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2010 **Mlando Basil Mvubu**

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Department of Textile Technologies

Characterization of Yarn Diameter Measured by Different Systems

Mlando B. Mvubu

Supervisor : Prof. Ing. Sayed Ibrahim, CSc.

Consultants: Ing. Gabriela Krupincová

: Ing. Eva Mouckova, PhD

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Annotation

This thesis work tries to establish ways of comparing yarn diameter measurement values obtained from different measuring systems particularly Uster Tester 4 and QQM 3 as attempts have been made in the past to try and correlate the results from these two instruments.

The work will also try and further investigate the versatility of the D-Yarn program in analyzing yarn diameter (and its variations) data compared to other similar analyzing systems.

Yarn diameter and its variations together with hairiness were measured and compared accordingly, using various instruments and systems and from there, conclusions were drawn as to the comparability (correlation) of the results from these instruments.

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1. Introduction

The pursuit for higher quality and low cost textile products always presents a difficult equation which has of yet no solution. Wide adoption of quality management techniques requires standardization and optimization of design, production, and quality control of textile products. To achieve this goal, precise measurement and suitable evaluation methods should be applied. The yarn uniformity has been recognized as being one of the most important factors. The unevenness of yarn may occur in the form of twist irregularity, diameter irregularity, and mass irregularity. Yarn irregularity may have a direct impact on the weight, permeability, and strength distributions; it may also indirectly impact the appearance, for example, by causing variation in the dye absorption behavior of the yarn.

Inherently, all yarns are subject to periodic and random variations. However, the effect of variation on the resulting fabric is difficult to predict. The difficulties are due to limitations in measurement technology, computation and especially unpredictable mapping from yarn to fabric. Generally, it is accepted that the yarn irregularity is defined as the continuous variation of mass per unit length and expressed by CV% or U%, where the yarn faults are known as discrete function and characterized by the number of faults per unit length.

Many laboratory methods have been introduced to characterize yarn irregularity. Also in the market many instruments from different producers are used for characterization of yarn unevenness. These instruments differ in the principle of measuring and the logic of evaluation of yarn irregularity. These instruments work on capacitive or optical principle or both together. The sensors are of different characteristics, for example, condensers used as by Uster 3 and 5 have the condenser width of 8 mm, whereas, Uster 4 uses a condenser of 10 mm. Recently an Instrument has been developed by University of Minho-Portugal, which has a condenser of 1mm. Optical measurements use different principles, as infra-red light, laser beam etc. All of these systems result in different values of yarn irregularity and in estimation yarn diameter, and its variability.

1. Literature Review

Among all yarn characteristics, Yarn diameter is probably one of the most important, yet this characteristic is also the most difficult to determine, in actual fact nobody can actually explain what is it exactly is meant by ***yarn diameter***. This is mainly due to its nature, yarn is primarily a fiber bundle bound together by cohesive forces and torque (each fiber spirals in a way that 'holds' other fibers in place). This nature of yarn is dependent on the yarn forming (spinning) method and is also subject to another very important Yarn Characteristic in its characterization, i.e. ***yarn irregularity***

While the exact determination of yarn diameter has so far proven elusive, some attempts have been made throughout the decades to approximate yarn diameter, some are based on theory some are based on practice. Therefore there have been Machines and Laboratory methods that have been developed to 'determine' (approximate) yarn diameter.

In this chapter, methods of Yarn Diameter, Irregularity and Hairiness measurements together with Spinning Methods will be reviewed.

2.1. Yarn Irregularity

By the very nature of the forming systems, yarns are irregular at microscopic level. This irregularity is not an issue of much concern in Textile Technology; it is when these irregularities manifest themselves at a macroscopic level that they start to become a cause for concern to Textile Technologists. In general terms, spinning yarns involves twisting together of bundles of fibers that are brought together by preceding processes such as carding, drawing and sliver forming.

Since the production of yarn is not completely controllable and the amount of fiber at any point in the production line is variable, the staple yarn is almost never regular or perfect. Also contributing to this, is the fact that fibers themselves do not have determinate shape and uniform geometry and are also blended with foreign elements.

The random fiber arrangement and fiber-length effect.

Throughout the history of yarn irregularity research and study, many such investigations have been made under several assumptions. The random fiber arrangement and the drafting of shorter fibers were thought of to be the main cause of yarn mass irregularity. J.G. Martindale [7] studied the irregularity of yarn caused by random fiber arrangement by assuming that the fibers are randomly arranged through blending, carding, doubling, roving and spinning. This model was based on the premise that the probability of a fiber crossing a given yarn cross-section is proportional to the length of the fiber.

Martindale's first approach was based on the assumption that a yarn cross-section contains a total of *N* fibers all of the same length. From this then the probability of a fiber crossing a given cross-section would be $P = \frac{n}{N}$ where ***n*** is the average number of fibers in the yarn cross-section. As ***P*** is very small for yarns, this process was estimated by a Poisson distribution whose mean is ***n*** and the standard deviation is $\sqrt{n}$. The coefficient of variation, CV, of yarn was then projected as $\frac{100}{\sqrt{n}}$.

In his second approach, Martindale [7] was more advanced in the sense that the fibers are no longer assumed to be of the same length. He proposed that a yarn cross-section contains a group of m fibers with the lengths $l_1, l_2, l_3, \ldots, l_m$, each group having n_r fibers, where:

$$\sum_{r=1}^{m} n_r = n \qquad (1)$$

Looking back to his first approach and assuming independence between groups of different fiber lengths, Martindale showed that the standard deviation of the number of fibers in a yarn cross-section is still $\sqrt{n}$ as follows:

$$\delta_n^2 = \sum_{r=1}^{m} \delta_r^2 = \sum_{r=1}^{m} n_r = n \qquad (2)$$

Thus implying that the CV is unaffected by the length characteristics of the fibers. This assertion was however contested by P. Grosberg [8]. In practice he showed that the fiber length and yarn regularity are correlated; therefore one can calculate the yarn irregularity from the mean fiber diameter, length and count of the yarn. In his experiments he showed that for a given fiber diameter, an increase in the mean fiber length would result in a decreasing CV, probably as a result of improved orientation.

In his final approach, Martindale considered a non-uniform fiber cross section area. He split the variations as being caused by these two aspects of yarn structure: the variations caused by the non-uniform fiber cross-section and the non constant number of fibers in any given cross-sections. From this he assumed that the number of fibers in the yarn cross sections has a mean ***n*** and variance δ_n^2 where each fiber has a mean cross section area $\overline{A}$ and variance δ_A^2. He obtained the yarn variance, δ_Y^2 as follows:

$$\begin{aligned} \sigma_Y^2 &= \bar{A}^2\sigma_n^2 + n\sigma_A^2 \\ &= n\bar{A}^2 + n\sigma_A^2 \\ &= n\bar{A}^2\left(1+\frac{\sigma_A^2}{\bar{A}^2}\right) \\ &= n\bar{A}^2\left(1+0.00001CV^2(A)\right) \end{aligned}$$

Here: $CV_A = 100\dfrac{\delta_A}{A}$ and therefore $\delta_A = \dfrac{A \times CV_A}{100}$.

From this, the limit irregularity of yarn is defined as:

$$\begin{aligned} CV(Y) &= \frac{100\sqrt{n}\bar{A}\sqrt{1+0.0001CV(A)^2}}{n\bar{A}} \\ &= \frac{100\sqrt{1+0.0001CV^2(A)}}{\sqrt{n}} \end{aligned}$$

Much later on, a third component was considered, i.e. configuration of fibers, in the analysis of yarn irregularity as a result of random fiber arrangement. The irregularity was given as the variation of local linear density, T(x):

$= n(x)m_t(x)m_s(x)$

Where n(x) is the number of fibers, $m_t(x)$ is the mean local linear density and $m_s(x)$ is the mean local fiber orientation. Assuming independence between these three components and using additive rule of variances, CV [%] could thus be given as:

$$CV^2[T] = CV^2[n] + CV^2[m_t] + CV^2[m_s] \quad (3)$$

It is also important to note that Yarn Irregularity is defined in to major ways, i.e. it is defined as the Coefficient of Variation of either mass or diameter, or just CV (mass) and CV (Diameter) respectively. Then therefore, the sources of Yarn Irregularity are summarized as follows [9]:

Variations in Fiber Characteristics:

As previously stated, the fact that staple fibers are of variable characteristics (particularly the geometrical ones), that combined with the manner in which fibers are assembled in forming yarn, that cause yarn to have an irregular surface, some places are thicker than others.

Effect of Drafting Waves:

It had been pointed out that fibers move in groups causing non-random wave-like patterns, these are called drafting waves and are one of the causes of periodic thin and thick places on the yarn. These drafting waves are believed to be caused by improper draft zone settings, improper top roller pressures and a high presence of short fibers in the bundle. However, the irregularity caused by the drafting arrangement is minimized by the doubling action; hence the major cause of these periodic waves is the drafting at the spinning frame rather than at the draw frames.

Effect of Twist Variation:

Twisting tends to concentrate the yarn structure into an irregular close-packed polygonal shape [11], but the cross-section still possesses a concave-convex irregular shape. However, historically the Yarn Structure has been modeled as a Cylinder with a circular cross section. With the developments in imaging technology it has been shown that the cross-sections of ring-spun and open-end-spun yarns are better approximated as an ellipse with an irregular outline. The eccentricities of the best-fit ellipses for ring-spun and open-end-spun yarns were obtained as 0:40 and 0:36, respectively, indicating that the cross-sectional shape of open-end-spun yarns is more circular than the ring-spun yarns. This resulted from the smaller linear density and yarn twist of ring-spun yarns.

In addition, there is a complex relationship between yarn diameter, twist, and mass. Therefore, it is hard to predict the effect of twist on yarn structure. For example, twist is not constant but concentrated in the thinnest parts of the yarn. Therefore, high twist compresses thin places and exaggerates the variations in the apparent diameter. Therefore, careful analysis of yarn irregularity must involve understanding yarn structure, especially the effect of twist on yarn geometry.

Effect of foreign Elements:

Neps are caused by foreign elements, immature raw material, and insufficient and improper cleaning during preparation processes. These faults are usually random and visible to the human eye. They are detected by many evenness-testing instruments. When a cross-section deviation exceeds a preset value, the instrument classifies the imperfection as either a nep or a thin or thick place. The standard levels are as follows, +200%, -50% and +50%, respectively. The length of the fault is usually in the order of a few centimeters of a yarn's neps[13] , thin places, and thick places can significantly affect the appearance of a woven or knitted fabric. While the thin and thick places do not lead to processing difficulties, neps on the other hand, do, particularly in knitting.

2.1.1. CV (mass) and CV (diameter).

It has previously been stated that yarn irregularity is caused by many factors, both by the nature of the spun fibre and the spinning process itself. Irregularity on the other hand can also be expressed in two different ways, i.e. irregularity of mass per unit length or diameter per unit length, there are other forms of irregularity but those are not widely discussed because they are mostly due to temporal or machine specific faults, these include CV_f and CV_{ma}, CV manufacturing and machine irregularity respectively.. It should be noted that Irregularity is caused mainly by the process of spinning (as has been discussed), nature of fiber, which usually manifest itself in the degree of hairiness and twist [13].

Mass Irregularity is a variation of fibre mass in the cross-section or in some section lengths of longitudinal fibrous product. Then the CVm is derived from the standard deviation of diameters (per unit length), generally, the lower the CVm value, the better the quality of the yarn. In order to calculate the coefficient of variation, the standard deviation must be divided by the mean value, and timed by 100 when expressed in percentage form as is normally the case.

$CV = \frac{s}{\bar{x}}$, where $\bar{x}$ is the mean value, or $CV = \frac{s}{\bar{x}} \times 100$ in percentage form.

It follows then that Diameter irregularity is connected to Mass irregularity, because it can be intuitively understood that yarn sections with larger mass per unit volume also have larger diameters, hence the variations in mass are directly linked to variations in diameter.

2.1.2. Variance-Length Curves (VLC Curves)

While the coefficients of variation (CV's) are important for proper analysis of yarn quality, they are however incapable of giving useful information regarding the source of the defective machine part in the case that irregularity in the yarn is caused by such. Of all the analyzing methods, only a diagram representation of the yarn profile (or irregularity) can help in this situation hence spectrograms are useful in this case.

By the 1950's, studies were carried out to establish a method of expressing CV in such a way that a more detailed analysis of the Variations would be possible and Machine Fault Sources can be identified. Resulting from this, Variance Length Curves were introduced.

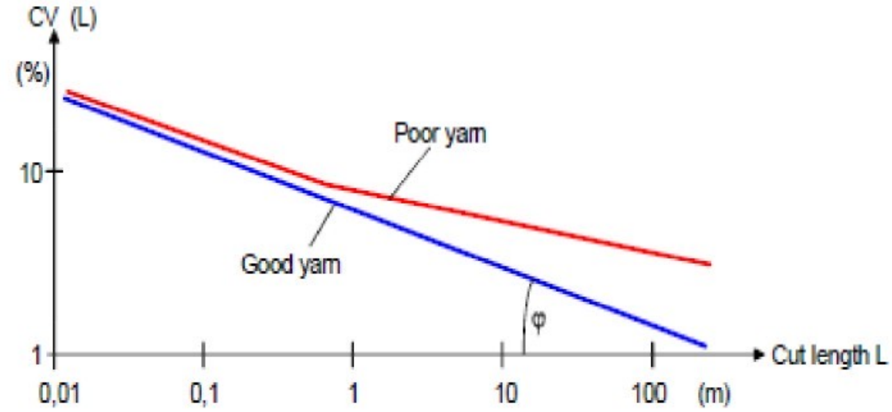


Figure 2.1: Variance length Curve as determined by cutting and weighing

A VLC curve can be set out by cutting a sample (yarn, sliver or roving) into pieces and determining their masses. The CV value is then calculated from each of these separate values. This procedure is repeated for various cut lengths and the corresponding CV values recorded, one obtains the Variance Length Curve as expressed below:

2.2. Yarn Diameter

Yarn diameter is one of the basic and most important parameters of yarn, important mainly for evaluation and computation of other yarn and fabric parameters. The value of yarn diameter is directly related with cover factor, permeability, THV (Total Hand Value) and Mechanical Parameters of Fabric. Yarn diameter can be evaluated from theoretical equations or estimated by use of experimental measurements and Measuring Machinery in the Laboratory or in Industry.

To start off, yarn can be divided into two parts, i.e. core and cover [18, 21]. In this arrangement, the core is that part of the yarn fibres assembly that is closely packed and near the axis; here the packing density is relatively high. In the cover, that part of yarn that is outermost, there are mostly hairiness fibres, ends, loops and other fibre segments and the packing density is relatively lower.

In reality, there is no boundary between the two parts, they are just imaginary, but help with the theoretical understanding of what exactly could be yarn diameter.

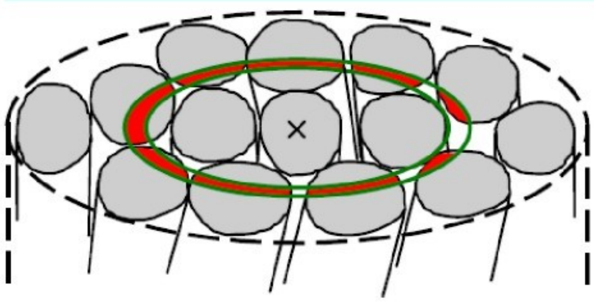


Figure 2.2.1: A Depiction of the Two Yarn Spheres, the Core and Cover

In the figure above, the red ellipse works as an imaginary boundary, the fibers inside it make up the "core" and those outside it make up the "cover".

2.3. Yarn Hairiness.

Hairiness is a key parameter that affects the yarn performance in the subsequent processes and degrades fabric appearance. This necessitates a precise yarn hairiness measurement and control. Yarn hairiness measurement has been discussed for several years, but it still remains a complex subject, which requires further in-depth understanding. The distribution of hair length is one of the most important characteristics of the yarn. To an extent, hairiness is required for further processing and to give a soft feel to the fabric. At the same time more number of long hairs on the yarn surface leads to pilling and fuzzy fabric appearance.

In recent years, yarn hairiness determination has occupied center stage in the subject of Yarn quality determination largely due to the availability or emergence of Commercial Testing instruments that allow the measurement of Yarn Hairiness in Industry [23].

There exist a lot of physical principles for determining yarn hairiness, these include: optical, photographic, and photoelectric methods, methods based on the application of laser rays, etc. There are two instruments commonly used for experimental evaluation of yarn hairiness. The first is the Zweigle hairiness tester which counts the number of hairs exceeding 1 up to 25 mm length from the compact body of yarn and the second is Uster tester with additional hairiness sensor which measures the cumulative length of all protruding fibers over one cm length of yarn.

2.4. Yarn Diameter, Hairiness and Unevenness Determination and Measurement Systems.

Since yarn diameter is not a universally understood concept, various methods of its determination use different (but sometimes similar) principles. Yarn hairiness also, is a complex subject, which has not been truly defined by the existing parameters. But on the main these machines and methods are divided into Capacitive and Optical principles and the Laboratory methods are based on the Image Analysis method.

2.4.1. The Theoretical Approach to Yarn Diameter Determination (by calculation)

For any attempt to determine yarn diameter, it is important to first look at its minimum possible value, i.e. Substance Diameter (D_s) , here it is imagined that the yarn is compressed such that the fibers have nor pores in between them, all the air from the inside of the yarn is removed. The cross-sectional area will be equal to the substance (fibers) cross-sectional area.

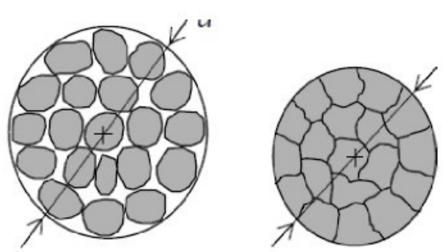


Figure 2.4.1: Yarn Compressed to Obtain Yarn Substance Diameter

The yarn has the substance diameter:

$$D_s = \sqrt{\frac{4S}{\pi}} = \sqrt{\frac{4T}{\pi\rho}} . \quad (4)$$

Where S = Cross Sectional Area, T = Yarn Fineness, ρ = Density of the fiber.

This diameter D_s is the smallest one and in comparison with common diameter D is valid $D > D_s$

2.4.2. Theoretical Approach to Yarn Hairiness and Diameter Determination:

Neckar and Voborova [22] of the Technical University of Liberec, developed a Theoretical model for Yarn Hairiness, this model was based on Neckar's earlier theoretical model and utilization of image analysis methods, it is meant to analyze the Yarn Hairiness more deeper than the available commercial tester's, particularly Uster and Zweigle.

The approach of the model was based on "viewing" the yarn body as made up of two concentric cylinders with radii r_1 and r_2 where hairiness is found on the outer cylinder surface. There exists different shapes of fibers in the sphere of hairiness between two radii r_1 and r_2, such as (Figure below) fiber end (1), loop (2), protruding fiber (3), reversal end (4), and reversal loop (5). The occurrence of the reversal shapes (4) and (5) is so small in yarn that these can be neglect.

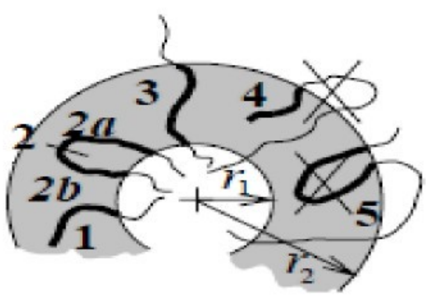


Figure 2.4.2: The depiction of fiber types on the Yarn Cross-section

Imaginatively, the loop (2) can be cut so as to obtain a couple of fiber ends (2a, 2b). Based on this idea, the fiber segments) protruding from the yarn body creates the sphere of hairiness.

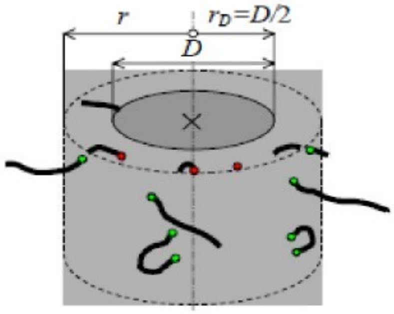


Figure 2.4.3: Protruding fibers

When looking at Fig.2.4.3 above it can be seen that the number of fibers protruding from the cylindrical shape of yarn compact body (diameter D, radius $r_D = D/2$) is maximum and the number of fibers protruding from the radius $r > r_D$ is smaller, because the free end of some of the fibers are not long enough to protrude beyond the length $r > r_D$ and as such terminate between these two radii.

The differential probability $\phi(r)$ dr, that a randomly chosen fiber that is definitely protruding from the radius r having its free end lying in the differential layer following immediately after the radius r (fig.2.4.4, below) is generally a function of the radius.

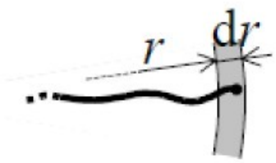


Figure 2.4.4: Free fiber End in a differential sphere

But it is assumed that this probability is independent of the radius ($\phi(r)$ = const.). Further it is assumed that the character of fiber orientation is independent of the radius too. Based on these assumptions, the following relation of packing density μ at any radius of the hairiness sphere was derived:

$$\mu = \left(\mu_D r_D / r\right) 2^{-(r-r_D)/h} \qquad (5)$$

Here μ_D is the initial packing density corresponding to yarn radius r_D and h is the "half-decrease interval" of the number of protruding fibers. (It means that half of the fibers that are protruding from the cylindrical area of radius r will also protrude from the cylindrical area of radius $r + h$.) Some of the parallel light beams can pass beside the yarn at a distance x, but others are "hindered" by hairs (fig. 2.4.5a, below). It is evident from fig.2.4.5b below that the light beam can pass through the gray strip of width d_* if none of the fiber centers is lying exactly at the middle of the strip. (Here we idealize each fiber cross section by a ring of diameter d^*)

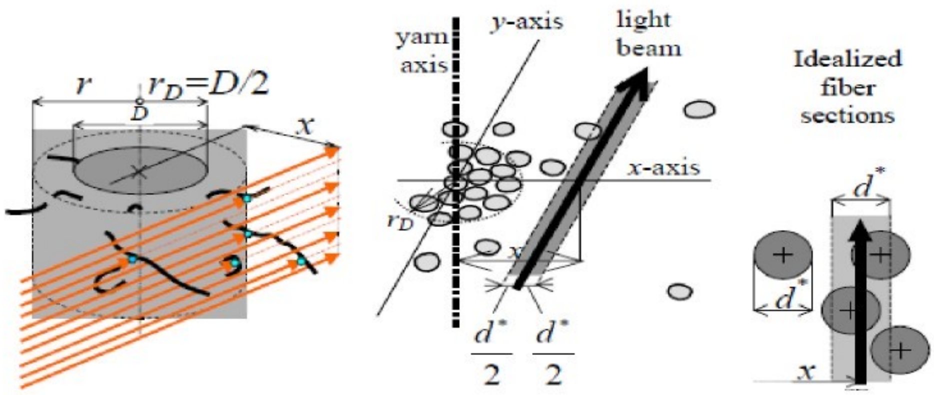


Figure 2.4.5(a) and (b): The Hindering of the Light beams by protruding fibers.

Based on this idea and the fact that experimental results show that it is necessary to think of 2 types (subscript 1 or 2) of fibers in the sphere of hairiness, each of them follows an exponential model, but with highly different values of parameters h_1, $h2$ and μ_{D1} μ_{D2}. Then the packing density in this "double-exponential" model is:

$$\mu = (r_D/r)\left[\mu_{D1} 2^{-(r-r_D)/h_1} + \mu_{D2} 2^{-(r-r_D)/h_2}\right], \tag{6}$$

And the probability P that the light beam passes beside the yarn at the distance x without any obstruction is:

$$-\ln P = \left[8r_D/\left(\pi d^{*2}\ln 2\right)\right]\sum_{i=1}^{2}\left[\mu_{Di}\, h_i\, 2^{r_D/h_i}\left(\int_0^{\pi/2} 2^{-\left(x-d^*/2\right)/\left(h_i\cos\alpha\right)}\mathrm{d}\alpha - \int_0^{\pi/2} 2^{-\left(x+d^*/2\right)/\left(h_i\cos\alpha\right)}\mathrm{d}\alpha\right)\right]. \tag{7}$$

Therefore, the probability $Z(x)$ that the light beam cannot pass beside the yarn at the distance x is:

$$Z(x) = 1 - P \qquad (8)$$

where P is given by equation (7) above. The so-called "blackening function" $Z(x)$ can be obtained from the experimental investigation of images by using image analysis techniques.

The frequency of the black pixels (*i. e.* fiber) at the distance x from the yarn axis (center of the widest black interval) determines the experimental "blackening function" $Z(x)$ as shown in fig.2.4.6. The parameters h_1, $h2$ and μ_{D1} μ_{D2} can be calculated using (7), (8) by statistical regression technique.

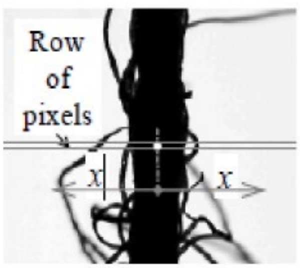


Figure 2.4.6: Yarn Image shown as an area of black pixels

At the same time, yarn diameter (based on the defined value of blackening function - D_{cover} can be evaluated, or the defined value of packing density – D_{dense}) and integral characteristic I_H, which can be compared with the hairiness index H of Uster Tester 4. An example of the resulting curves is illustrated in fig.2.4.7. The correlation between I_H and H is usually very high (R2 ≅ 0.98).

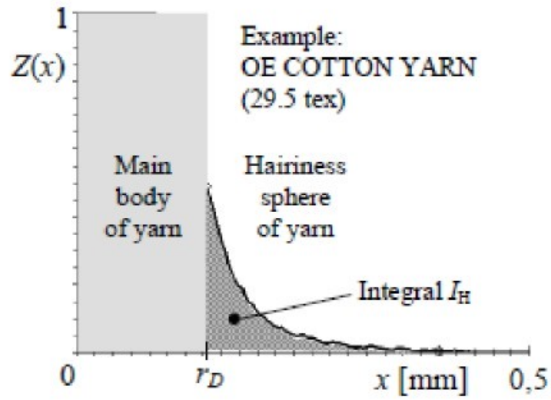


Figure 2.4.7: Blackening function: theoretical and experimental

2.4.3. Uster Tester 4

Arguably the most widely used brand in yarn quality management worldwide, both in industry and research centers such that each Quality Manager around the world wants to find out how his/her yarns measure up against the Uster Statistic. To date there is a 5^{th} version, i.e. USTER 5, Uster 4 [1, 13] and 5 combine both the Capacitive and Optical method of measuring.

In the Capacitive section, the mass variation of yarn (also sliver and roving) is converted to an electric signal. A high frequency electric field is generated in the sensor slot between a pair of capacitor plates. If the mass between capacitor plates changes, the electric signal is altered and the output signal of the sensor changes accordingly. The result is an electric signal variation proportional to the mass variation of the test material passing through.

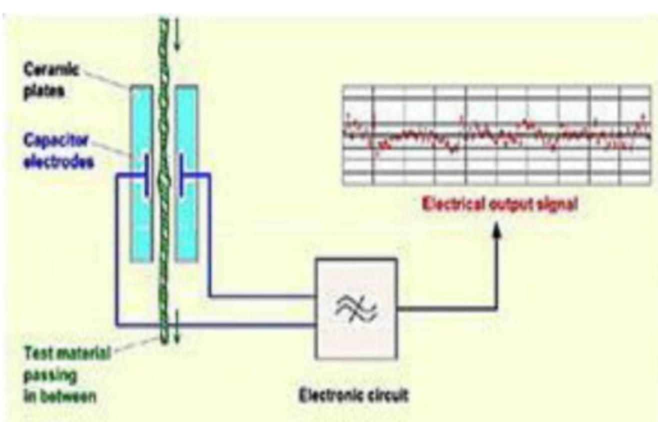


Figure 2.4.8(a): The scheme of the capacitive section on the Uster Tester.

The Optical system was introduced on Uster Tester 4; Uster tester 4 uses a two-dimensional measuring principle (Fig.2.4.8 (b)) for laboratory applications, because it is very rare that a yarn is perfectly round. The shape of a yarn's cross-section essentially depends on the spinning method.

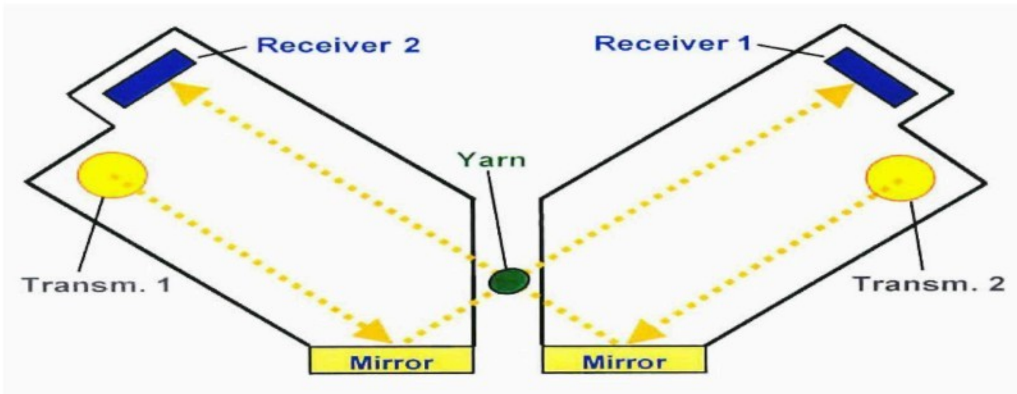


Figure 2.4.8(b): Measuring principle of the OM sensor

The measurement of a yarn body is based on a combined, digital-analog sensor technology in the form of a photo ASIC on which a high-resolution line scan camera and an integrating analog sensor operate together. The infrared transmitter of the OM sensor provides a nearly parallel light beam. A sharp image of the yarn is created by special optics on the photo ASIC.

The line scan camera and corresponding algorithms then evaluate the effective yarn body, whereby the fibers which protrude from the yarn body are not considered in this measurement. In addition, the arrangement of the sensors at angles of 0° and 90° provides information on the mean, two-dimensional yarn diameter and the shape of the tested yarn. The mean yarn diameter is determined with great precision by the line scan camera Line scan cameras operate according to the principle of line-by-line scanning of objects.

Technological characteristics of measurement:

Regarding the measuring method, it must be added that the OM sensor is not sensitive to the color and the brightness of the object to be tested. The measurement of the optoelectronic OM sensor is absolute. As a result of the two-dimensional arrangement of the sensors, the system evaluates the mean core diameter and therefore provides a more accurate description of the yarn cross-section. Disturbing fiber assemblies which protrude from the yarn body and very short-wave variations are fully considered in the evaluation and are shown as peaks in the diagram of the mean yarn diameter.

The OM sensor provides reproducible measurement values, irrespective of the testing speed. Independently operating cleaning and control mechanisms counteract any influences of dirt and fly. With a measuring field length of 0.3 mm (capacitive 8 mm), even very short-wave variations are considered in the quality assessment. These variations in particular are often considered optically disturbing.

Definition of the opto-electronically determined quality parameters:

The Following Table provides an overview of the quality parameters of the new OM sensor

Sign	Unit	Definition
2DØ	mm	Mean value of the two-dimensional diameter of the measured yarn length.
CV2D8mm	%	Coefficient of variation of the diameter of 8 mm reference length. The CV value is calculated by dividing the standard deviation s by the mean value.
CV2D0.3mm	%	Coefficient of variation of the diameter of 0.3 mm reference length (= effective measuring field length).
CV FS	%	Coefficient of variation of the fine structure. The CV FS is calculated with the help of CV2D8mm and CV2D0.3mm. Offers the possibility of assessing short-term variations in the structure.
CV1D0.3mm	%	Coefficient of variation of the one-dimensional diameter (silhouette), related to 0.3 mm.
Shape		Dimensionless value between 0 and 1 which describes the roundness. The value corresponds to the relation of the short to the long main axis of an ellipse (1 = circular, 0.5 = elliptical). Mean value of the measured yarn length.
D	g/cm^3	Mean yarn density, calculated at first with the nominal count.

2.4.4. QQM 3

It was developed in VUB (Cotton Research Institute), Czech Republic [24]. Unlike Uster Tester, the QQM device is portable which then gives it the advantage of being usable Online, i.e. directly on the spinning line on the Ring Spinning and Open End machines. Form the measuring, analysis and data source for further investigation can be provided. It is a tool for identifying faults on spinning units, Provides measurement and analysis of CV% as well as imperfections and Spectrograph.

Figure 2.4.9(a): The QQM 3

The QQM has 2 Optical sensors of 2mm width, equipped with infra diodes and transistors positioned in the direction of yarn delivery, 10 mm apart, sampling rate is limited to 300 m/min (capability 600 m/min) because "hand held" TTl is slower. Sensors are programmed for sampling each 2 mm, data processing, measuring yarn speed. Memory equalizer controls the serial port.

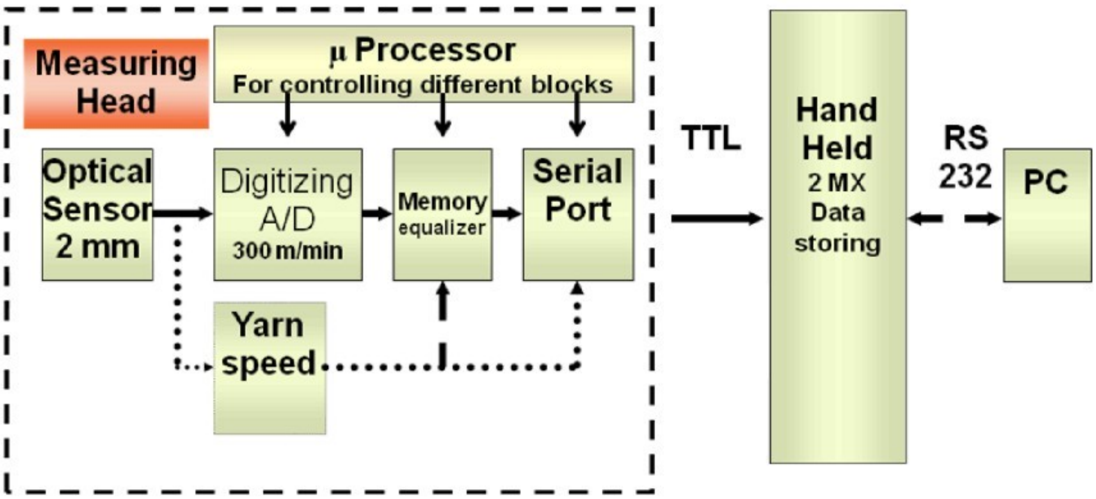


Figure 2.4.9(b): Principle of QQM instrument

Measurement module:

- Used for detailed analysis on a longer yarn section. Calculates the basic unevenness characteristics such as CV% (U %) on different lengths (10, 100, 500, 1000, 5000 and 10,000 mm), beside other unevenness yarn characteristics such as thick, thin places.
- Selection of longer length is needed to gives more reliable results.
- Number of measured points is one half of the yarn length in mm.

Sample Output:

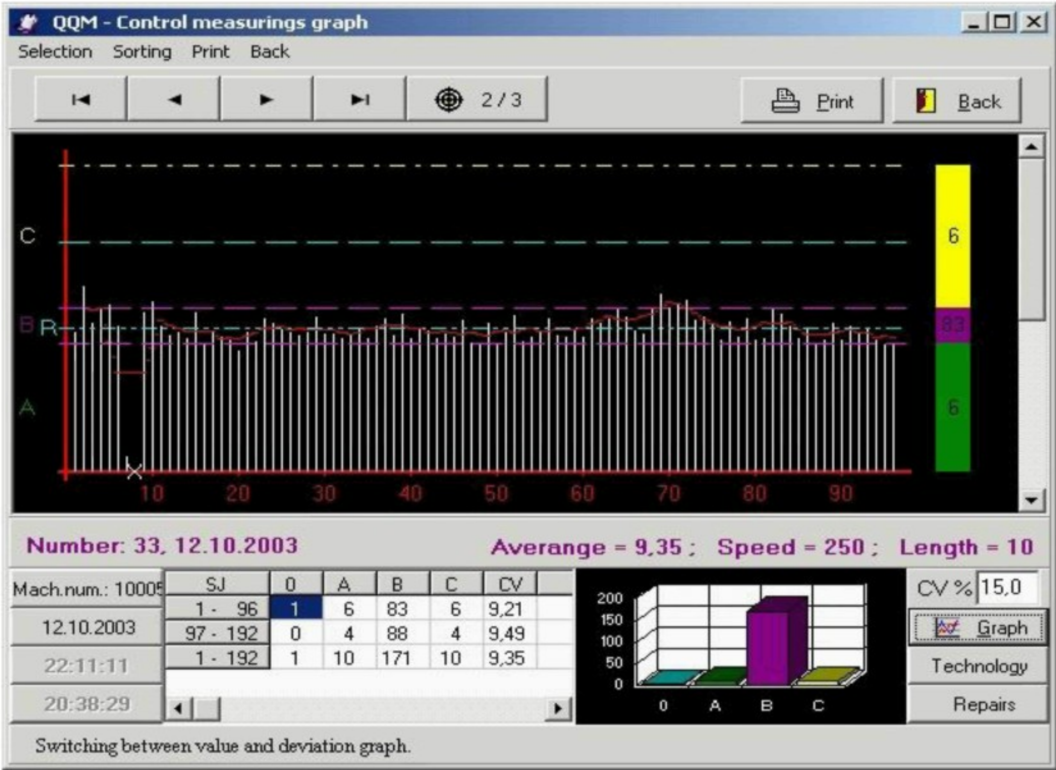


Figure 2.4.9(c): Spectrograph of QQM 3

2.4.5. Laboratory Measuring System

This is a system introduced by B. Neckar and D. Kremanakova [15, 16 and 17] of the Technical University of Liberec, Czech Republic. This system is based on Image Analysis of yarn images by a computer program to determine diameter and CV taking into consideration yarn packing density. In this method a near parallel light beam is positioned under a sample of yarn on a microscope equipped by a CCD camera. The image of the yarn is captured and pre- processed and stored in a binary system. Some light beams can pass through without any problems (at the sides of the yarn), some others are "hindered" by the fibers. The longest section of black pixels formed by the hindrance of light by fibers creates the yarn body and is assumed to be the diameter of the yarn. The midpoint represents the yarn axis. The relative frequency of black points at each distance can be found experimentally (usually 800 pictures) from different places of a yarn is named as “blackness function”. A double exponential function is fitted to find both the so-called dense and cover diameters. The yarn packing density in the cross section is taken into consideration in this model this density depends upon twist, fiber orientation and yarn fineness. Yarn cross section is prepared and a system of annular rings centered on yarn axis (yarn center of gravity) is used. The packing density is then expressed as function of distance from yarn axis. Local packing density is expressed as the ratio of the fibers cross sectional area in annular ring to the total area of annular ring. The diameter of the yarn is found at 15% of yarn packing density.

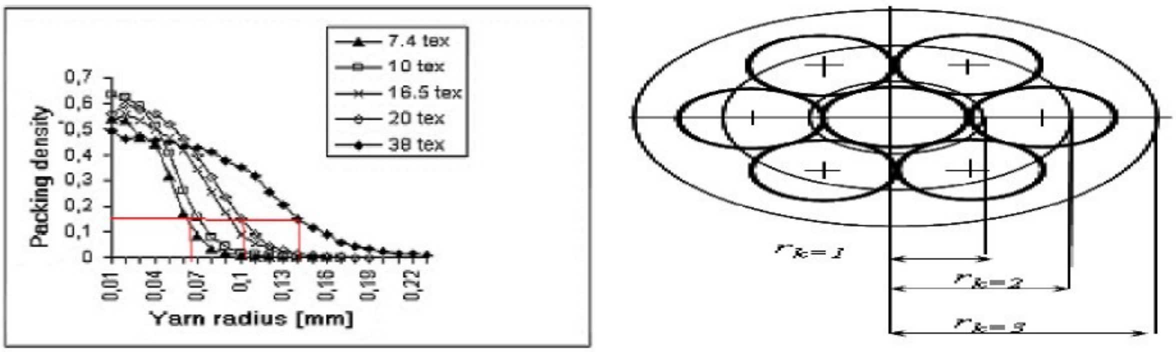


Figure 2.4.10: Packing Density determination

A second method was developed by Dr. Monika Vysanska & Gabriela Krupinkova, which is based on processing of the longitudinal images of the yarn. It extracts the yarn body without the hairs, by an image dilation process to measure the diameter.

2.4.6. Zweigle OASYS.

Optical **A**ssessment **S**ystems through **Y**arns Simulation. The system operates with the principle of absolute optical measurement using infrared light. The structure of a yarn is subject to variations of a periodic or random character. The measuring system compares the yarn diameter with the constant reference mean and records variations in length and diameter. The yarn testing module use an infrared light sensor operating with a precision of 1/100 mm over a measuring field ength of 2 mm and at a sampling interval also of 2 mm. The speed of measurement may be selected on a graduated scale between 100 and 400 m/min.

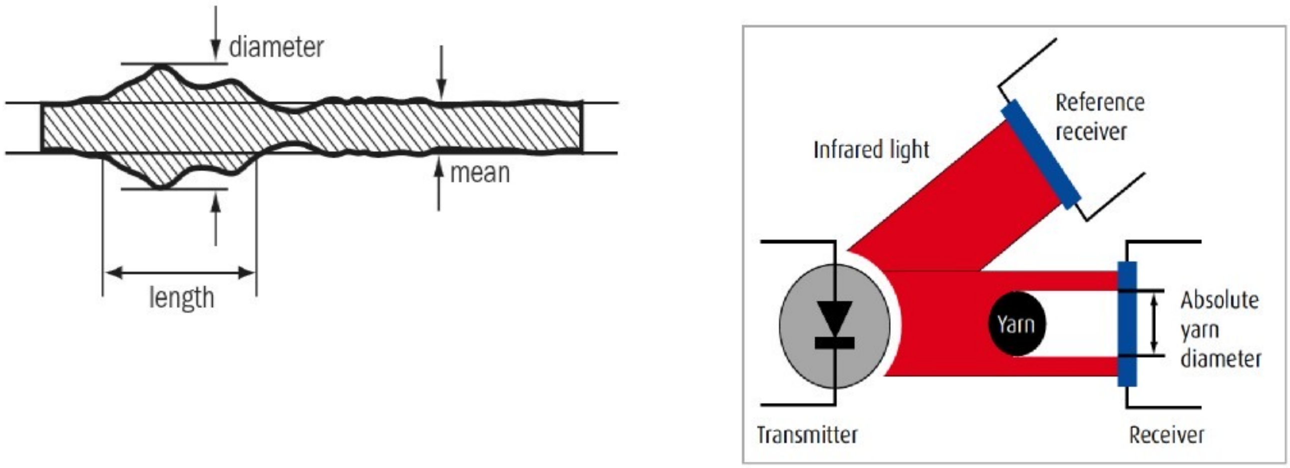


Figure 2.4.11(a): Principle of the Oasys measuring System

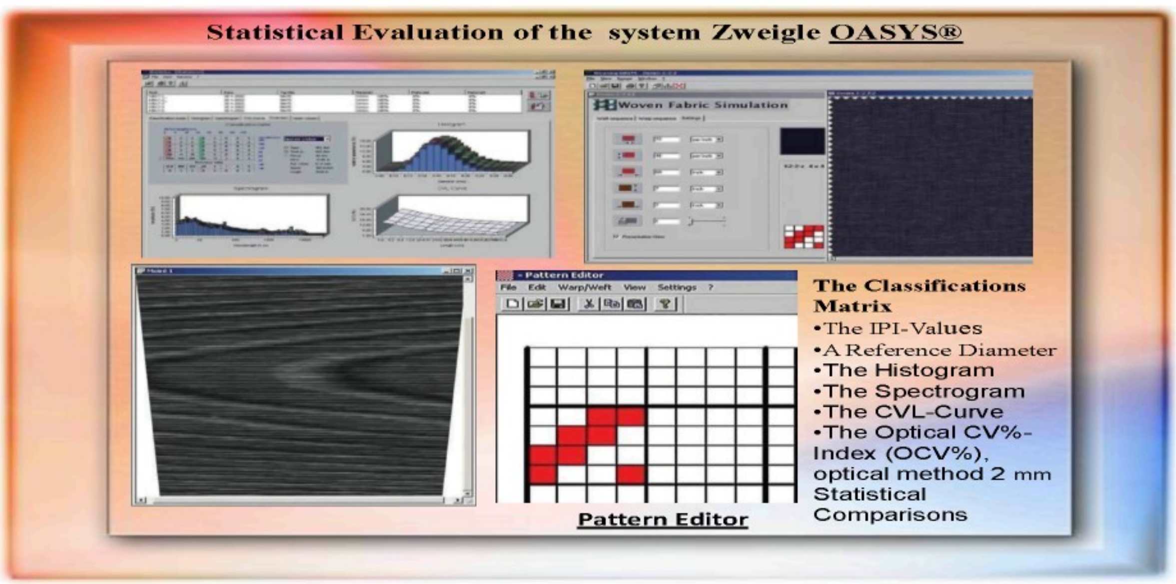


Figure 2.4.11(b): Sample output of the information from OASYS

2.4.7. Lawson-Hemphill –YAS System

The YAS (Yarn Analysis System) [4] is an important new technology for measuring spun and air textured yarns. This system scans and measures diameter and diameter evenness of the yarn, and automatically grades the yarn for appearance. It offers a new tool for delivering yarns that give consistent fabric appearance. Other features include: hairiness testing, fabric simulation, yarn clearing simulation, etc.

The measurement was done by a CCD camera, which is capable of measuring every 0.5 mm of the yarn with precision of 0.00325 mm at test speed of 100 m/min. Figure 2 shows the CCD camera measurement principle. Figure 2 CCD Camera yarn diameter measurement principle To prove the sensitivety of the camera, a picture of a nep was taken with a microscope. (Each line on the microscope scale is equal to 0.1mm.) The yarn was then measured with the CCD camera and the diameter results were compared. As seen in Figure 3, the diameter of the normal section of the yarn is about 1 scale wide, which is 0.1 mm. The nep diameter is about 0.4 mm. Figure 3 Diameter of the yarn and nep. The YAS program shows the yarn diameter as 34 pixels, which is 0.1105 mm. (See Figure 4.) Figure 4 Diameter of yarn as measured by CCD camera.

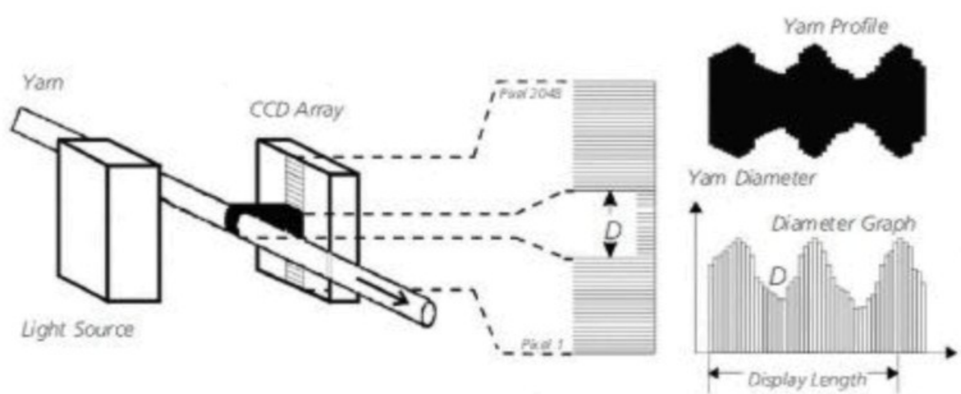


Figure 2.4.12 (a): The measuring method of the YAS System

Figure 2.4.12 (b): The Lawson-Hemphill – General view of CCT equipped with digital camera for yarn diameter.

2.4.8. Keisokki KET-80 and Laserspot

Keisokki KET-80 and Laserspot [25] are two types of evenness testers based on capacitive and optical measurement principles, respectively. Like Uster Tester III, KET-80 provides a U% and CV(%), a CV(L) curve, and a spectrogram. It also provides a deviation rate, a DR%, which is defined as the percentage of the summed-up length of all partial irregularities exceeding the preset cross-sectional level to the test length. In practice, however, the yarn signal is primarily processed by the moving average method for a certain reference length. As a result, long-term irregularities are likely to be detected.

Figure 2.4.13(a): Keisokki KET-80 and LTS-V

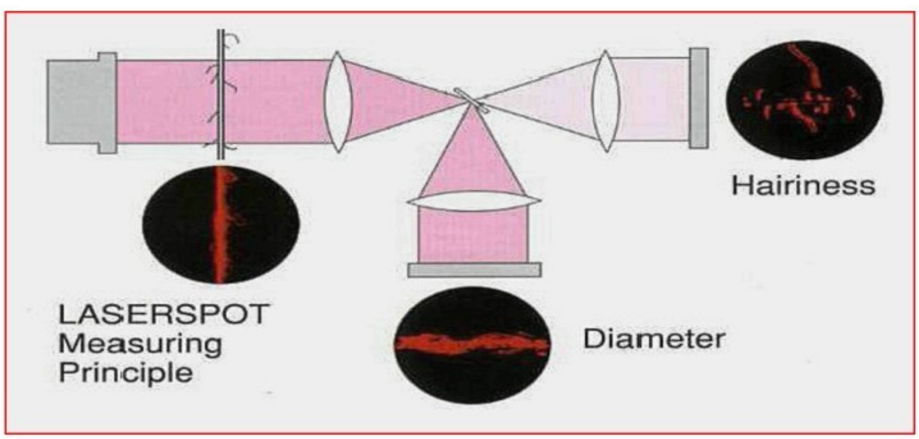


Figure2.4.13 (b): Laserspot Yarn evenness testing with Fresnel Principle

The lasesspot evenness and hairiness testing instrument uses laser beam and is based on the Fresnel diffraction principle. With this principle the yarn core is separated from hairs, allowing yarn diameter and hairiness to be measured simultaneously.

2.4.9. The flying laser spot scanning system

The Flying Laser Spot Scanning System [26] consists of three parts: the sensor head, the specimen feeding device, and the data analysis system. When an object is placed in the scanning area, the flying spot generates a synchronization pulse that triggers the sampling. The width between the edge of the first and the last light segment determines the diameter of the yarn. Depending on the spot size and specimen feeding speed, the measurement values may vary. Therefore, it is important to calibrate the system for the feeding speed and the spot size.

2.4.10. Comparison of Yarn Measuring Systems - Advantages and Disadvantag

optical	-sees like eye - suitable for hairiness deter- mination - more sensitive to diameter variations - the fiber material does not affect measurement due to conductivity	-discrete sampling causing lower resolution irregular shape of yarn cross-section - inhomogeneous radiant in- tensity - sensitive to vibrations dur ing measurement
capacitive	- continues sampling	- sensitive to both tempera ture and humidity - not suitable for hairiness calculation - sensitive to fiber material

2.5. Implications of Yarn Forming Systems.

Different spinning methods have advantages and disadvantages peculiar to each one of them; this is largely due to the actual method of forming yarn, i.e. twist insertion and tensioning, twists per unit length, hairiness and factors in each system. The different methods also result in different cross-sectional shapes of the yarn; this in turn has implications on irregularity, diameter and hairiness.

2.5.1. Ring Spinning

The Ring Spinning Machine was invented in 1828 by an American, Thorp, in 1830, Jenk; another American contributed the travelling rotation on the ring. Since then, there have been numerous specific modifications on the system; however the concept has remained unchanged in its 180 years of existence [27].

The mode of operation (twist insertion mechanism) of this system is thus:

a) Attenuation of the roving until the required fineness is achieved

b) Impact strength on the fiber strength by twisting it (the spindle assisted by the traveler, inserts twist under tension)

c) Winding up of the resulting yarn in a form suitable for storage, transportation, and further processing.

While it is the oldest method available, it still is head and shoulders above the rest in terms of advantages as pertaining to the quality of the output. These include:

- It is universally applicable, i.e. any material can be spun to any required fineness.
- It delivers a yarn with Optimal characteristics (especially with regard to structure and strength)
- It is uncomplicated and easy to master.
- It is flexible as regards quantities (blend and lot sizes).

2.5.2. Open End Spinning (Rotor)

It was invented in the Czech Republic in 1963 at the Cotton Research Institute [27] . It is arguably second to the Ring Spinning method in terms of versatility and is a spindle-less system. Yarn produced by this system is charecterised by belt fibres and minimal hairiness

Yarn formation in this system is charecterised by its difference to other systems in that in other system an uninterrupted stream of fibres proceeds continuously, but with gradual attenuation from the feed to the take up package. In Rotor Spinning this process is interrupted, the fibre strand being opened to individual fibres at predetermined position by an Opening Roller. This enables twist to be imparted by rotation of the yarn end, this leads to higher speeds of rotation.

2.5.3. Air Jet Spinning (Murata)

The operating system starts from the Draw Frame with sliver fed from a can [29]; from there it is passed to a drafting arrangement where it is attenuated by a draft. The drafted fibre strand then proceeds to a Two Jet Arrangement which is directly after the drafting set-up. The second Jet is actually where the false twist is inserted. The air-vortex generated in this jet, with an angular velocity of more than 1 million r/min, twists the strand as it passes through so that the strand rotates along a screw-thread path in the jet to reach rates of rotation of about 250 000 r/min.

The ability of the vortex to carry the yam along is so high that the turns of twist in the yam run back to the drafting arrangement. The fibre strand is accordingly accelerated practically to the full rate of rotation as soon as it leaves the front roller. The edge fibres needed to bind the yam together represent exceptions. They must exhibit relatively few turns of twist in the same sense as the false-twisted core fibres or can even be twisted in the opposite direction. This is partly

ensured by causing the strand to issue from the nip line in a broad-spread form, but mainly by generating in the first jet a vortex having an opposite sense of rotation to the vortex in the second Jet.

This first vortex is weaker in intensity than the second and cannot affect the core fibres but can grasp the edge fibres projecting from the strand at one end. Since the first vortex acts against the twist direction generated by the second jet, it prevents the edge fibres from being twisted in or even twists them in the opposite sense around the core fibres.

The turns of twist generated by the second Jet are cancelled in accordance with the false-twist law. The core fibres, i.e., the vast majority, no longer exhibit any twist; these fibres are arranged in parallel. On the other hand, the edge fibres (which previously exhibited no twist, relatively little twist, or even twist in the opposite sense) receive twist in the sense imparted by the second Jet as determined by the law of false twist; they are therefore wound around the fibre strand. They bind the body of fibres together and ensure coherence.

The Murata Jet Spinner represents a very interesting process, which has already been introduced into practical applications with some successes

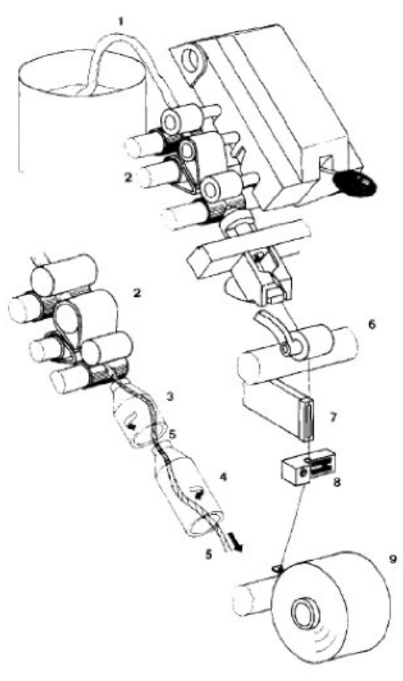


Figure 2.5.1: The Murata jet-spinning principle

2.5.4. Vortex Spinning.

The actual Operating principle took some work to be realized, the main work being done by Goetzfried and Lord. The Industrial process was developed in Poland by the company Wifma-Polmatex [27].

In this Spinning method, yarn is formed by an air vortex in a tube. Air is sucked into the tube through tangential slots. The air moves upwards along the tube wall in a spiral and finally arrives at the upper tube seal. An air vortex, rotating continuously in the same direction, is generated at the seal. Open fibre material is allowed to enter the system through an opening. The rising air stream grasps this material and transports it upwards into the vortex. To form a yarn strand, an open yarn end is passed into the tube through a passage in the upper seal. The vortex grasps this yarn end and whirls it round in circles in the same way as the fibres. Twist is inserted by each revolution of the yarn end due to the fact that the upper yarn length is held by the withdrawal rollers and the lower end is in rotation.

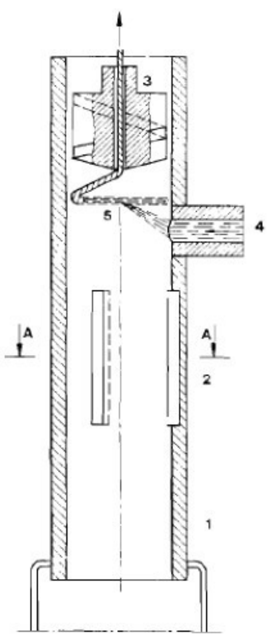


Figure 2.5.2: Vortex Spinning Setup

2.5.5. Compact Spinning

This spinning system is a modification of the Ring Spinning system [27] , most of the technical advances in ring spinning were aimed at improving the performance of the existing technology. In recent years, however, a bona fide innovation has occurred. It has been called compact or condensed spinning, because it minimizes width and height of the spinning triangle associated with ring spinning. This modification was initialized by Dr. Ernst Fehrer in 1995 in Switzerland and has been adopted by many manufacturers to date. As the term implies, the fibres that emerge from the nipping zone of the front roller are compacted, by a reduction in the size of the spinning triangle, prior to twist insertion. A control in the dimensions or reduction in the size of the spinning triangle has the following positive impact on yarn quality and characteristics:

- Lower hairiness values
- Higher strength
- Improved yarn evenness
- Less fly liberation during spinning and subsequent processing

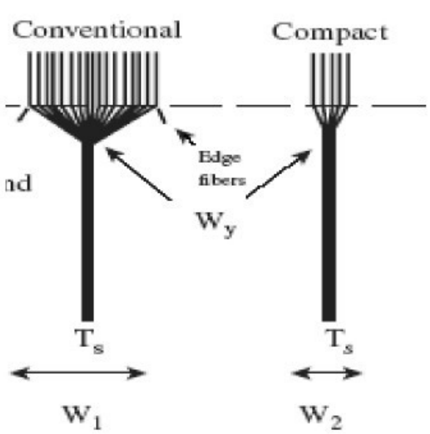


Figure 2.5.3: Reduced Spinning Triangle in Compact Spinning

2.6. Tools for Statistical Data Treatment

For all comparative studies, statistical data treatment is central to carrying out the requisite comparison, be it by comparing raw values or tables and or graphs. In some cases it is necessary to further treat the data (e.g. smoothing/filtration) before it can be analysed.

2.6.1. Data Filtering

In measurements that require signal processing, i.e. where a certain property is measured indirectly by interpreting an electrical signal for example, the signal usually comes with some sort of noise, even in the most optimal faultless measuring process there is always noise present, this ever present noise is referred to as White Noise. However, due to irregularities during measurements or faulty equipment there can be extra noise that might be added on to white noise. In either case, there has to be a mechanism of removing or minimizing this noise from the data set, this mechanism is referred to as a Data Filter.

2.6.2. Autocorrelation

Autocorrelation is the cross-correlation of a signal with itself. Informally, it is the similarity between observations as a function of the time separation between them. It is a mathematical tool for finding repeating patterns, such as the presence of a periodic signal which has been buried under noise.

In statistics, the autocorrelation of a random process describes the correlation between values of the process at different points in time, as a function of the two times or of the time difference. Suppose that the process is further known to have defined values for mean μ_i and variance σ_i^2 for all times i. Then the definition of the autocorrelation between any two time s and t is

$$R(s,t) = \frac{\mathrm{E}[(X_t - \mu_t)(X_s - \mu_s)]}{\sigma_t \sigma_s}, \qquad (9)$$

where "E" is the expected value operator. Note that this expression is not well-defined for all time series or processes, because the variance may be zero (for a constant process) or infinite. If the function R is well-defined, its value must lie in the range [−1, 1], with 1 indicating perfect correlation and −1 indicating perfect anti-correlation

If X_t is a second-order stationary process then the mean μ and the variance σ^2 are time-independent, and further the autocorrelation depends only on the difference between t and s: the correlation depends only on the time-distance between the pair of values but not on their position in time. This further implies that the autocorrelation can be expressed as a function of the time-lag, and that this would be an even function of the lag $\tau = t - s$. This gives the more familiar form

$$R(\tau) = \frac{\mathrm{E}[(X_t - \mu)(X_{t+\tau} - \mu)]}{\sigma^2}, \qquad (10)$$

and the fact that this is an even function can be stated as: $R(\tau) = R(-\tau)$. (11)

2.6.3. Savitzky-Golay Filter

The Savitzky–Golay smoothing filter is a type of filter first described in 1964 by Abraham Savitzky and Marcel J. E. Golay.

The Savitzky–Golay method essentially performs a local polynomial regression (of degree k) on a series of values (of at least k+1 points which are treated as being equally spaced in the series) to determine the smoothed value for each point. Methods are also provided for calculating the first up to the fifth derivatives.

The main advantage of this approach is that it tends to preserve features of the distribution such as relative maxima, minima and width, which are usually 'flattened' by other adjacent averaging techniques (like moving averages, for example).

2.6.4. Moving Average

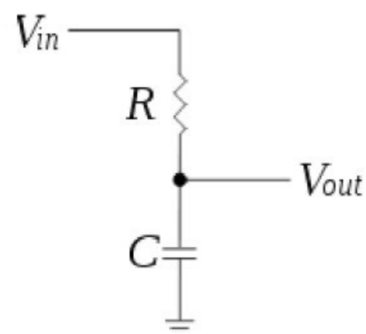
In statistics, a moving average, also called rolling average, rolling mean or running average, is a type of finite impulse response filter used to analyze a set of data points by creating a series of averages of different subsets of the full data set.

Given a series of numbers, and a fixed subset size, the moving average can be obtained. The average of the first subset of numbers is calculated. The fixed subset is moved forward to the new subset of numbers, and its average is calculated. The process is repeated over the entire data series. The plot line connecting all the (fixed) averages is the moving average. Thus, a moving average is not a single number, but it is a set of numbers, each of which is the average of the corresponding subset of a larger set of data points. A moving average may also use unequal weights for each data value in the subset to emphasize particular values in the subset.

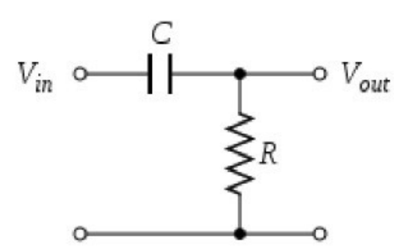
A moving average is commonly used with time series data to smooth out short-term fluctuations and highlight longer-term trends or cycles.

Mathematically, a moving average is a type of convolution and so it is also similar to the *low-pass filter* used in signal processing.

2.6.5. Low-Pass and High-Pass Filters



A *Low-Pass Filter* is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency. It is sometimes called a high-cut filter, or treble cut filter when used in audio applications. Low-pass filters play the same role in signal processing that moving averages do in some other fields, such as finance; both tools provide a smoother form of a signal which removes the short-term oscillations, leaving only the long-term trend**.**



A *High-Pass Filter* is an LTI (Linear time-invariant) filter that passes high frequencies well but attenuates (i.e., reduces the amplitude of) frequencies lower than the cutoff frequency. The actual amount of attenuation for each frequency is a design parameter of the filter. It is sometimes called a low-cut filter; the terms bass-cut filter or rumble filter are also used in audio applications

2.6.6. The D-Yarn Program

The D-yarn program was developed by Professors J. Militky and S. Ibrahim of the TUL in Czech Republic. It is a program written in Mat-Lab code to treat the data output from Uster tester, QQM3, or from CCT Lawson-Hemphill instrument as time series data. In actual fact all these data outputs are sequential in nature, taken at constant interval.

- First of all the data should be treated and corrected to give the actual units for yarn diameter, because the output data are given in some form of electric signal which comes out from the measuring sensors, this is done by multiplying by the relevant applicable multiplier to correct for this depending on each machine.
- The second step is to draw the frequency diagram, at first the optimum number of pins (interval width) according to this equation should be found out:

$$M = \text{int}[2.46\ (N-1)^{0.4}] \tag{12}$$

As it can be seen from the equation (12) above, the result must be rounded off to the nearest integer

- Fitting the distribution of data as a bimodal distribution (two Gaussian distributions), estimating the two means of yarn diameter, standard deviations and the percentage of each value. This feature is not found in any software established by any of the measuring instrument makers.

$$f_G(x_i) = A1 * \exp\left(-\frac{(x_i - B1)}{C1}\right)^2 + A2 * \exp\left(-\frac{(x_i - B2)}{C2}\right)^2$$

Where A1 and A2 are proportions of shorter and longer hair distribution respectively, B1 and B2 are the means and C1 and C2 are the standard deviations.

- All the features given by Uster soft ware is also given in D-Yarn such as diameter variation diagram, Histogram, DR, LVC, and spectrum. Beside all of these functions, the D-program deals with more other functions which are not included in any software from instrument builders.

- For example, test of bimodality of the distribution, stationarity and ergodicity of the signal. Autocorrelation function, and partial autocorrelation function, Amplitude spectrum, power spectrum density, and Hurst coefficient and fractal dimension.

In other words, the D-yarn software is dealing with:

- Basic graphs
- Basic assumption testing
- Structural unevenness
- Spectral and harmonic analysis
- Short-range dependences
- Data stochastic nature
- Chaotic behaviour

3. Experimental Section (Instrumentation and Experimental Setup)

The tests were conducted on 13 different yarns (plain) and 3 different Slub yarns, the plain yarns were divided into two fibre types i.e. cotton and viscose, both 100%, the slub yarns were divided into 100% Cotton and Cotton blends of Viscose and Polyester. Tests for determining yarn Irregularity, Diameter and Hairiness were conducted on 3 testing machines, i.e. Uster4, QQM3 and Zweigle and two Laboratory Methods were also used to measure yarn diameter longitudinally and by cross section respectively. Results were tabulated and expressed in graphs and charts (where appropriate), some of the results were treated with Data Smoothing software and compared with untreated (unsmoothed) data together with results from the Protocols from the machines used.

3.1. Characteristics of Tested Yarns

The 13 tested plain yarns were available in 3 different cobs per type except for the NovaSpun yarns; all these samples were used in an effort to overcome cob-specific imperfections. These yarns were classified as follows:

Table 3.1.1 (a): Tested Yarns and their Basic Characteristics (Plain Yarns)

Fiber Type	Forming System	Fineness(Tex)	Twist (Z/tpm)
100% CO	Combed Ring Spun	7.4	1132
100% CO	Combed Ring Spun	10	1116
100% CO	Combed Ring Spun	16.5	925
100% CO	Combed Ring Spun	20	746
100% CO	Combed Ring Spun	24	740
100% CO	NovaSpun	7.4	1475
100% CO	NovaSpun	10	1206
100% CO	NovaSpun	16.5	864
100% CO	Compact Spun	12	1059
100% VS	Vortex	16.5	******
100% VS	Vortex	20	******
100% VS	Vortex	25	******
100% VS	Open End	20	******

NB: The stars represent twist values that could not be measured due spinning methods.

There were fewer samples of Slub Yarns so there was only one cob for every sample type.

Table 3.1.1 (b): Tested Yarns and their Basic Characteristics (Slub Yarns)

Fiber Type/Blend	Spinning System	Fineness (Tex)
Cotton 100%	Ring Carded	20Tex
50% CO & 50% PES	Ring Carded	20Tex
50% CO & 50% VS	Ring Carded	20Tex

3.2. Used Testing Equipment Settings

Uster4

Uster was used simultaneously with the QQM; the machine was set to function at a testing speed of 200m/min and tested 200m of each sample for 1 min. The Uster machine is directly connected to a PC; therefore a summary of result can be immediately seen on the screen and necessary adjustments or re-runs can be made when needs be. Each sample was tested 3 times.

QQM3

Like in Uster, the testing speed is set at 200m/min. The device can be connected to a PC with QQM software installed and the results obtained from there.

Zweigle

Each sample is tested on at a speed of 50m/min, each of 5 tests is on 100m of yarn, the pre tension is set at 5 cN.

Longitudinal Image Analysis

As explained before, for both versions of this method (Neckar & Vysanska) the equipments used were a Microscope and Camera mounted perpendicular to the table and yarn axis, The camera was connected to the PC with *NIS Elements* software for Image Capturing and pre-treating (converting to J-Peg format and Binary system). The settings are as outlined in the Textile Faculty of TUL's Internal Standard (**IS 22-102-01/01 Yarn Diameter and Hairiness).**The images are processed by special computer programs based on *Mat-lab* and *Pascal.*

Yarn Cross Section Analysis

This section involves preparing the yarn samples over a period of 4 days as per the settings outlined in the Textile Faculty of TUL's Internal Standard (**IS 22-103-01/01 Yarn Packing Density**). The sample are coated with a mixture of glue and xylene, soaked in wax in special cubes and frozen. Thereafter the samples are cut into very thin slices using special Lab a cutter then placed under a Microscope and Camera set at **20*** magnification. Images are processed by a Rebol based program.

3.3. Working Procedure.

The 16 yarns were tested first by Uster 4 used simultaneously with the QQM3, and then only the plain yarns were further tested by the two Image analysis methods then finally by Zweigle.

3.3.1. Measurements on Commercial Equipments.

Uster 4

After testing the Yarns on the machine, a protocol is obtained from the Uster program, here and after referred to as the Uster Protocol, this protocol contains the test number (entered at the beginning of each test and corresponding to the QQM test number of the same yarn sample), and the Uster protocol contains information on tested Yarn quality and characteristics, some of these are recorded in a table (as is shown in the results section) then they are expressed in graphs.

Individual unprocessed data is also obtained from Uster; this data is then processed independently on the Mini-Tab program which produces its own analysis (about the mean yarn diameter, CV and other statistical data) together with a *Distribution plot* of the diameter. The statistical data from Mini-Tab is then recorded and compared with the corresponding results from other measuring methods.

When looking at the Diameter distribution Plot from the Individual data (Mini-Tab) results, it is observed that the plot is a Bi-Modal Gaussian Distribution while the plot from the Uster Protocol shows a Uni-Modal distribution. This then suggests that the Uster program conducts some form of data "cleaning" or "smoothing" on its own data before it is statistically processed.

As a result, the individual data is then smoothed using the Savitzky-Golay method for smoothing data. The smoothing results in the plots of the Individual Data looking almost identical to the Uster Protocol plot.

QQM 3

The procedure for the QQM is Identical to that of Uster4 except that the QQM protocol does not contain as much information as the Uster protocol particularly the exact Diameter Values, this is because QQM measures Yarn Irregularity only, diameter is only implicitly determined.

Individual data is also smoothed with the Savitzky-Golay method and the resulting analysis and plot are compared with those obtained from other methods.

Zweigle

As this is a Hairiness tester only, the plain yarns were all tested following the standard procedure and the protocols were obtained with values for S_{12} and S_3 calculated accordingly.

Data Smoothing/Filtering by Savitzky-Golay

As explained above, the difference in diameter distribution plots from the Uster Protocol and the one produced by Mini-Tab (from raw data) suggested that Uster most probably filters the signal (to deal with noise). However, there are many filtering methods in use today, therefore it is difficult to choose the most suitable one, this problem is further compounded by the fact that some established filtering algorithms can be adapted (modified) to be use for specific data/signal types, as such, the decision to adopt the Savitzky-Golay method was arrived at after a trial and error operation of trying various other algorithms, comparing the results with the Uster protocol results. The Savitzky-Golay method was chosen because it produces a diameter frequency distribution plot similar to the one in the Uster protocol and because it keeps the mean value unchanged.

3.3.2. Measurements on the Laboratory Image Analysis Methods

There is a minimum of 800 images required for each sample; these images are then processed by Computer programs (based on the Pascal language and Mat-lab). However, the Vysanska method only requires processing by a Mat-lab program to obtain results. The Neckar method requires processing by both Mat-lab and the Pascal program to obtain results.

For both methods, the Images were taken on 4*0.6 magnifications and the Calibration was 3.67 µm/pxl. The results are then tabulated and compared graphically with those obtained from other measuring methods.

3.3.3. Measurements of Yarn Diameter by Cross-section

In this method, 35 Images of yarn cross section are taken; these are then processed on a program written in the Rebol Language. The result (excel output) shows values of Yarn packing density and yarn radius, A graph of Yarn Packing Density versus Yarn Radius is plotted, Effective yarn radius is read off the graph as the Radius corresponding to 15% yarn Packing Density, from this, Effective Yarn Diameter is determined. This procedure was followed for all the samples except for the Vortex Spun samples as these are very difficult to analyze in this method. The results are also put in a table and graphically compared to the others.

4. Results and discussion

Yarn samples were tested to determine Diameter, Diameter CV and Hairiness. The results are then presented separately for each of these yarn characteristics, results are analyzed individually and then a summary at the end of this section shows how they relate to each other.

4.1. Analysis of Yarn Diameter

Yarn diameter was tested by 6 different methods, i.e. Calculated diameter, Uster4 tester, QQM3 protocol, Neckar's and Vysanska's Image analysis methods and the Method of Yarn Cross-Sectional Diameter, the results were tabled as below; a graphical comparison of the result was then carried out. Calculated Diameter is diameter calculated using the equation: $D = \sqrt{\frac{4T}{\pi\mu\rho}}$, where T is Fineness in Tex, μ is packing density and ρ is substance density.

Table 4.1.1: Table of Yarn Diameter Results in mm for Normal Yarn

Tex	Spinning Method	Calculated Diameter (mm)	QQM	Uster (mm)	Neckar (M2)		Vysanska(M1) mm	Cross-Section Diameter (mm)
					Cover D	Dens D		
7.4	CO Ring	0.1052	0.1664	0.1290	0.11550	0.11360	0.1299	0.1038
10	Co Ring	0.1234	0.1882	0.1450	0.13403	0.13070	0.1315	0.1293
16.5	CO Ring	0.1629	0.2518	0.2000	0.17250	0.16050	0.1637	0.1492
24	CO Ring	0.2026	0.3159	0.2450	0.22120	0.20490	0.2126	*****
20	CO Ring	0.1812	0.2766	0.2280	0.21000	0.18890	0.2005	*****
7.4	CO Nova	0.1102	0.1355	0.1160	0.10772	0.10635	0.1288	0.1079
10	CO Nova	0.1256	0.1608	0.1370	0.12690	0.12440	0.1288	0.1275
16.5	CO Nova	0.1714	0.2129	0.1820	0.17100	0.16410	0.1645	0.1474
12	CO Comp	0.1317	0.1999	0.1520	0.14099	0.13666	0.1369	0.1380
16.5	VS Vortex	0.1764	0.2254	0.1900	0.17090	0.16040	0.1643	*****
20	VS Vortex	0.1964	0.2514	0.2080	0.19750	0.18180	0.1898	*****
25	VS Vortex	0.2222	0.2605	0.2330	0.22220	0.20480	0.2137	*****
20	VS (OE)	0.1964	0.2681	0.2450	0.20820	0.17430	0.1945	0.1564

Notes: (****) represents cross sectional diameter values that could not be evaluated, **M1** is used to indicate Vysanska's Image Analysis method and **M2 (cover and dense)** are used to indicate Neckar's Image Analysis Method.

All the values are in millimeters. It should be noted that QQM does not measure diameter directly, diameter is inferred from QQM Individual results extracted separately. Also, there were no Vortex Yarn cross-sectional diameter results because the logic used to determine diameter from cross section cannot be meaningfully applied to Vortex Yarn cross sections, this is largely due to the fact that this Logic is derived from a theory that depends on yarn packing density arrangement on the cross section, where Yarn Diameter is defined as corresponding to 15% packing density and Vortex yarn structure is does not conform to this Logic

The result were plotted in a graph, all the other testing methods were compared with the calculated values of Diameter. This was done to see how these methods compare with each other in terms of final result given their differences in Measuring Techniques and Evaluation Logic.

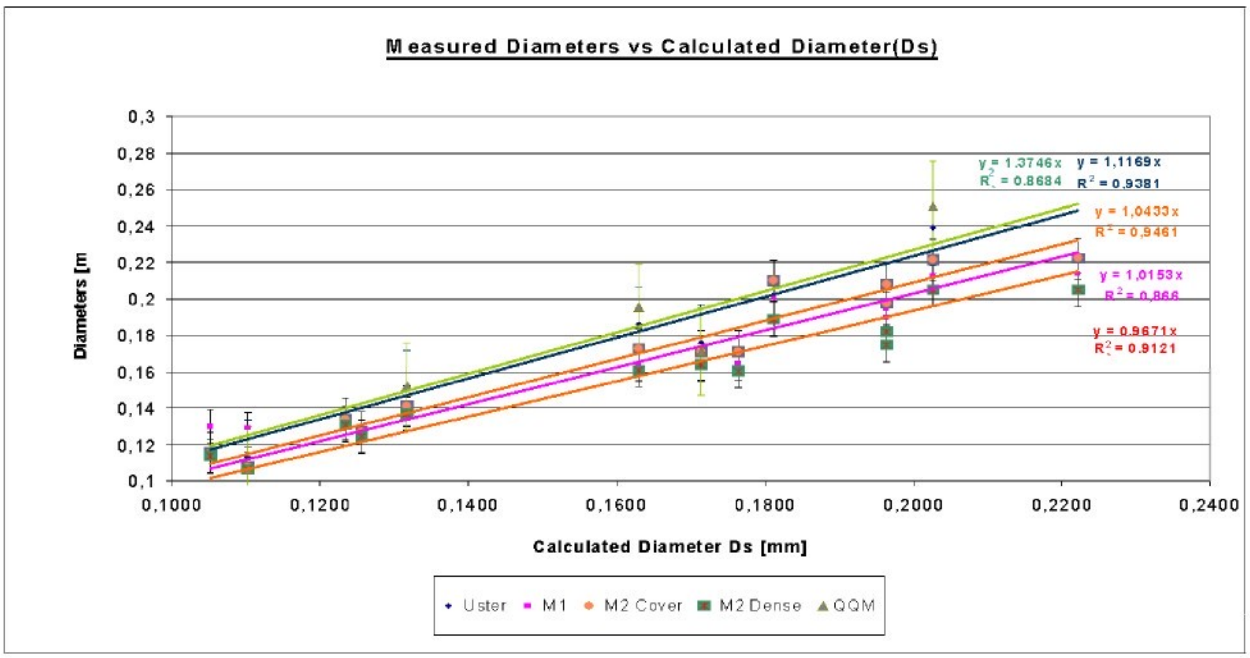


Figure 4.1.1: Comparison of Measured Yarn Diameters (different methods) with Calculated Diameter

The graphs were ploted in the form $y = ax$ and not $y = ax + c$, i.e. $c = 0$, This was done so as to observe how the gradients ('a') compare with each other as the gradient represents the amount

(%) of deviation of each method from the calculated diameter (graphs in the form $y = ax + c$ are available in appendix 1)

From the graph it can be seen that the QQM values are the highest and the the M2-Dense values are generally smaller, but generally there seems to be a good correlation among all the measuring methods. Judging by gradients, it can be seen that the M2-Dense values were 3% below the Calculated values, while all the others were above the Calculated values, i.e. M1 +2%, M2Cover +4%, Uster +12 %, and QQM +37%.

The fact that the Image analysis methods values are so close to the calculated values is indicative of the fact that these methods all depend on the packing density in one way or the other while Uster and QQM are somewhat too different in their approach as they use the Optical method with a system of lasers unlike image analysis which uses a camera.

The results were plotted against each other to check correlation and the correlation coefficients were put in a Matrix below.

Table 4.1.2: Correlation co-efficient Matrix (R^2)

	Calculated Diameter (mm)	QQM	Uster (mm)	Neckar (M2) Cover D	Dens D	Vysanska(M1) mm	Cross-Section Diameter (mm)
Calculated	**1**	**0.7853**	**0.9003**	**0.9464**	**0.9387**	**0.9206**	**0.6869**
QQM		**1**	**0.9353**	**0.9111**	**0.8934**	**0.8610**	**0.8081**
Uster			**1**	**0.9738**	**0.9174**	**0.9319**	**0.7894**
M2 Cover				**1**	**0.9768**	**0.9703**	**0.9507**
M2 Dense					**1**	**0.9507**	**0.9174**
M1						**1**	**0.6869**
Cross-section							**1**

From the Correlation Matrix it can be observed that most methods show a good correlation with each other as for most relations $R^2 \geq 0.8$, which is an accepted level for correlation, however, it should be pointed out that some seem to be better than others and some are not so good.

Good correlations can be noted between Uster Diameter and M2-Cover, M1 and M2 and between Uster and QQM. Weaker correlation is observed between Cross-sectional Diameter values and Calculated Diameter values and also between Cross-sectional and M1. In theory we would expect that these correlations should be good as all three take into account the packing density, but it should also be noted that M2-cover has the best co-relation with the Cross-sectional values.

Good correlation among Uster, M2-Cover and M1 can be attributed to the similarity in what these methods regard as "diameter", they are all dependent on some form of Imaging (Image Analysis and Optical Measuring).

Weak correlation among Calculated diameter and QQM can be also attributed to the fact that QQM does not measure Diameter directly, it is largely implicitly determined, between Cross-sectional and Uster, it can be attributed to Packing Density implications in that the method of Cross-Sectional diameter counts individual fibers whereby it is difficult to ensure that surface fibers remain intact. This is the opposite of what makes Uster correlate so well with M2-cover and M1. It can also be observed that the best correlation involving Cross sectional Diameter involves M2-Dense, again this is attributable to the similarity to what these methods "count" as diameter.

4.1.1. Investigating Uster's "Signal to Diameter" Evaluation Logic

The results from the Uster Protocol when compared to the results obtained from the other methods still show some considerable difference yet the correlations are fairly good, this then suggests that there is something that Uster is doing to the data during or before processing. The most probable thing is Data Filtering or Smoothing.

An attempt was then made to establish whether crude data from Uster when processed independently would show similar results with the protocol results. In the case that the results are not the same, then that would mean that there is indeed something that Uster does to the data before or during processing, if the results however have a good correlation (calculated and protocol) then that would be a strong indication of some sort of smoothing or filtering.

When raw data was extracted from Uster and QQM, it was then treated with “smoothing” Software; the smoothing software uses the Savitzky-Golay method. This method was chosen after a lengthy period of trial and error trying to find out the method that produces the best results from a list that included many other filtering or smoothing methods.

The Effect of Smoothing/Filtering on Uster and QQM Data

Due to the vast amounts of data and graphs, only one “case study” will be shown; the other results are available in the Appendix

Case Study: 20Tex Viscose Vortex Yarn

The original print out from Uster tester protocol (Top) and the plot of the raw data of a 20 Tex vortex yarn plotted on Mini-Tab (Bottom) are given in fig.4.1.2. It is seen clearly that both diagrams are completely identical. This means that the data is completely correctly processed.

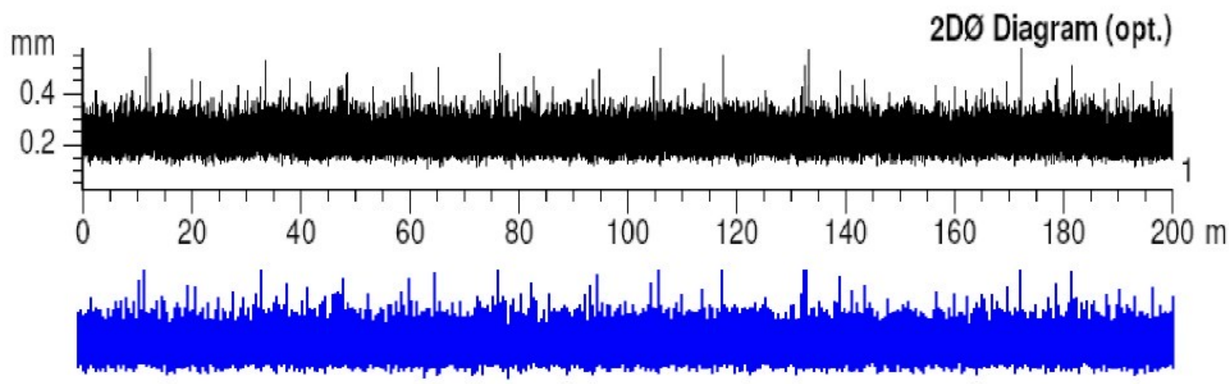


Figure 4.1.2: Comparison of Uster protocol and raw data

When the raw data from Uster and QQM is plotted to ascertain the distribution pattern of the diameter and compared to the distribution plot from the Uster protocol, it was discovered that there is a great difference between the distributions, Uster Protocol shows a Uni-Modal Gaussian Distribution while the raw data distribution shows Bi-Modal Gaussian distribution for the same yarn sample.

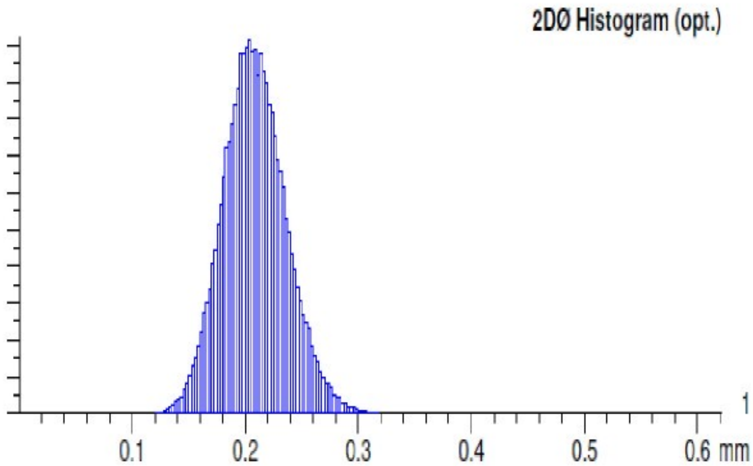


Figure 4.1.3: Uni-Modal Gaussian distribution for 20Tex Vortex (Uster protocol)

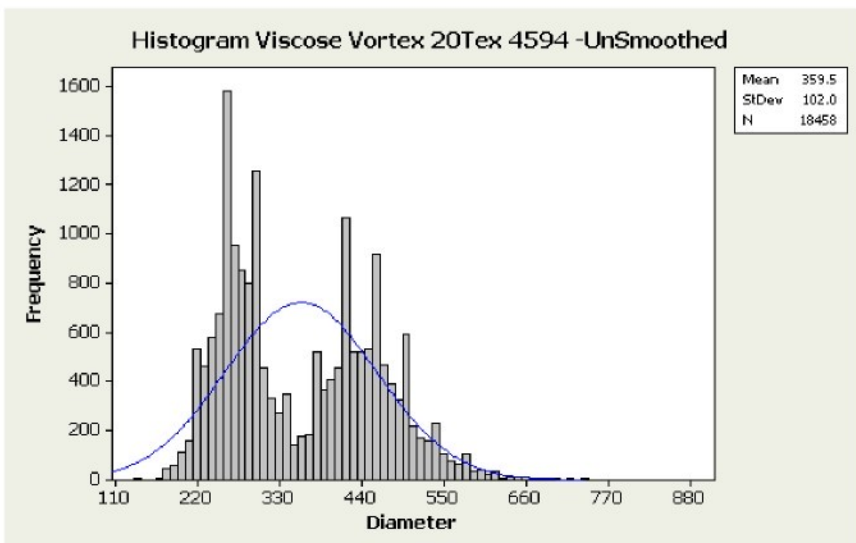


Figure 4.1.4: Distribution Plot from raw data for Uster for 20Tex Vortex

When looking at the raw data plot, it is obvious that the plot is different from the Uster protocol. This leads to the need to go to the basic rules of plotting histograms, and significant tests of bimodality.

Also the values of mean Diameter from Uster is (**2Dφ=0.208 mm**), where according to normal statistical calculations, it gives **0.228mm (**obtained by multiplying the mean, from fig.4.1.4. by the correcting factor: $359.5 \times 0.000634 = 0.228$ **)**, which is fairly high; this is because all values have been taken in consideration, i.e. no filtration. In contrast to this, Uster is most probably filtering the data in some unknown way.

This then means that if we would like to assume that the distribution is uni-modal as suggested by the Uster protocol plot, then we have to filter some values.

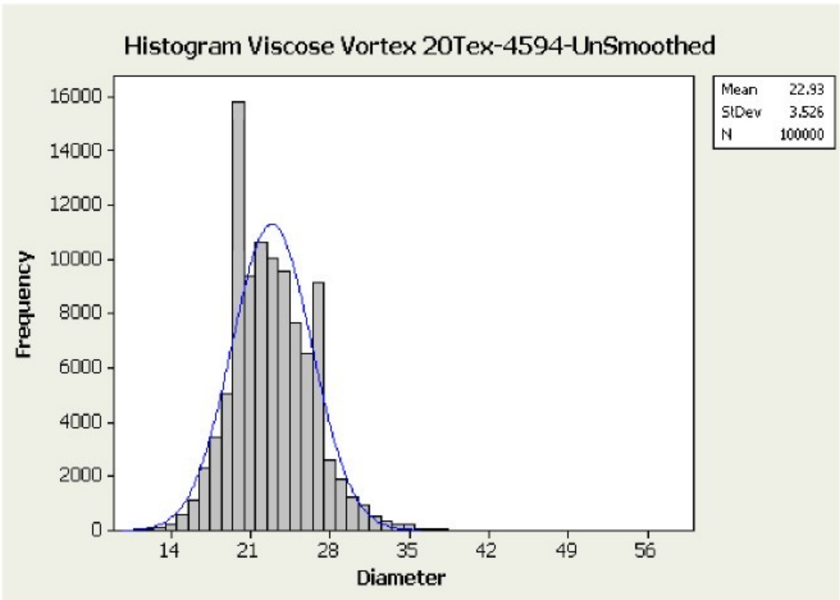


Figure 4.1.5: QQM Raw Data's Diameter Distribution

The QQM-3 gives the following values of Mean diameter = **0.229 mm** (like in Uster, obtained from multiplying the mean in fig 4.1.5. by a correcting factor: $22.93 \times 0.01 = 0.2293$ **),** a value closer to the Uster calculated result, while the result obtained from QQM protocol is **0.2514mm** while the result obtained from Neckar's Image Analysis for Cover Diameter is **0.1975mm,** Vysanska's Image Analysis gives: **0.1898mm.**

The next step is to try and calculate a diameter value similar/close to the Uster protocol value and this diameter is calculated by normalization with the Uster and QQM correction factor and using Savitzky-Golay smoothing operation and setting ensuring appropriate settings (on the Auto-Signal software). It should however be pointed out that the act of Smoothing by this method does not change the mean, i.e. mean diameter for the reasons previously explained on the Literature review. The fig.4.1.6&4.1.7 show the results:

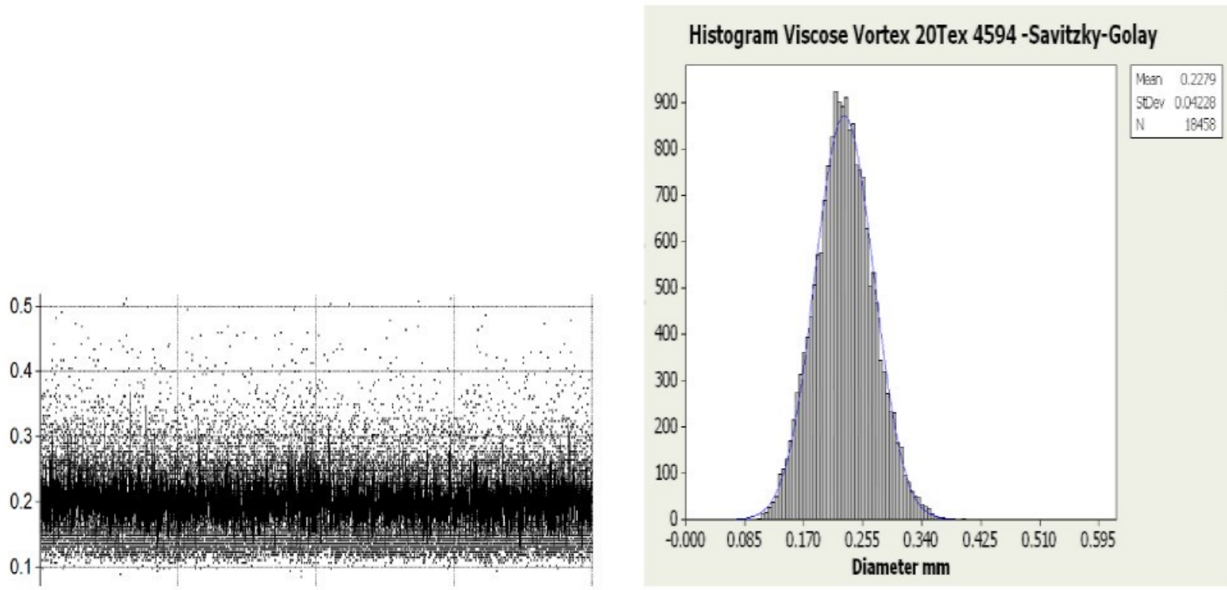


Figure 4.1.6: Uster Raw Data Smoothing and Diameter distribution after Smoothing

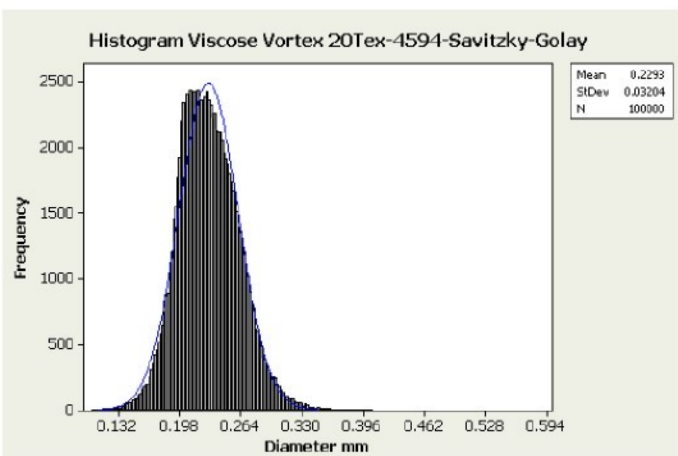
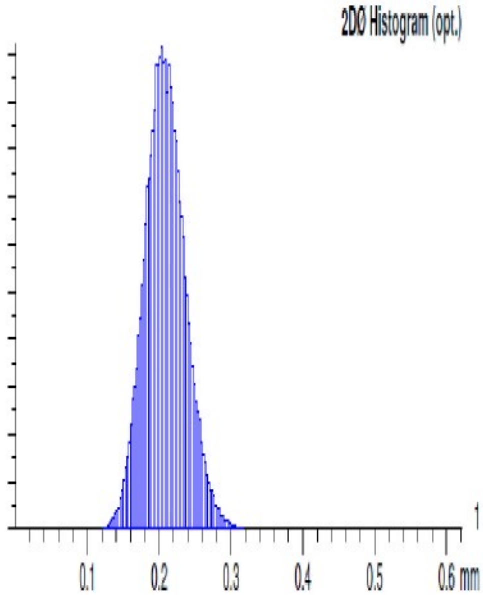
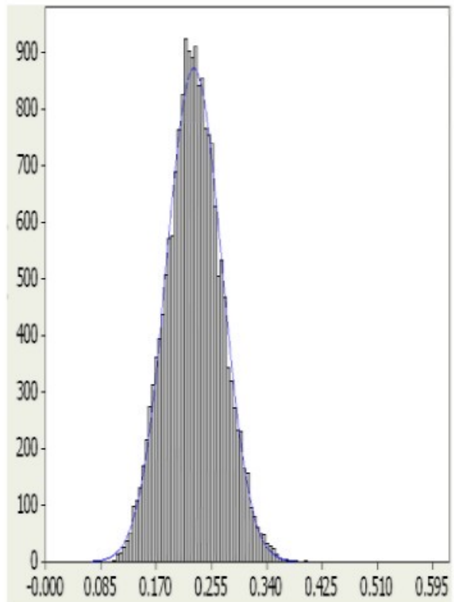


Figure 4.1.7: QQM Raw Data Diameter Distribution after Smoothing

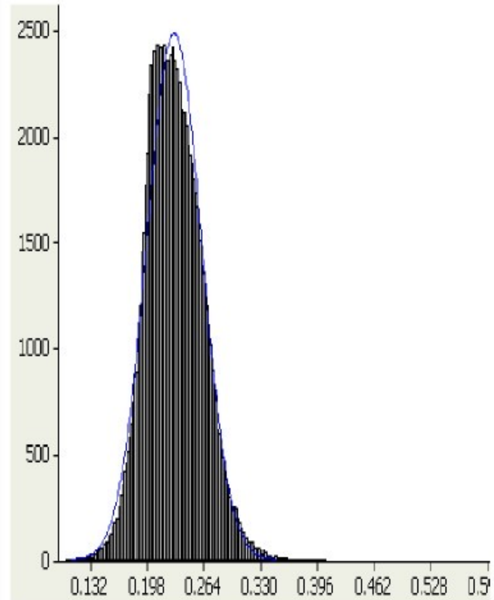
The results of smoothing shows that the Uster and QQM Raw data can be manipulated to have a distribution similar to that of the Uster protocol, i.e. distribution in figures 4.1.6 and 4.1.7 looks similar to that in Figure 4.1.3 the bi-modality is gone, albeit there is still some slight difference. This then confirms that Uster does indeed filter its signal before processing, although the exact algorithm is yet unknown.



Uster Protocol



Uster Calculated



QQM Calculated

Figure 4.1.8: Comparison of the Distribution plots of yarn diameter of 20 Tex Viscose Vortex

The comparison in fig 4.1.8 above shows that the Diameter Frequency distributions for all three methods, i.e. Uster protocol, Uster calculated and QQM calculated are almost identical. This not only makes a strong case for “filtering” by Uster but also shows that when treated independently QQM data behaves like Uster data, a result that had proven illusive before.

The above was just a Case study to illustrate the process of filtering yarn diameter data values. To confirm the positive effects of data filtration on correlation the following graphs were plotted for the rest of the samples:

Table 4.1.3: Uster Protocol Diameter with Calculated Diameters from Uster and QQM

		Uster Diametre (mm)		QQM Calculated
Tex	Sample	Protocol D	Calculated D	Diametre (mm)
7.4	CO Ring	0.1290	0.143	0.1386
10	Co Ring	0.1450	0.159	0.1559
16.5	CO Ring	0.2000	0.192	0.2068
20	CO Ring	0.2450	0.254	0.2408
24	CO Ring	0.2280	0.234	0.2647
12	CO Compact	0.1520	0.167	0.1699
7.4	CO Nova	0.1160	0.133	0.1152
10	CO Nova	0.1370	0.152	0.1367
16.5	CO Nova	0.1820	0.178	0.1810
16.5	VS Vortex	0.1900	0.192	0.1982
20	VS Vortex	0.2080	0.217	0.1949
25	VS Vortex	0.2330	0.239	0.2215
20	VS OE	0.2450	0.250	0.2279

The above table shows Uster protocol diameter together with diameter calculated from the raw data from Uster and QQM, as explained earlier, the calculations were conducted on Minitab after filtering by the Savitzky-Golay filter. It can be seen that the results are booth appreciably closer to the Uster protocol values.

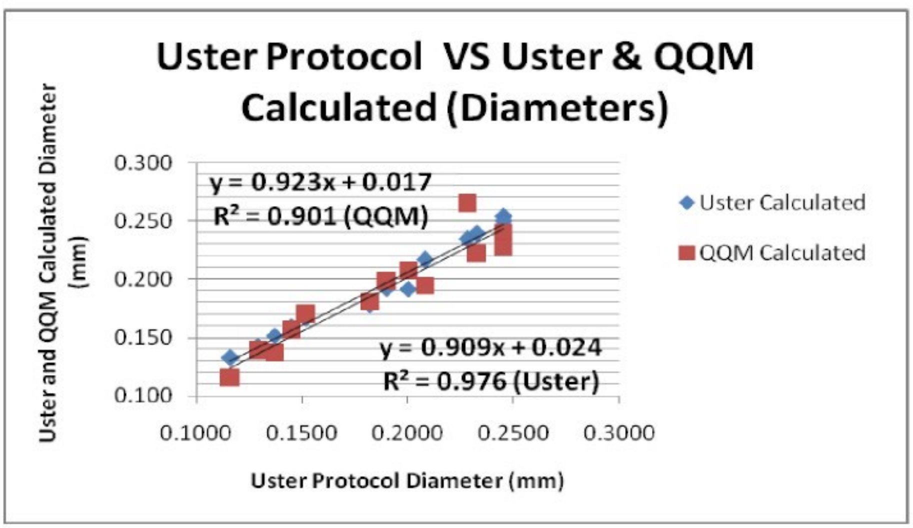


Figure 4.1.9: Correlation of Uster Protocol diameter with Uster Calculated diameter and QQM Calculated diameter

The graph in fig 4.1.9 confirms that the filtered data is in good correlation with Uster protocol diameter and calculated diameter, the correlation (lighter line) shows a coefficient of **0.90,** while for Uster protocol versus Uster calculted it is as might be expected very good at **0.98.**

4.2. Analysis of Yarn Irregularity Data

The yarn irregularity in this case is charecterised by the variation co-efficient (CV %). The CV was measured by the Uster and the QQM. Part of the reason could be that these two methods do not use the same measuring field length, Uster measures primarily on 8mm (but Uster4 uses 10mm) in two dimensions [13], while QQM measures on a 2mm length [24], now since CV is generally larger for small cut lengths and smaller for longer cut lengths, it can be assumed that it is not meaningful to compare these two of readings.

Table 4.2.1.: Yarn CV % results from Uster Protocol and QQM Protocol

Tex	Sample	Uster Protocol	QQM 3 Protocol
		CV (%)	CV (%)
7.4	CO Ring	12.38	10.2
10	Co Ring	10.46	8.93
16.5	CO Ring	11.22	11.27
20	CO Ring	11.14	10.6
24	CO Ring	9.44	10.97
12	Compact	10.66	10.37
7.4	Nova	11.44	10.34
10	Nova	10.65	11.3
16.5	Nova	8.90	10.68
16.5	Vortex	13.49	11.91
20	Vortex	10.71	11.77
25	Vortex	10.47	10.64
20	VS (OE)	10.19	10.98

The table shows values from Uster Protocols and QQM protocols for respective yarn CV %. At face value, these values are not that different from each other. Attempts had been made in the past [30] to establish correlation between Uster and QQM but have so far come to naught, Uster CV% seems difficult to compare or correlate with QQM CV.

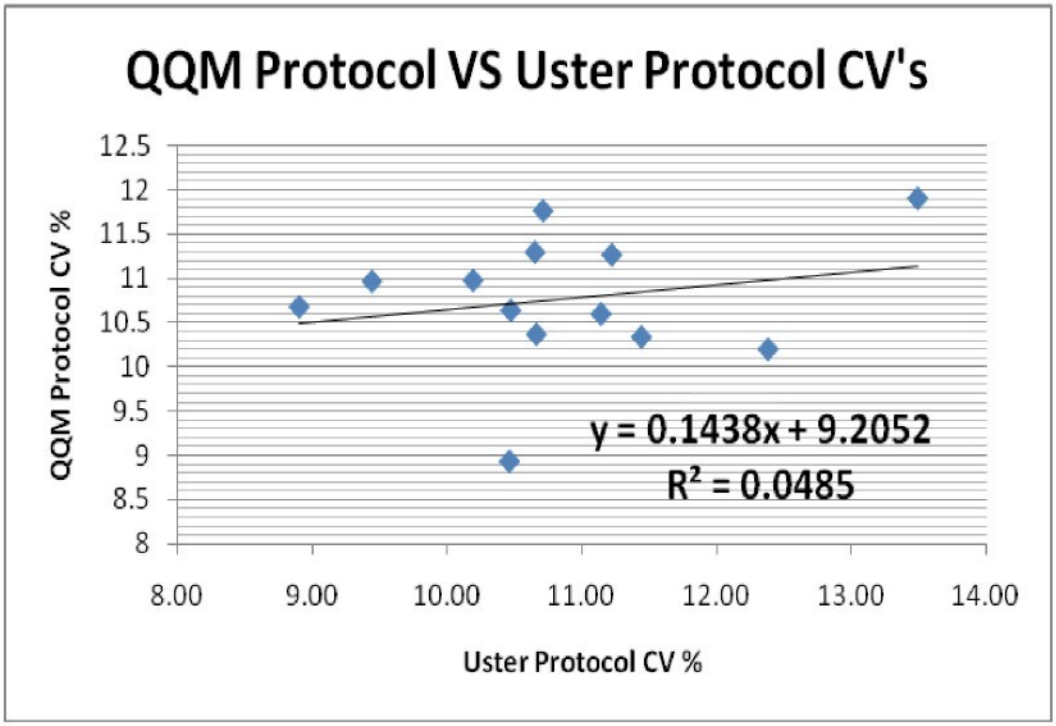


Figure 4.2.1: Correlation Between Uster Protocol CV and QQM Calculated CV

This graph (Fig 4.2.1) shows the poor correlation between Uster and QQM CV's, as was discused earlier. the correlation is almost non-existant.

The effect of Smoothing on CV

As previously explained, the raw data from both Uster and QQM is extracted and Statistically analysed externally using Mini-Tab, for CVs, the Coefficients of Variations were recorded (before Smoothing), then there after the same data is Smoothed by the Savitzky-Golay method then Analyzed on Mini-Tab, then the results were compared.

Tables 4.2.2: : Unsmoothed and Smoothed raw data from Uster and QQM

		Uster CV		QQM CV	
Tex	Sample	Protocol	Calculated	Protocol	Calculated
7.4	CO Ring	12.38	12.77	10.2	12.98
10	Co Ring	10.46	10.51	8.93	10.48
16.5	CO Ring	11.22	11.13	11.27	10.97
20	CO Ring	9.44	9.01	10.6	10.33
24	CO Ring	11.14	11.31	10.97	10.98
12	CO Compact	10.66	10.79	10.37	10.75
7.4	CO Nova	11.44	11.89	10.34	12.07
10	CO Nova	10.65	10.73	11.3	10.87
16.5	CO Nova	8.90	9.23	10.68	9.93
16.5	VS Vortex	13.49	13.52	11.91	12.62
20	VS Vortex	10.71	10.89	11.77	11.01
25	VS Vortex	10.47	9.94	10.64	11.01
20	VS OE	10.19	9.82	10.98	10.80

From the two tables it can be seen that when looking at the raw data analysis, Uster tends to have a higher CV than QQM, almost double, it should be noted that one of the main cause for this, other than the difference in measuring methods, is the fact that for the same length of yarn (Uster and QQM were used simultaneously) Uster has about 18 000 data points while QQM has 100 000. However, it can be observed that for both methods, smoothing tends to bring CV down, for Uster by about 33% and for QQM by about 10%, this further point to the suspicion that Uster does indeed filter its readings (signal) before analyzing it.

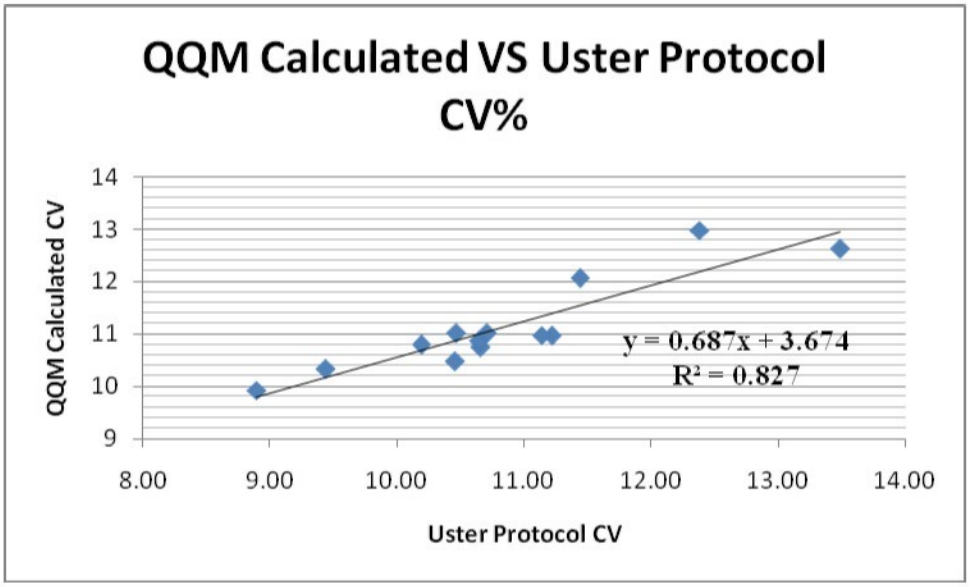


Figure 4.2.2: Comparing Comparing QQM Smoothed CV to Uster Protocol CV

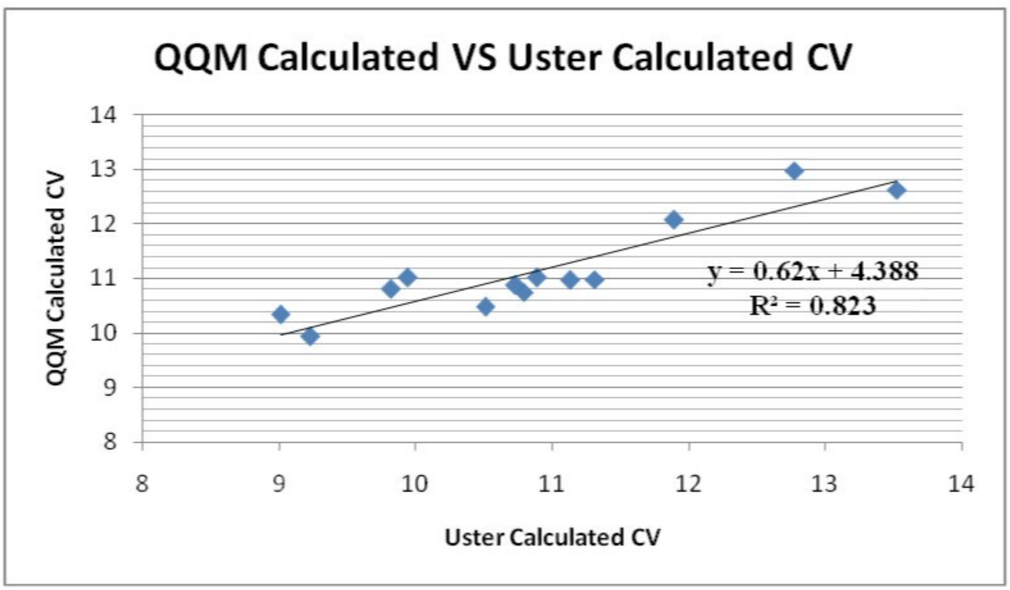


Figure 4.2.3: Smoothed Raw Uster CV versus Smoothed QQM CV(calculated)

The graph above (Fig:4.2.2) shows some marked improvement on the correlation co-efficient, it is worth noting that due to Smoothing of the QQM data, the correlation co-efficient went up 17 times, i.e. it improved from 0.048 to 0.83.

The second graph (Fig: 4.2.3) also has a simmilar correlation co efficient, Although it should be expected to be bigger than the other one because in this case both raw data sets are analyzed the same, they are both smoothed by the Savitzky-Golay and analyzed on Minitab.

These results then gives even more indication that when the raw data from QQM is analyzed independently, the correlation with Uster results can improve tremendou

4.3. Analysis of Yarn Hairiness Data

Yarn hairiness was measured by two instruments, i.e. Uster Tester4 and Zweigle G567. Results obtained for **13 yarn** (plain yarns) samples are tabulated below and then the results were represented graphically.

Table 4.3.1: Hairiness Test results from Uster and Zweigle

Tex	Spinning	Uster	Zweigle	
	Method	H	S12	S3
7.4	CO Ring	3.95	7604.20	1242.40
10	Co Ring	3.89	4767.80	299.20
16.5	CO Ring	5.23	6954.60	739.00
20	CO Ring	5.82	8687.20	1011.00
24	CO Ring	5.73	8869.40	1176.80
7.4	Nova	3.51	8527.00	1337.60
10	Nova	4.07	8195.60	1014.60
16.5	Nova	5.48	10356.20	1484.40
12	Compact	3.68	8621.20	342.60
16.5	Vortex	3.64	806.40	5.80
20	Vortex	3.78	866.60	1.60
25	Vortex	3.7	729.20	3.80
20	VS (OE)	5.25	2955.00	588.80

The Uster results (H) show the Sum total (in cm) of lengths within a 1cm length of tested yarn, while Zweigle shows S12 (sum of actual hairs between 1mm and 2mm from the core) and S3 (hairs longer than 2mm).

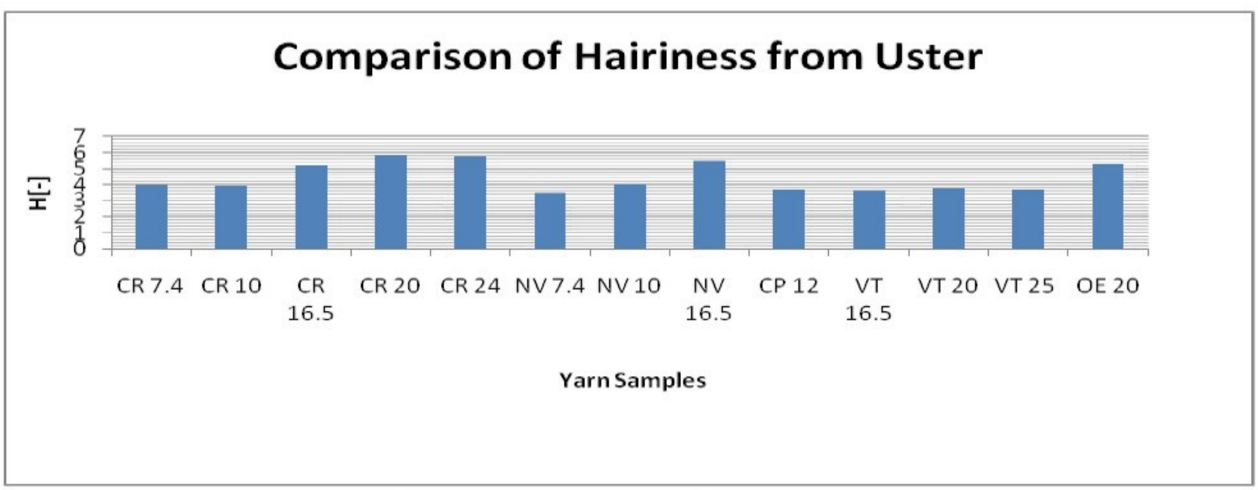


Figure 4.3.1: Uster Hairiness Results

The results follow a trend of hairiness increasing with increasing fineness. Also, Vortex spun yarn tends to have less hairiness as is to be expected due to this yarn's characteristic belt fibers which minimizes hairiness.

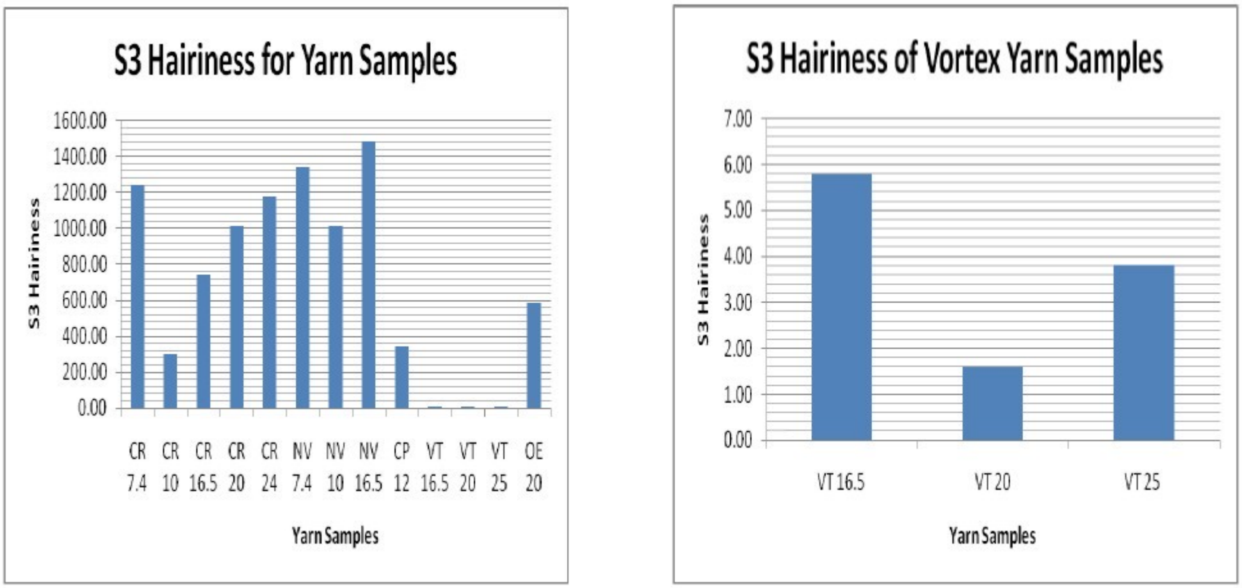


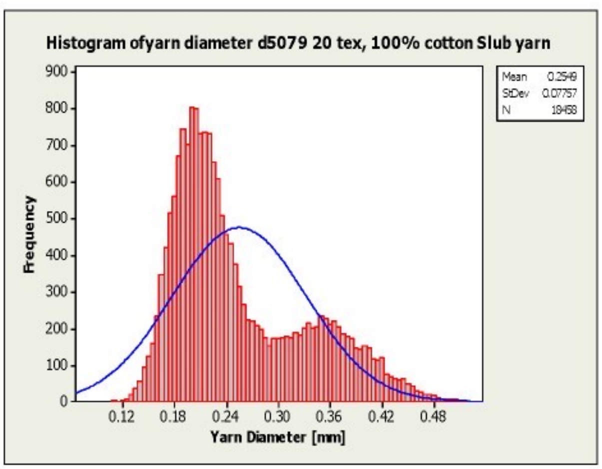
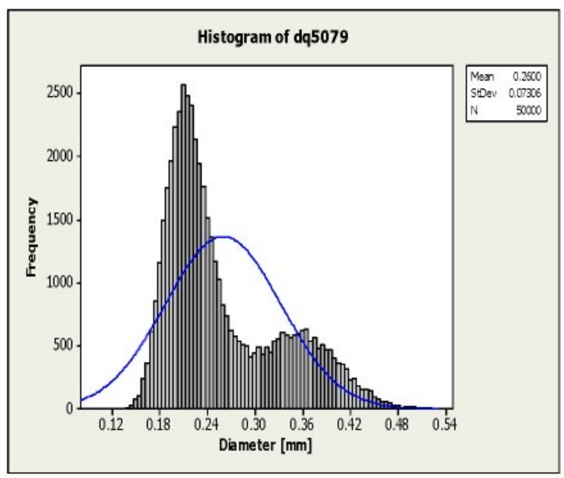
Figure 4.3.2: Zweigle hairiness Results

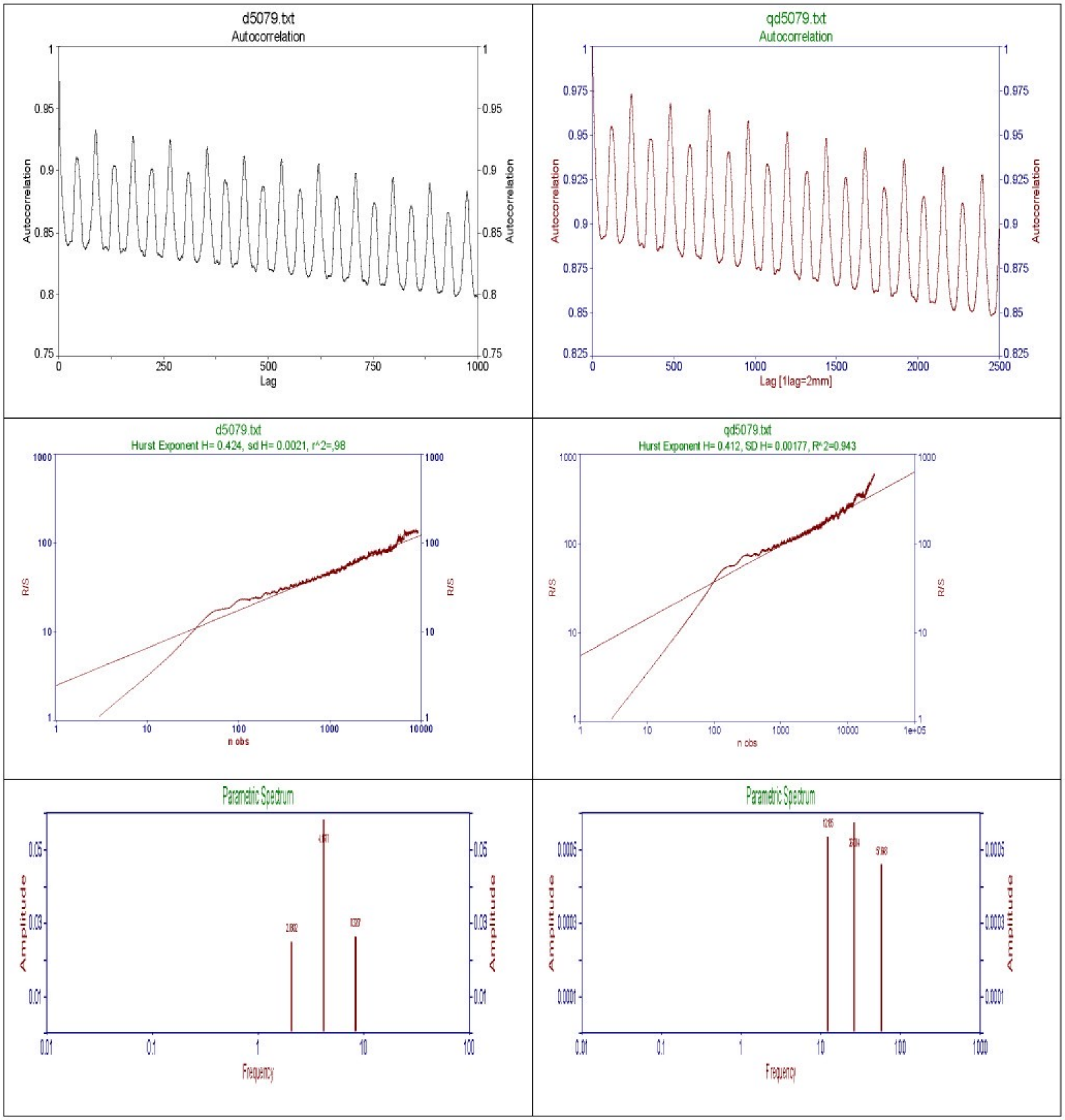
Again these Zweigle results show a simmilar trend to results from Uster, i.e. hairiness seems to increase with fineness, however there are some slight differences which can be explained by the fact that Zweigle catergorises hairiness into S_{12} which is generally considered to be "good" hairiness, that has some benefits particularly in fabrics, e.g. dye affinity and comfort. The second category is S_3 which can be thought of as "bad" hairiness, which is what the graphs above represent, so Zweigle results in this case are not showing "total" hairiness like Uster results.

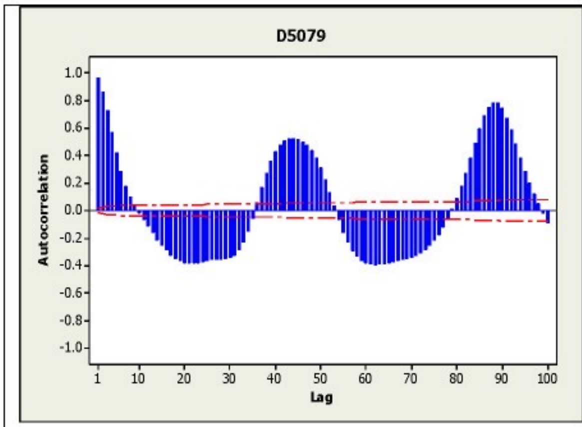
4.4. Comparison between Uster and QQM

From table [4.2.1] and graph [figures; 4.2.1 & 4.2.2] we can conclude that there is a very poor correlation between the values obtained from QQM protocol and Uster Protocol, however, it was suggested that if the data could be treated in the same way, i.e. "third party" algorithm the comparability might improve.

Therefore to further compare Uster data with QQM data it is important to see if they have the similar characteristics individually, i.e. other than correlating the results. To do this, it is important to look at the graphical (statistical) behavior of each of the two signals/data. To do this, a comparison of Slub Yarn (100% Cotton Ring Carded) data from Uster and QQM which was statistically analyzed by the D-Yarn program and Mini-Tab, the resulting plots were as follows:

USTER	QQM
	


d5079.txt
Autocorrelation
Lag
qd5079.txt
Autocorrelation
Lag [1lag=2mm]
d5079.txt
Hurst Exponent H= 0.424, sd H= 0.0021, r^2=,98
R/S
n obs
qd5079.txt
Hurst Exponent H= 0.412, SD H= 0.00177, R^2=0.943
R/S
n obs
Parametric Spectrum
Amplitude
Frequency
Parametric Spectrum
Amplitude
Frequency



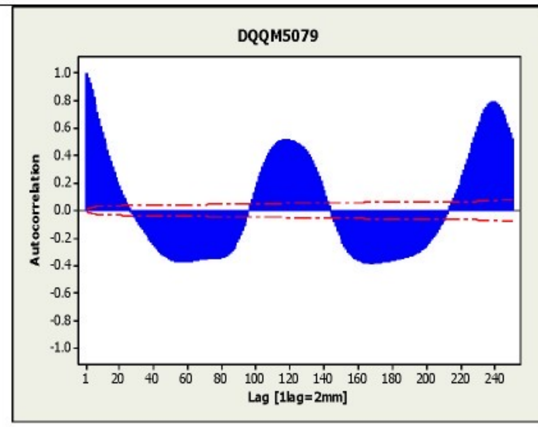


Figure 4.4.1: A comparison of Uster data and QQM data

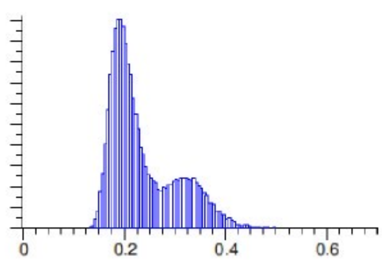
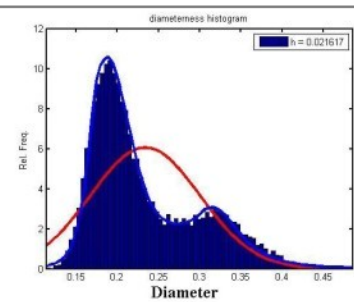
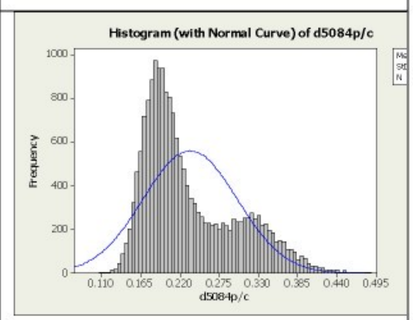
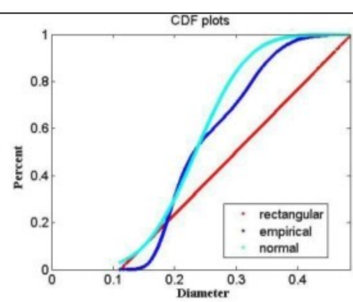
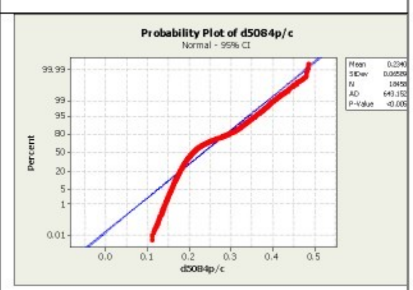
In the above comparison it can be clearly seen that the when treated by an Independent algorithm, the two data sets have almost Identical characteristics. This result, as has already been stated, had already been thought to be unattainable. Hence it can be concluded that if the QQM data is processed in an appropriate manner it can be comparable to Uster.

4.5. Comparison of Evaluation Algorithms

While Uster is the most widely used instrument for yarn quality determination, there are however many other instruments that are in used in both industry and academia. It is therefore necessary to have an algorithm that will be some sort of a "mediator" among these instruments and other measuring techniques.

There are of course many Statistical data treatment software that can be employed to perform this task, but it should be borne in mind that these instruments already have sophisticated algorithms, therefore the "mediator" algorithm should bring something more special to the proverbial table. In this work, it has been seen that Mini-Tab is quite versatile in analysis, i.e. better than all the other packages that were tried, while the D-Yarn program also produced some interesting analysis.

Therefore, a comparison between Minitab and the D-Yarn is necessary. It is also necessary to see how these two programs measure up against Uster, due to Uster's International appeal. A comparison was made using Slub Yarn (50% CO & 50% PES, 20Tex Ring Carded).

Uster protocol	**D-yarn**	**minitab**
		
N/A		

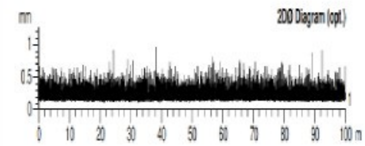
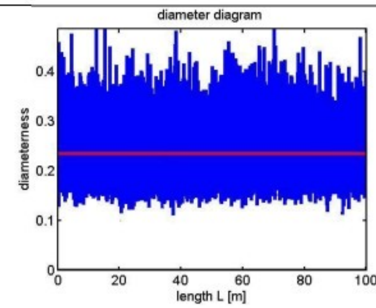
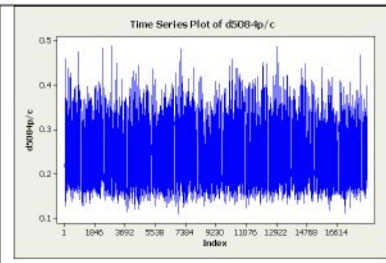
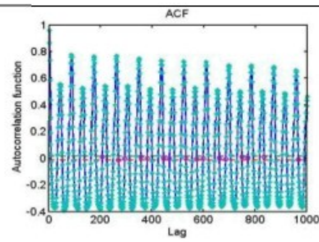
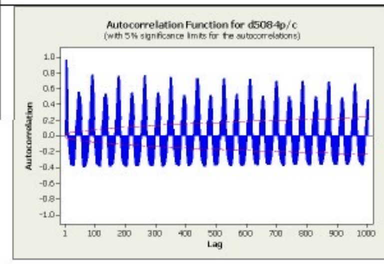
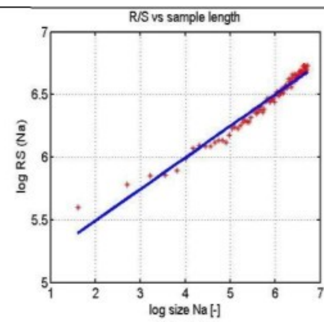
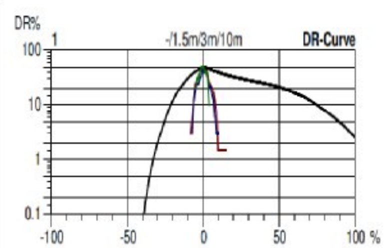
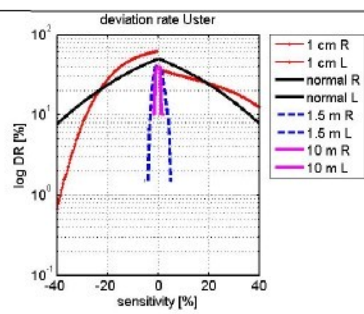
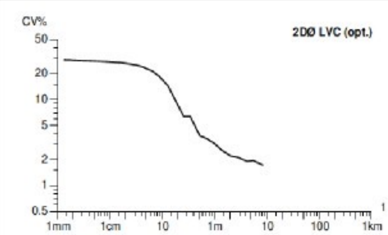
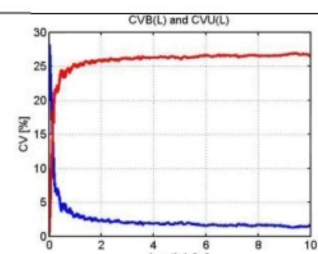
		
N/A		
N/A		N/A
		N/A
		N/A

Figure 4.5.1: Comparison of Uster Protocol, D-Yarn and Mini-Tab

It is clear from just the small sample of the output of different programs, that the D-Yarn program is a powerful program and more universal than even Uster itself and could be used for characterization of yarn mass irregularity, diameter or hairiness for Data from different instruments. Further than these plots, the D-yarn program is able to analyze diameter distribution as a bi-modal distribution and interpret it as two diameters, this output is produced (a more detailed version is on Appendix (4-6) :

Basic diameter:

mean = 0.239245.

standard deviation = 0.0587679.

******************************.

Nonparametric two modes .

******************************.

mode 1 = 0.179745.

mode 2 = 0.197772.

optimal bin = 0.00057556.

******************************.

Correlation Coefficient R^2

0.9950

Two Gaussians .

******************************.

mean 1 = 0.202616.

mean 2 = 0.303697.

st dev 1 = 0.0224123.

st dev 2 = 0.0425879.

portion 1 = 0.655966.

portion 2 = 0.339943.

bimodal separation = 0.777546.

5. Conclusion

The results show that the different diameter measuring techniques have good correlation, however, this correlation is not enough because it can still be seen that the actual values are far apart, hence the need to further investigate the algorithms employed by Uster and QQM.

An investigation into the CV results showed poor correlation between Uster and QQM, a result that was not surprising given that there had been attempts in the past to compare Uster results with QQM results, these attempts had come to naught.

The Uster tester is the most used instrument in the world, there is also an internationally recognized Uster statistics, and the Instrument costs over some 6 mil. Czech Crowns (about US $300 000). The QQM 3 is a small instrument, portable, and can be used directly in the mill, costs about 300,000 Czech crowns (about US $ 15 000). Therefore, the ability to compare the results of these two instruments is of paramount importance when looking at the price difference.

The investigation into the Uster Tester's data processing technique (algorithm) revealed that Uster conducts some data filtering before further analyzing the data. It was also discovered that QQM's data can have similar characteristics as Uster if they are treated independently. This result together with poor correlations between Uster protocol results and QQM protocol result showed that QQM's evaluation Algorithm is somehow flawed.

5.1. Contribution of this Work.

- By applying the method of analyzing raw data from measuring instruments, it is now now possible to compare values from different methods.
- It has been shown that QQM results can give similar information as Uster when an appropriate evaluation/analysis technique is applied.
- The D-Diagram program is able to analyze diameter distribution as a bi-modal distribution and interpret it as two diameters, each with its own mean, standard deviation and % of distribution. (Similar idea to Neckar's Theory) [16,17 and 21]

5.2. Future Work

- This work concentrated on two yarn diameter measurement instruments, i.e. Uster Tester 4 and QQM 3. In future, more instruments should be analyzed in this method, to give more credence to the findings of this work.

- Also, the investigation of yarn irregularity in this work was reliant only on CV (diameter). Therefore to get a bigger picture, the other aspects of yarn irregularity need to be investigated in a similar method as this work.

- Yarn Irregularity from Neckar's Image analysis was not used in this work, in future it is possible that some more interesting findings could be made should the Neckar's CV be compared with CV from measuring instruments.

- The fact that D-Yarn is able to analyze diameter distribution as a bi-modal distribution and interpret it as two diameters, a method similar to Neckar's Cover diameter and Dense diameter approach should be cause for further investigation into the similarities of the two and might lead to an even better understanding of the ever elusive subject of Yarn Diameter.

- Lastly, the results from such work can carry even more weight, particularly for Diameter Variations (CV) if more yarn samples of the same kind (same fiber and spinning method, different fineness) are tested and a generally larger sample size is used, as opposed to only 16 used in this work.

6. List of Symbols

CV%	**Coefficient of variation**	**[%]**
d	**Diameter**	**[mm]**
L	**Length**	**[m]**
m	**Mass**	**[g]**
p	**Pressure**	**[Pa]**
T	**Twist**	**[Turns/m]**
Tex	**Yarn fineness**	**[grams/kilometer]**
t	**Time**	**[s]**
V	**Linear speed**	**[m/min]**
ρ	**Fiber density**	**[Kg/m^3]**
μ	**Fiber packing density**	**[dimensionless]**

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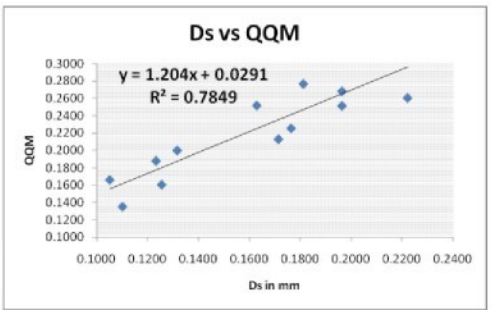
Computational Intelligence (SCI) 55, 57 –73 (2007), © Springer-Verlag Berlin Heidelberg 2007

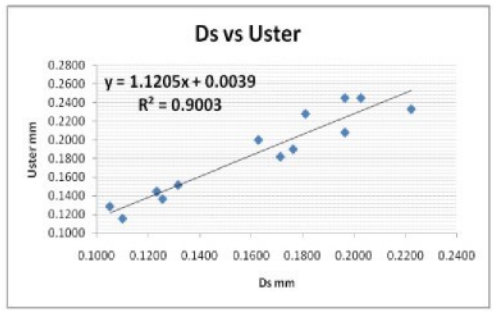
(D-Yarn Program: D-Diameter & D-Hair).

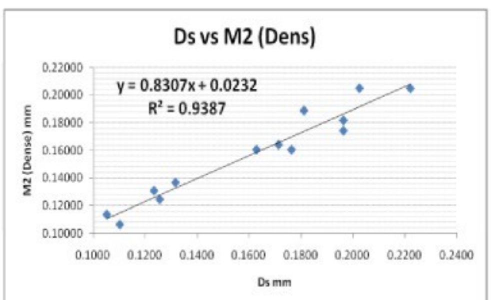
8. Appendices

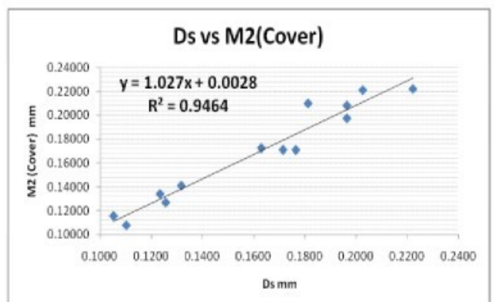
Appendix 1: Correlation graphs comparing different diameter measuring methods with the calculated diameter

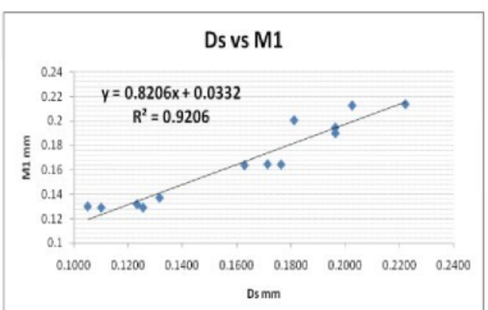
NB: Ds represents calculated diameter, **M1** is used to indicate Vysanska's Image Analysis method and **M2 (cover and dense)** are used to indicate Neckar's Image Analysis Method.











Appendix 2: A Summary of Protocol results from Uster Tester 4.

Fiber Type	Technology	Fineness	U% %	CVm %	H	sh	2DØ mm	CV2D 8mm %	s2D 8mm mm	Shape
Cotton	NovaSpun	7.4 TEX	12.26	15.63	3.51	0.93	0.116	11.44	0.015	0.89
		10TEX	10.97	13.87	4.07	1.08	0.137	10.65	0.016	0.89
		16.5TEX	9.06	11.42	5.48	1.25	0.182	8.9	0.017	0.88
	RingComb	7.4Tex	12.16	15.3	4	1.01	0.129	12.38	0.018	0.85
			12.24	15.45	3.95	1	0.129	12.38	0.018	0.85
			12.09	15.2	3.99	1.01	0.128	12.32	0.017	0.85
		10TEX	10.48	13.18	3.94	0.85	0.145	10.46	0.017	0.85
			10.24	12.87	3.89	0.86	0.145	10.39	0.017	0.85
			10.64	13.4	3.86	0.86	0.145	10.79	0.017	0.85
		16.5TEX	10.83	13.68	5.23	1.03	0.2	11.03	0.023	0.83
			10.88	13.75	4.95	1.04	0.195	11.22	0.023	0.83
		20TEX	10.09	12.82	4.74	1.23	0.228	11.07	0.026	0.85
			10.12	12.79	5.82	1.25	0.227	11.14	0.026	0.85
		24TEX	8.77	11.1	5.28	1.15	0.244	9.22	0.024	0.86
			8.82	11.18	5.73	1.26	0.245	9.44	0.024	0.85
			9.05	11.54	5.15	1.12	0.243	9.32	0.024	0.85
	Compact	12TEX	10.8	13.61	3.77	0.84	0.152	10.66	0.017	0.86
			10.37	13.11	3.68	0.84	0.152	10.39	0.017	0.85
			10.43	13.26	3.66	0.84	0.153	10.47	0.017	0.85

Viscose	Vortex	16.5TEX	16.03	20.25	3.64	0.77	0.19	13.49	0.026	0.83
			15.65	19.83	3.57	0.74	0.189	12.96	0.026	0.83
		20TEX	13.31	16.81	3.53	0.81	0.208	10.47	0.023	0.82
			14.51	18.41	3.78	0.73	0.208	12.14	0.026	0.84
			13.12	16.57	3.79	0.74	0.209	10.71	0.023	0.83
		25TEX	12.35	15.66	378	0.73	0.234	10.47	0.025	0.84
			11.66	14.74	3.7	0.69	0.233	9.86	0.023	0.84
			12.04	15.23	3.81	0.72	0.234	10.34	0.025	0.84
	Open End	20TEX	11.84	15	6.13	1.27	0.245	10.19	0.025	0.82
50%CO/50%VS	Ring Card SL	20Tex	30.2	36.66	5.49	1.98	0.237	27.59	0.064	0.87

Appendix 3: A Summary of Protocol results from QQM3.

Fiber Type	Technology	Fineness	Twist Nominal	Average	U %	Fineness Measured	U%	CV %	CV 10	CV 50	CV100
Cotton	NovaSpun	7.4 TEX	1475	13.55	5.83	7.08	7.96	10.34	7.21	3.48	1.91
		10TEX	1206	16.08	6.48	9.27	8.85	11.3	8.03	3.77	1.72
		16.5TEX	864	21.29	7.82	14.62	8.31	10.68	7.49	3.69	1.73
	RingComb	7.4Tex	1132	16.64	6.03	9.79	8.24	10.2	8.21	4.02	2.17
			1132	******	******	******	******	******	******	******	******
			1132	16.11	6.14	9.3	8.39	10.46	8.26	3.98	2.09
		10TEX	1116	18.82	4.91	11.94	6.71	8.63	6.73	3.5	1.84
			1116	18.34	5.22	11.45	7.13	8.93	6.99	3.61	1.83
			1116	19.17	4.73	12.31	6.46	8.51	6.72	3.51	1.83
		16.5TEX	925	25.18	6.44	19.37	8.8	11.27	8.25	4.04	2.47
			925	24.33	6.53	18.28	8.92	11.24	8.26	3.81	2.17
		20TEX	800	27.65	5.83	22.72	7.96	10.6	8.4	4.08	2.13
			746	28.33	5.9	23.69	8.06	10.49	8.31	4.04	2.14
		24TEX	738	31.59	6.04	28.6	8.25	10.4	7.91	3.73	2.04
			738	31.14	6.38	27.89	8.72	10.97	8.37	3.89	2.17
			738	31.68	6.12	28.74	8.36	10.53	8.02	3.77	2.19
	Compact	12TEX	1059	19.52	5.9	12.67	8.06	10.65	7.72	3.7	1.95
			1059	19.99	5.5	13.18	7.51	10.37	7.43	3.47	1.8
			1059	19.17	6.02	12.31	8.22	10.83	7.8	3.8	2.08

Viscose	Vortex	16.5TEX	1400	22.56	7.02	16.1	9.59	11.91	9.51	3.96	1.9
			1400	23.32	6.76	17.02	9.23	11.46	9.12	3.89	1.94
		20TEX	1200	25.14	6.49	19.32	8.87	11.16	8.35	3.62	2.01
			1200	22.93	6.63	16.55	9.43	11.77	9.45	3.96	2.05
			1200	22.15	6.63	15.62	9.06	11.35	8.84	4.04	2.13
		25TEX	1264	22.18	6.78	15.65	9.26	11.65	8.8	4.17	2.42
			1200	26.05	6.03	20.52	8.24	10.64	8.33	3.81	1.99
			1200	24.56	6.71	18.57	9.17	11.46	9.02	4	2.19
	Open End	20TEX	877	26.81	6.08	21.55	8.31	10.98	8.4	3.92	2.43

Appendix 4: D-yarn program Output; analysis of diameter distribution as a bi-modal distribution and its interpretation as two diameters for the 50%CO/50%PES Slub Yarn, Carded Ring Spun at 20 Tex:

Basic diameter .

*****************************.

mean = 0.239245.

standard deviation = 0.0587679.

*****************************.

Nonparametric two modes .

*****************************.

mode 1 = 0.179745.

mode 2 = 0.197772.

optimal bin = 0.00057556.

*****************************.

Correlation Coefficient R^2

0.9950

Two Gaussians .

*****************************.

mean 1 = 0.202616.

mean 2 = 0.303697.

st dev 1 = 0.0224123.

st dev 2 = 0.0425879.

portion 1 = 0.655966.

portion 2 = 0.339943.

bimodal separation = 0.777546.

Appendix 4 Continued…..

T test of means .

******************************.

T1 statistics = 347.73.

T2 statistics = 290.886.

Critical value = 1.96001.

******************************.

L ratio test of fits .

******************************.

Lratio statistics = 21182.1.

Critical value chi2, d.f.4 = 9.48773.

******************************.

Bootstrap pivot data

95 proc.Konf. interval -0.341834. -0.373091.

Prumer Bootst = -0.357303.

Rozptyl Boots = 5.82208e-005.

Bootstrap pivot rectangular

95 proc.Konf. interval -0.0218255. -0.0336363.

Prumer Bootst = -0.0275975.

Rozptyl Boots = 8.85141e-006.

******************************.

Appendix 5: D-yarn program Output; analysis of diameter distribution as a bi-modal distribution and its interpretation as two diameters for the 1000%CO Slub Yarn, Carded Ring Spun at 20 Tex:

Basic diameter .

******************************.

mean = 0.254878.

standard deviation = 0.0775404.

******************************.

Nonparametric two modes .

******************************.

mode 1 = 0.183653.

mode 2 = 0.178403.

optimal bin = 0.0012921.

******************************.

Correlation Coefficient R^2

0.9913

Two Gaussians .

******************************.

mean 1 = 0.206452.

mean 2 = 0.338977.

st dev 1 = 0.0295889.

st dev 2 = 0.0575867.

portion 1 = 0.648218.

portion 2 = 0.345098.

bimodal separation = 0.760107.

Appendix 5 Continued….

T test of means .

*******************************.

T1 statistics = 206.47.

T2 statistics = 173.431.

Critical value = 1.96009.

*******************************.

L ratio test of fits .

*******************************.

Lratio statistics = 7481.07.

Critical value chi2, d.f.4 = 9.48773.

*******************************.

Bootstrap pivot data

95 proc.Konf. interval -0.338975. -0.390881.

Prumer Bootst = -0.364869.

Rozptyl Boots = 0.000174477.

Bootstrap pivot rectangular

95 proc.Konf. interval -0.0247451. -0.0438421.

Prumer Bootst = -0.0341554.

Rozptyl Boots = 2.78851e-005.

*******************************.

Appendix 6: D-yarn program Output; analysis of diameter distribution as a bi-modal distribution and its interpretation as two diameters for the 50%CO/50%VS Slub Yarn, Carded Ring Spun at 20 Tex:

Basic diameter .

******************************.

mean = 0.245204.

standard deviation = 0.0681321.

******************************.

Nonparametric two modes .

******************************.

mode 1 = 0.177387.

mode 2 = 0.18336.

optimal bin = 0.00113533.

******************************.

Correlation Coefficient R^2

0.9878

Two Gaussians .

******************************.

mean 1 = 0.199944.

mean 2 = 0.305858.

st dev 1 = 0.0230681.

st dev 2 = 0.0601913.

portion 1 = 0.588167.

portion 2 = 0.409282.

bimodal separation = 0.636045.

Appendix 6 Continued …..

T test of means .

******************************.

T1 statistics = 166.689.

T2 statistics = 146.091.

Critical value = 1.96009.

******************************.

L ratio test of fits .

******************************.

Lratio statistics = 8216.71.

Critical value chi2, d.f.4 = 9.48773.

******************************.

Bootstrap pivot data

95 proc.Konf. interval -0.338485. -0.390314.

Prumer Bootst = -0.364507.

Rozptyl Boots = 0.000174506.

Bootstrap pivot rectangular

95 proc.Konf. interval -0.0247451. -0.0438421.

Prumer Bootst = -0.0341554.

Rozptyl Boots = 2.78851e-005.

******************************.