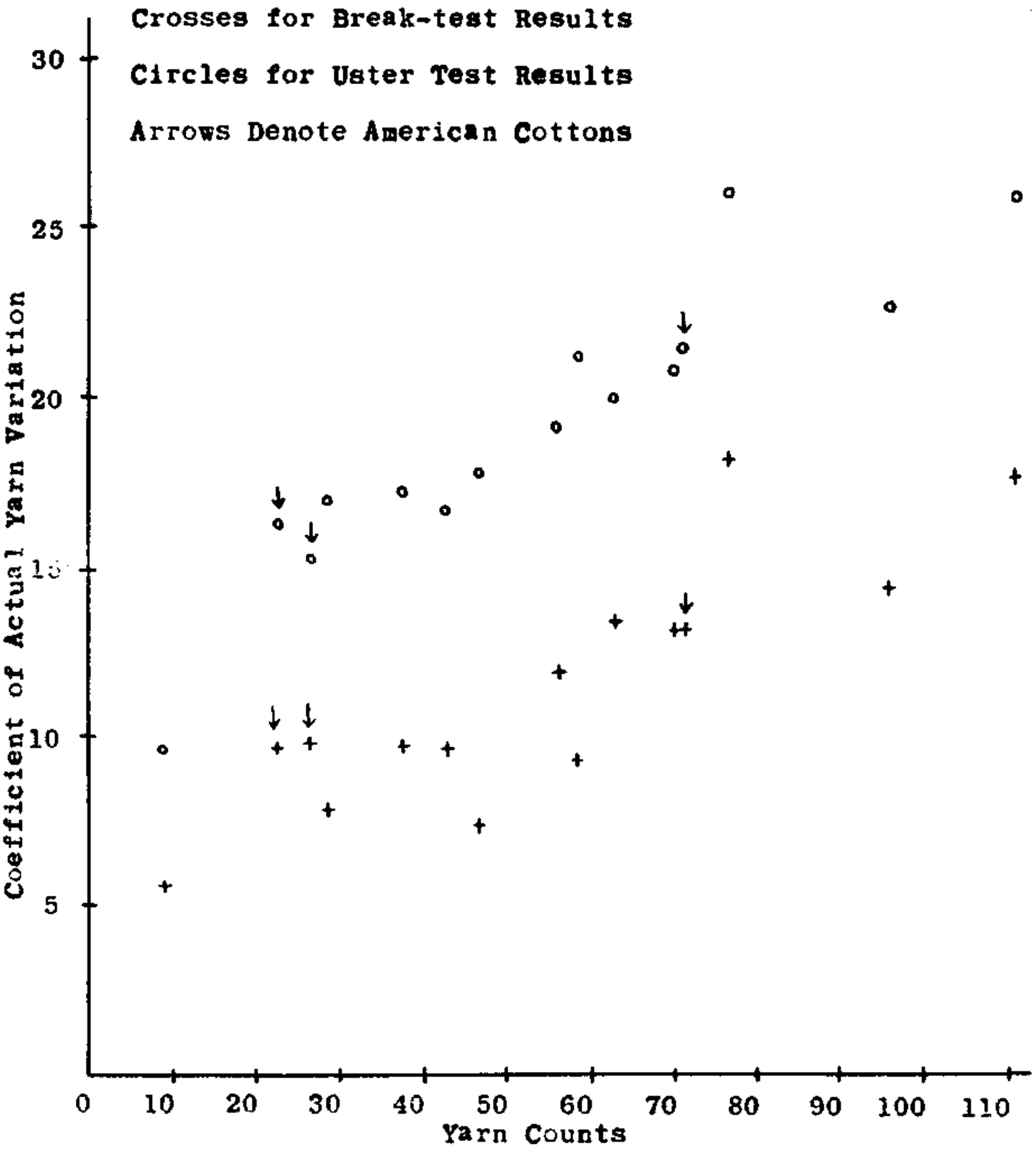


Figure 2. Relationship Between Yarn Counts And Coefficient of Actual Yarn Variation

obtained by the Duerst and Enrick methods using the Uster values for the actual yarn variation values.

Table 3. Comparison of Degree of Perfection Values Computed by Various Methods

Sample Number	CV(break-test) / CV(Duerst)	CV(Uster) / CV(Duerst)	CV(Uster) / CV(Enrick)
1	1.13	1.96	2.05
2	1.14	1.95	1.98
3	1.06	1.65	1.68
4	0.85	1.89	2.04
5	0.93	1.67	1.83
6	0.86	1.49	1.64
7	0.63	1.51	1.68
8	0.70	1.60	1.79
9	0.92	1.51	1.65
10	0.97	1.44	1.62
11	0.91	1.42	1.61
12	1.18	1.70	1.94
13	0.82	1.41	1.52
14	0.83	1.30	1.50
15	0.93	1.37	1.59

Figure 3 and Table 4 show the comparison between the minimum yarn variation values determined by the Duerst and Enrick methods. Figure 3 shows that the minimum variation values for both methods appear to increase parabolically as the yarn count increases. The CV(limit) values for the yarns made from American cotton do not agree with the Egyptian cotton values. This difference is understandable as the formulas used in the calculation of these values included fiber fineness which is different for each type of cotton. The American cotton values would fall on a separate curve

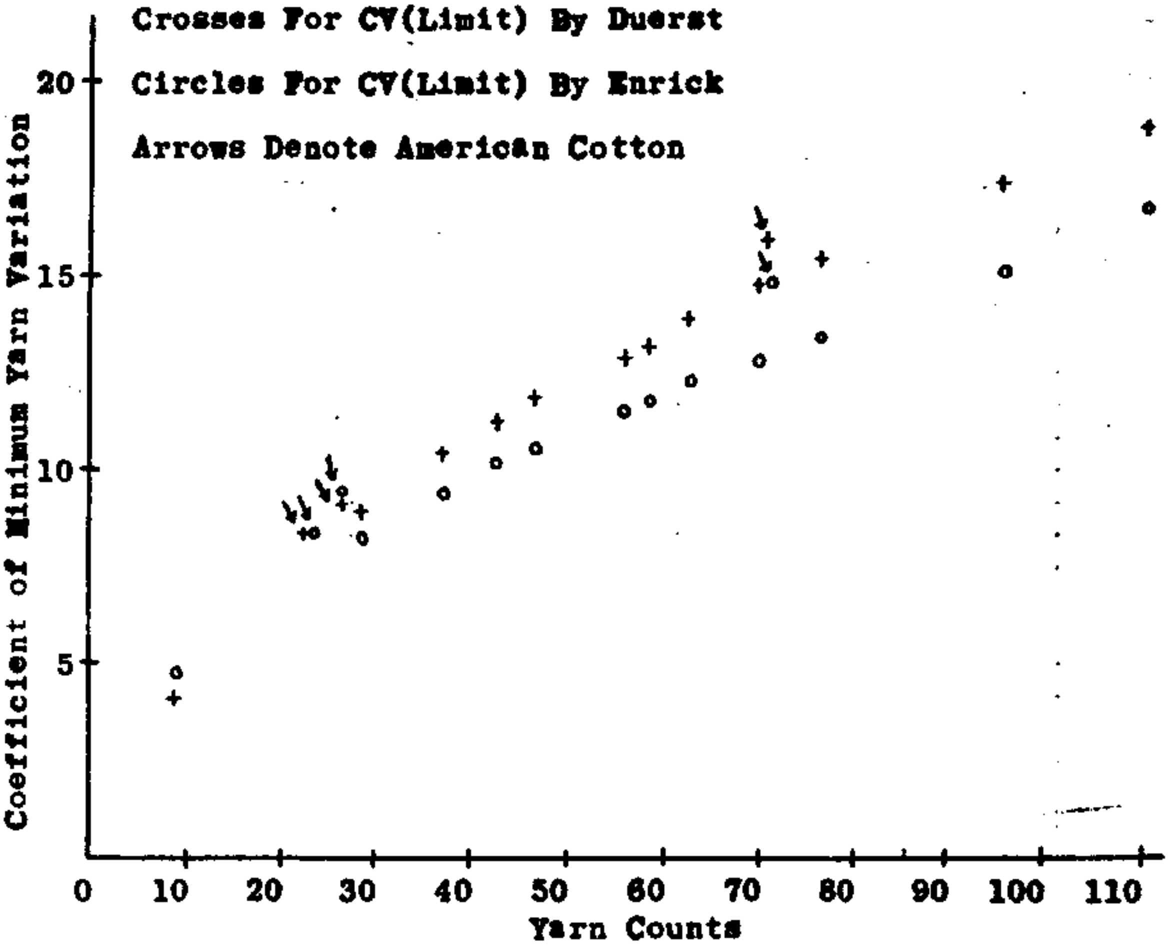


Figure 3. Relationship Between Yarn Counts and Coefficient of Minimum Yarn Variation

slightly higher than the curve for Egyptian cotton.

Table 4. Summary of Minimum Yarn Variation Determinations

Sample Number	CV(limit) by Duerst	CV(limit) by Enrick
1	4.89	4.68
2	8.31	8.22
3	9.12	8.97
4	8.95	8.29
5	10.28	9.41
6	11.11	10.10
7	11.64	10.50
8	13.16	11.74
9	12.85	11.50
10	13.79	12.24
11	14.56	12.86
12	15.28	13.41
13	15.75	14.63
14	17.30	15.02
15	18.76	16.16

Duerst's minimum yarn variation values are slightly higher than those determined by Enrick's method. This difference becomes proportionally greater as the yarn counts increase. This difference is further emphasized when the CV(limit) values are squared in Table 5 and illustrated graphically in Figure 4. The squared minimum variation values lie on straight-line curves as the yarn count increases. The formulas for these curves for the Egyptian cotton yarns only were determined by the method of least squares.

Table 5. Summary of Squared Values of Minimum Yarn Variation Determinations

Sample Number	Sized Counts	$(\text{CV-limit})^2$ by Duerst	$(\text{CV-limit})^2$ by Enrick
1	9.3	23.91	21.90
2	22.3	69.06	67.57
3	26.6	83.17	80.46
4	29.2	80.10	68.72
5	37.6	105.68	88.55
6	43.4	123.43	102.01
7	46.9	135.49	110.25
8	58.6	173.19	137.83
9	56.2	165.12	132.25
10	63.6	190.16	149.82
11	70.2	211.99	165.38
12	76.4	233.48	179.83
13	70.7	248.06	214.04
14	95.9	299.29	225.60
15	111.0	351.94	261.15

The method for determining these formulas from the values in Table 5 is fully explained by Brownlee (28) and is a standard statistical procedure. The formulas can be used to estimate the squared minimum yarn variation value for a known yarn count with the restriction noted below on Micronaire values. By Duerst's method the formula is:

$$Y = 3.26X - 15.15 \qquad (26)$$

where: Y = squared value of CV(limit) by Duerst

X = yarn count for Egyptian cotton with an average Micronaire value (Upland Scale) of 3.5

By Eurick's method the formula is;

$$Y = 2.35X \qquad (27)$$

where; Y = squared value of CV(limit) by Eurick.

X = yarn count for Egyptian cotton with an average Micronaire value (Upland Scale) of 3.5

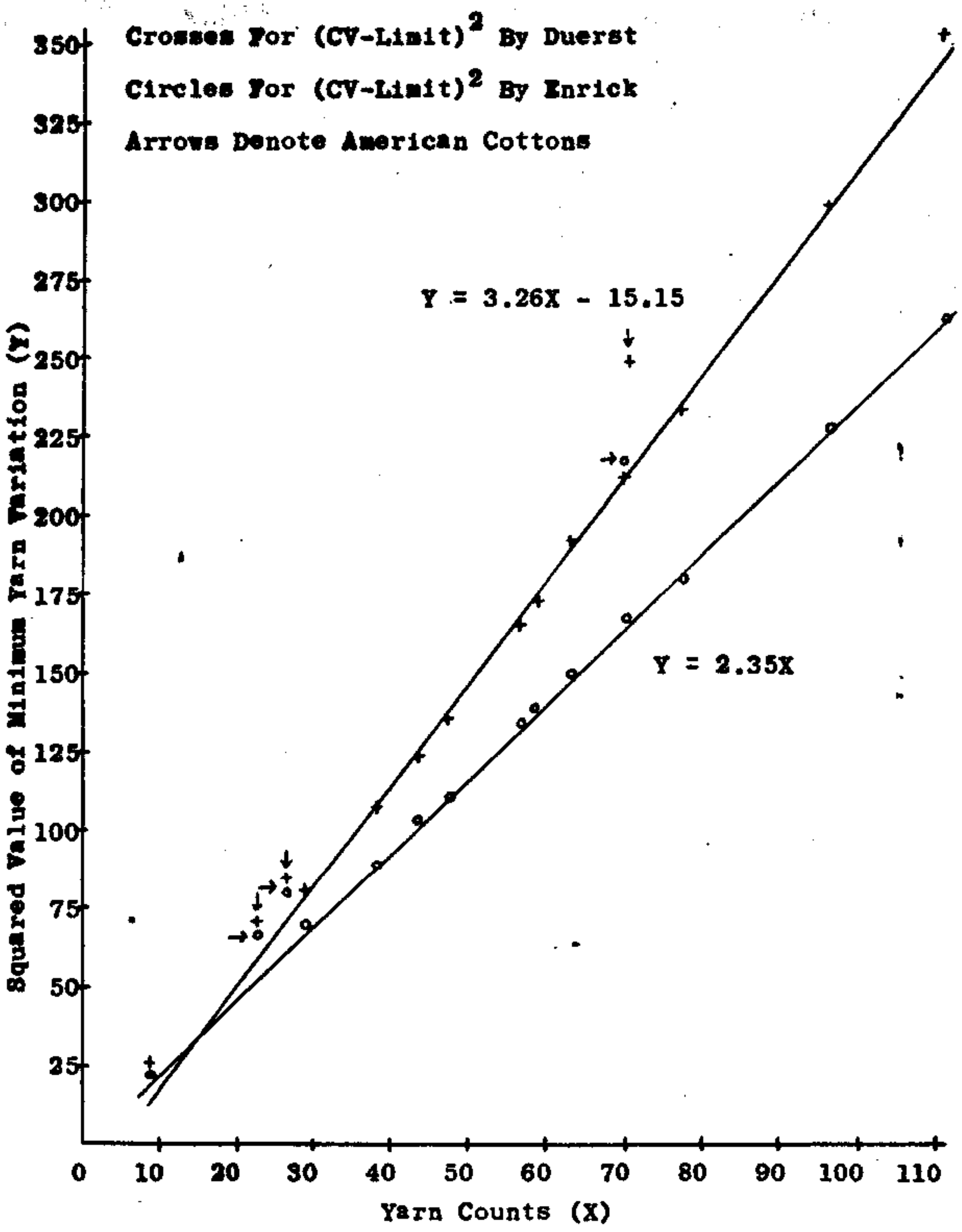


Figure 4. Relationship Between Yarn Counts and Squared Value of Minimum Yarn Variation

CHAPTER V

DISCUSSION OF RESULTS

In Chapter I the hypothesis was made that the variation in the number of fibers per yarn cross section could be determined from the variation in yarn break-strength if the yarn was approximately at maximum twist. Additional calculations were made to establish a comparison between theoretical maximum yarn twist and manufactured yarn twist in an attempt to explain the inconsistent strength versus weight-per-unit-length variation results. Duerst (12) states in his treatise on cotton yarn calculations that the maximum yarn twist for maximum strength can be determined by the following formula:

$$t = \frac{280}{L_1 u} \qquad (28)$$

where: t = maximum twist

L_1 = effective staple length (grader's staple length for carded yarns and five per cent greater for combed yarns)

u = average number of fibers per cross section diameter determined by formula (15)

The theoretical maximum twist was calculated by this formula and the manufactured twist determined from the Spinner's

Rule that twist is equal to a multiple times the square root of the yarn count. The twist multiples are listed in Table 1 (Chapter III). Table 6 summarizes these calculations for comparison. In most cases the yarns tested were undertwisted by Duerst's formula and would lead to the conclusion that the conditions of the strength-variation hypothesis had not been followed. However, Samples 1, 2, 3, and 13 are all sufficiently close to maximum twist by the Duerst formula that the conditions of the hypothesis appear to be satisfied, but Figure 2 (Chapter IV) shows that the difference between the variation values is not particularly larger or smaller than the difference for the other yarns.

Table 6. Comparison of Calculated Yarn Maximum Twist and Calculated Yarn Actual Twist

Sample Number	Twist Maximum	Computed Actual Yarn Twist
1	9.1	10.4
2	19.7	17.0
3	21.7	18.6
4	23.2	18.4
5	26.6	20.8
6	28.8	22.4
7	30.2	23.3
8	34.1	26.0
9	33.3	25.5
10	35.8	27.1
11	37.7	28.5
12	39.6	29.5
13	32.0	28.4
14	44.9	33.3
15	48.6	36.9

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

In any manufactured product a certain amount of variation is inevitable. Some of this variation is attributable to chance and some of it to assignable causes. A manufacturer cannot afford to produce an uneconomical product. In making decisions relative to the economy and efficiency of producing different counts of yarn some common standard of comparison must be used. To directly compare measured yarn variations of different yarn counts neglects the increasing variations attributable to chance causes as the yarn counts increase.

The Degree of Perfection technique was designed to avoid this pitfall. Its use permits the comparison of different yarn counts and an evaluation of overall product efficiency. The manufacturer can then decide from his knowledge of production costs, sales volume, and related matters whether it would be more economical to discontinue producing a certain count yarn, or whether it would be more economical in the long run to determine and lower assignable causes of product variation. The Degree of Perfection values of all counts of yarn produced should be approximately equal. A rise in the value for a certain yarn would indicate a possible source of trouble. A decrease in the value for a certain yarn would indicate the existence of a possible procedure for reducing assignable variation that might be applied to the production of other yarn counts. This could lead to an overall increase in mill efficiency. When yarns are made on order, a trial run determination of the Degree of Perfection would permit comparison with the mill's values for other yarns already being made. This comparison might indicate that it would be uneconomical for the mill to accept a contract for a certain count yarn without expensive experimentation and alteration of existing production techniques. The Degree of Perfection technique could also be used by purchasers of yarns to evaluate the yarns bought against a desired standard.

It has been determined that the factors affecting cotton yarn irregularity are the variation in the number of fibers per cross section area and the variation of individual fibers themselves. Also, it has been shown that cotton yarn irregularity has a definite minimum or inherent variation which increases as the yarn counts increase. The existence of this minimum variation explains the inaccuracy of attempting to compare yarns of different counts solely on the basis of some measurement of actual yarn variation. To compare yarns of varying counts the Degree of Perfection was utilized and defined as the ratio of the actual yarn variation to the minimum yarn variation. The value of this ratio at a minimum is one, when the yarn is perfect. For comparison purposes the yarn with the lower Degree of Perfection value is the better yarn.

Two methods of determining the minimum yarn variation were explained and tested, and it was found that the Duerst method gave higher values than the Enrick method. Which is the better method to determine the minimum yarn variation is a difficult question to decide. The theoretical determination of minimum yarn variation by Martindale appears to be more satisfactory from the standpoint of rigid mathematical proof. Duerst's theory involves certain empirical relationships that prevent rigid mathematical derivation. Practice has shown that these empirical relationships appear to exist and thus the writer does not feel qualified on the basis of this thesis to pass judgment on the best theoretical determination of minimum yarn variation, or the best method of measuring minimum yarn variation.

However, it is felt that both Duerst and Enrick have neglected one of the factors of yarn variation in their respective methods of measurement. Their methods are both based on the variation in the number of fibers per yarn cross section, and utilize the average fiber weight-per-unit-length (Micronaire). This procedure implies that the variation in the fibers themselves is either non-existent or negligible in relation to the fiber mean value. No information could be found in the literature on the value of the variation among the individual fibers in a yarn cross section.

It is believed that this point should not pass unnoticed however, as it is difficult to imagine nature producing any two items exactly alike. The density of cotton (i.e., cellulose) is constant. Fiber fineness measurements measure the fiber linear density (weight-per-unit-length), but this value is not constant. The maturity of the cotton fibers is a measure of the amount of cellulose deposited on the inner wall of the fiber. It is possible to have two samples of cotton fibers of equal fineness values (Micronaire) and equal sample weights. However, if the amount of variation of fiber maturity were very large in one sample and very small in the other sample, there could be a significant difference in the number of fibers in each sample. Whether the yarn variation values would be significantly different in the case of a wide variation in the weight-per-unit-length of the fibers used to make the yarn is unknown. The answer might show that the individual fiber variation actually has a negligible effect compared to the variation in the number of fibers per yarn cross section, but from a theoretical standpoint this factor should not be ignored. It is recommended that further research be conducted to determine the answer to this problem.

The method of determining the actual yarn variation by an electronic tester such as the Uster for measuring yarn weight-per-unit-length variation is faster and less subject to error than the method of single strand break-tests. The fact that a correlation between the two methods may exist is not important to this thesis. The two methods should have produced the same results and did not. The use of strength variation values in determining the Degree of Perfection values gave erroneous results. The use of the single strand break-test method requires more refinement in stipulating the conditions under which it could be used. It appears that the electronic tester method would be applicable in all cases.

The Degree of Perfection values appear to be satisfactory for comparing yarns of different counts. The entire procedure for the determination of these values is lengthy and can be simplified for use as a quality control measure. A satisfactory Degree of Perfection value for the yarns being produced in a mill can be selected. A straight-line formula such as formula (27) or formula (28) can be determined for the average fiber fineness used in making the initial cotton blend. This formula can then be used with a desired Degree of Perfection value to estimate the actual yarn variation desired for a given count yarn.

For example, from Table 3 the desired Degree of Perfection value of 1.6 might be selected for both the Duerst and Enrick methods. Then, by the Duerst method the standard actual yarn variation formula at an average fineness of 3.5 would be:

$$\text{standard CV(actual)} = 2.89\ \sqrt{\text{counts}} - 4.65 \qquad (29)$$

Also, for the Enrick method the standard yarn variation formula at an average fineness of 3.5 would be:

$$\text{standard CV(actual)} = 2.46\ \sqrt{\text{counts}} \qquad (30)$$

Yarns can then be tested on an electronic tester such as the Uster and their values compared directly without extensive calculations with a desired standard value. This would appear to be a useful quality control measure.

APPENDIX

Table 7. Determination of Actual (Sized) Yarn Count

Test	Weight (Grams/120 yds)	Count
Sample 1		
1	6.9594	9.3
2	6.9970	9.3
3	7.0018	9.3
Sized Count = 9.3's CV(count) = 0.00		
Sample 2		
1	2.9118	22.3
2	2.8754	22.5
3	2.9425	22.0
Sized Count = 22.3's CV(count) = 1.15		
Sample 3		
1	2.4511	26.4
2	2.3848	27.2
3	2,4745	26.2
Sized Count = 26.6's CV(count) = 1.99		
Sample 4		
1	2.2122	29.3
2	2.2299	29.1
3	2.2182	29.2
Sized Count = 29.2's CV(count) = 0.34		
Sample 5		
1	1.7691	36.6
2	1.6971	38.2
3	1.7085	37.9
Sized Count = 37.6's CV(count) = 2.26		
Sample 6		
1	1.4967	43.3
2	1.5151	42.8
3	1.4708	44.1
Sized Count = 43.4's CV(count) = 1.52		
Sample 7		
1	1.3963	46.4
2	1.3834	46.8
3	1.3655	47.5
Sized Count = 46.9's CV(count) = 1.19		
Sample 8		
1	1.1145	58.1
2	1.0910	59.4
3	1.1120	58.3
Sized Count = 58.6's CV(count) = 1.19		

(Continued)

Table 7. Determination of Actual (Sized) Yarn Count (Continued)

Test	Weight (Grams/120 yds)	Count
Sample 9		
1	1.1771	55.1
2	1.1357	57.1
3	1.1463	56.5
Sized Count = 56.2's CV(count) = 1.83		
Sample 10		
1	1.0192	63.6
2	1.0181	63.6
3	1.0203	63.5
Sized Count = 63.6's CV(count) = 0.11		
Sample 11		
1	0.9145	70.9
2	0.9300	69.7
3	0.9248	70.1
Sized Count = 70.2's CV(count) = 0.87		
Sample 12		
1	0.8518	76.1
2	0.8327	77.8
3	0.8617	75.2
Sized Count = 76.4's CV(count) = 1.73		

Test	Weight (Grams/120 yds)	Count
Sample 13		
1	0.9294	69.7
2	0.9045	71.6
3	0.9148	70.8
Sized Count = 70.7's CV(count) = 1.34		
Sample 14		
1	0.6778	95.6
2	0.6894	94.0
3	0.6612	98.0
Sized Count = 95.9's CV(count) = 2.11		
Sample 15		
1	0.5882	110.2
2	0.5914	109.6
3	0.5727	113.1
Sized Count = 111.0's CV(count) = 1.69		

Table 8. Single Strand Break-Test Results

Breaking Strength (pounds)									
Sample 1		Sample 2		Sample 3		Sample 4		Sample 5*	
3.20	3.35	1.03	1.17	0.97	0.85	1.00	0.94	335	370
3.35	3.40	0.96	1.25	1.01	0.93	1.07	1.08	325	340
3.60	3.35	1.01	1.12	0.97	1.16	1.24	0.98	355	315
3.25	3.50	1.13	1.07	0.94	0.98	1.03	1.03	300	350
3.45	3.60	1.00	0.97	0.94	1.01	1.07	0.95	385	290
3.45	3.50	1.03	0.97	0.72	0.87	0.93	1.07	315	335
3.20	3.45	0.82	0.89	0.82	0.85	1.04	1.08	345	320
3.30	3.45	0.84	0.94	0.91	0.95	0.91	1.01	275	320
2.95	3.35	1.09	0.94	1.08	1.01	1.01	1.02	275	275
3.05	3.15	0.97	1.10	0.94	1.08	0.95	0.99	365	330
3.20	2.95	1.01	1.04	0.88	1.05	0.97	0.99	345	305
3.30	3.35	1.12	1.03	0.92	1.01	0.88	0.94	275	355
2.95	3.10	1.08	1.01	0.77	0.97	0.95	0.95	335	325
2.85	3.35	1.17	0.87	0.93	0.88	0.96	1.02	350	305
3.35	3.35	0.94	1.01	1.01	0.85	0.94	1.06	365	345
3.35	3.20	1.07	1.12	1.00	1.11	0.93	1.13	290	350
3.35	3.30	1.15	1.07	0.88	0.91	1.07	0.97	325	305
3.25	3.35	1.12	0.87	0.91	0.86	0.97	0.89	320	290
3.55	3.35	1.05	1.07	0.94	0.87	0.87	0.89	295	270
3.50	3.60	1.17	1.05	1.02	0.91	0.94	0.90	330	265
Average									
	3.31		1.03		0.94		0.99		322*
CV(actual)									
	5.53		9.50		9.70		7.65		9.56

* Grams

(Continued)

Table 8. Single Strand Break-Test Results (Continued)

Breaking Strength (Grams)									
Sample 6		Sample 7		Sample 8		Sample 9		Sample 10	
260	320	280	285	240	205	205	280	180	200
290	290	315	295	260	190	230	230	165	130
260	305	340	260	240	215	240	230	145	130
260	305	315	285	235	200	165	225	155	190
310	315	290	305	185	190	225	225	160	170
305	265	275	290	235	205	220	215	155	200
370	335	280	310	225	210	200	240	170	170
280	315	275	305	195	215	190	235	170	205
350	265	270	290	220	200	215	210	190	185
330	315	305	300	220	235	180	225	175	165
310	330	295	290	230	220	260	220	180	215
310	355	275	280	200	235	220	220	200	200
315	315	295	320	230	190	270	190	140	200
300	340	260	315	185	230	195	230	215	195
320	335	260	270	210	210	220	240	135	170
265	275	280	240	230	205	235	170	155	180
280	345	310	255	220	190	190	200	160	180
330	275	270	310	180	235	170	240	145	165
320	265	270	295	185	240	205	240	215	190
290	285	315	305	200	215	185	215	200	195
Average									
	305		290		214		218		176
CV(actual)									
	9.55		7.28		9.18		11.87		13.44

(Continued)

Table 8. Single Strand Break-Test Results (Continued)

Breaking Strength (Grams)									
Sample 11		Sample 12		Sample 13		Sample 14		Sample 15	
200	145	125	130	175	150	120	100	95	80
185	135	160	110	150	135	120	100	95	100
180	195	150	140	160	145	130	105	80	120
205	160	170	100	130	120	105	105	75	125
160	205	130	145	150	135	110	90	85	95
140	185	140	110	145	120	115	100	100	70
185	165	135	100	145	110	90	100	100	70
150	185	100	95	140	130	110	85	115	120
195	155	145	110	160	120	125	135	130	120
145	180	115	100	130	130	125	125	120	120
155	180	130	125	145	130	100	95	95	95
135	215	120	140	170	125	75	135	115	100
155	145	120	145	130	150	80	100	85	100
145	195	125	75	135	170	105	115	125	115
160	180	105	75	135	110	105	125	95	130
130	170	120	160	155	180	140	95	85	75
155	180	140	120	180	145	115	120	115	90
160	195	115	155	110	155	110	95	85	125
195	160	95	135	155	150	120	115	90	90
160	155	130	100	125	145	105	135	115	120
Average									
	170		124		142		110		102
CV(actual)									
	13.19		18.03		12.98		14.28		17.51

Table 9. Yarn Variation By Uster Tester

Reading Number	Integrator U%	Average Value	Correction Factor	U%
Sample 1				
1	7.75	2.0	0.96	7.44
2	8.00	3.0	0.94	7.52
3	9.00	5.0	0.91	8.19
4	7.75	4.0	0.92	7.13
5	7.75	3.0	0.94	7.29
6	8.00	4.0	0.92	7.36
7	8.00	3.0	0.94	7.52
8	8.25	1.5	0.97	8.00
9	8.25	2.5	0.95	7.84
10	8.75	2.0	0.96	8.40
CV(actual) = 9.89			U%(average) = 7.67	
Sample 2				
1	13.0	0.0	1.00	13.00
2	14.0	1.0	0.96	13.44
3	13.5	1.0	0.96	12.96
4	13.5	1.0	0.96	12.96
5	14.0	2.0	0.92	12.88
6	14.5	2.5	0.90	13.05
7	14.5	3.0	0.89	12.91
8	14.0	3.0	0.89	12.46
9	14.5	2.0	0.92	13.34
10	14.0	2.0	0.92	12.88
CV(actual) = 10.24			U%(average) = 12.99	
Sample 3				
1	14.0	3.0	0.89	12.46
2	12.5	3.0	0.89	11.13
3	12.5	3.0	0.89	11.13
4	14.5	4.5	0.84	12.18
5	14.0	4.0	0.86	12.04
6	13.0	3.0	0.89	11.57
7	13.0	2.5	0.90	11.70
8	14.0	3.0	0.89	12.46
9	15.0	4.0	0.86	12.90
10	15.0	4.0	0.86	12.90
CV(actual) = 15.06			U%(average) = 12.05	

(Continued)

Table 9. Yarn Variation By Uster Tester (Continued)

Reading Number	Integrator U%	Average Value	Correction Factor	U%
Sample 4				
1	11.5	-2.0	1.09	12.54
2	12.5	-1.0	1.04	13.00
3	12.5	-2.0	1.09	13.63
4	13.0	-3.0	1.14	14.82
5	13.0	-2.5	1.12	14.56
6	13.0	-2.0	1.09	14.17
7	12.0	-3.0	1.14	13.68
8	12.0	-2.5	1.12	13.44
9	12.0	-2.0	1.09	13.08
10	11.5	-2.0	1.09	12.54
CV(actual) = 16.93			U%(average) = 13.55	
Sample 5				
1	14.0	0.0	1.00	14.00
2	14.0	-0.5	1.02	14.28
3	14.0	0.0	1.00	14.00
4	13.0	-1.0	1.04	13.52
5	13.0	-2.0	1.09	14.17
6	13.0	-2.0	1.09	14.17
7	13.0	-1.5	1.07	13.91
8	12.0	-1.5	1.07	12.84
9	12.5	-1.5	1.07	13.38
10	12.5	-1.5	1.07	13.38
CV(actual) = 17.21			U%(average) = 13.77	
Sample 6				
1	13.5	2.0	0.92	12.42
2	14.0	1.5	0.94	13.16
3	16.0	3.5	0.87	13.92
4	15.0	3.0	0.89	13.35
5	14.0	2.5	0.90	12.60
6	14.0	2.0	0.92	12.88
7	14.5	2.0	0.92	13.34
8	14.0	2.0	0.92	12.88
9	14.5	1.5	0.94	13.63
10	15.0	1.0	0.96	14.40
CV(actual) = 16.87			U%(average) = 13.26	

(Continued)

Table 9. Yarn Variation By Uster Tester (Continued)

Reading Number	Integrator U%	Average Value	Correction Factor	U%
Sample 7				
1	17.5	5.0	0.83	14.53
2	18.0	5.5	0.82	14.76
3	17.0	4.5	0.84	14.28
4	16.5	4.0	0.86	14.19
5	16.0	3.0	0.89	14.24
6	16.5	4.0	0.86	14.19
7	16.5	4.5	0.84	13.86
8	16.5	5.0	0.83	13.70
9	16.0	4.5	0.84	13.44
10	16.0	4.0	0.86	13.76
CV(actual) = 17.62			U%(average) = 14.10	
Sample 8				
1	16.5	0.5	0.98	16.17
2	17.5	2.0	0.92	16.10
3	18.0	2.0	0.92	16.56
4	19.0	3.0	0.89	16.91
5	19.5	3.5	0.87	16.97
6	19.5	2.5	0.90	17.55
7	19.0	2.5	0.90	17.10
8	19.5	2.5	0.90	17.55
9	18.0	1.5	0.94	16.92
10	17.0	0.5	0.98	16.66
CV(actual) = 21.06			U%(average) = 16.85	
Sample 9				
1	18.5	3.0	0.89	16.47
2	17.0	3.0	0.89	15.13
3	18.0	3.0	0.89	16.02
4	17.5	2.5	0.90	15.75
5	16.5	2.0	0.92	15.18
6	16.0	2.0	0.92	14.72
7	15.5	1.5	0.94	14.57
8	16.0	2.0	0.92	14.72
9	16.0	2.0	0.92	14.72
10	16.0	2.0	0.92	14.72
CV(actual) = 19.00			U%(average) = 15.20	

(Continued)

Table 9. Yarn Variation By Uster Tester (Continued)

Reading Number	Integrator U%	Average Value	Correction Factor	U%
Sample 10				
1	16.5	2.5	0.90	14.85
2	17.0	3.5	0.87	14.79
3	19.0	4.0	0.86	16.34
4	18.0	3.0	0.89	16.02
5	19.0	3.0	0.89	16.91
6	17.5	3.0	0.89	15.58
7	19.5	5.0	0.83	16.19
8	20.0	4.5	0.84	16.80
9	18.0	4.0	0.86	15.48
10	19.0	4.5	0.84	15.96
CV(actual) = 19.87			U%(average) = 15.89	
Sample 11				
1	18.0	1.5	0.94	16.92
2	15.5	1.0	0.96	14.88
3	16.5	1.5	0.94	15.51
4	18.0	2.0	0.92	16.56
5	18.0	3.0	0.89	16.02
6	18.0	1.5	0.94	16.92
7	19.0	1.0	0.96	18.24
8	19.0	1.5	0.94	17.86
9	17.5	2.0	0.92	16.10
10	19.0	3.0	0.89	16.91
CV(actual) = 20.74			U%(average) = 16.59	
Sample 12				
1	20.0	-2.0	1.09	21.80
2	20.0	-2.0	1.09	21.80
3	20.0	-1.0	1.04	20.80
4	20.0	-1.0	1.04	20.80
5	19.0	-1.0	1.04	19.76
6	19.5	-0.5	1.02	19.89
7	20.0	-1.0	1.04	20.80
8	19.0	-1.5	1.07	20.33
9	19.5	-1.5	1.07	20.87
10	20.0	-1.0	1.04	20.80
CV(actual) = 25.97			U%(average) = 20.77	

(Continued)

Table 9. Yarn Variation By Uster Tester (Continued)

Reading Number	Integrator U%	Average Value	Correction Factor	U%
<u>Sample 13</u>				
1	18.0	0.0	1.00	18.00
2	18.0	0.0	1.00	18.00
3	17.5	-0.5	1.02	17.85
4	17.5	0.0	1.00	17.50
5	17.5	0.5	0.98	17.15
6	18.0	1.0	0.96	17.28
7	17.5	0.5	0.98	17.15
8	19.5	1.5	0.94	18.33
9	18.5	0.5	0.98	18.13
10	19.5	1.0	0.96	18.72
CV(actual) = 22.26			U%(average) = 17.81	
<u>Sample 14</u>				
1	18.0	-1.0	1.04	18.72
2	17.0	-2.0	1.09	18.53
3	17.5	-1.0	1.04	18.20
4	18.5	0.0	1.00	18.50
5	17.0	-1.0	1.04	17.68
6	17.0	-1.0	1.04	17.68
7	17.5	0.0	1.00	17.50
8	18.0	0.0	1.00	18.00
9	17.0	0.0	1.00	17.00
10	18.0	0.0	1.00	18.00
CV(actual) = 22.48			U%(average) = 17.98	
<u>Sample 15</u>				
1	19.0	-0.5	1.02	19.38
2	18.5	-1.5	1.07	19.79
3	18.5	-2.5	1.12	20.72
4	20.5	-2.0	1.09	22.35
5	21.0	-3.0	1.14	23.94
6	19.5	-2.0	1.09	21.26
7	18.5	-2.0	1.09	20.17
8	18.5	-2.0	1.09	20.17
9	18.0	-2.0	1.09	19.62
10	17.0	-2.0	1.09	18.53
CV(actual) = 25.74			U%(average) = 20.59	

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