RMUTP International Conference: Textiles & Fashion 2012
July 3-4, 2012, Bangkok Thailand

CHARACTERIZATION OF YARN DIAMETER MEASURED ON DIFFERENT

S. Ibrahim, J. Militky , D. Kremenakova[1] and R.Mishra[1]

[1]Technical University of Liberec, Faculty of Textile Engineering, Studenska 2, 46117, Liberec, Czech Republic

Abstract: Yarn diameter is an important determinant of many fabric parameters and properties e.g. cover factor, porosity, thickness, air permeability, fabric appearance,.. etc. There are many methods based on different types of sensors used for characterization of yarn unevenness. These instruments differ in the principle of measuring and the logic of evaluation of yarn irregularity. It is essential to investigate more deeply which of these methods is more reliable and to establish a relationship between the results obtained from different techniques. Uster tester 4 equipped with the optical sensor OM, Lawson Hemphill YAS system, Quick Quality management QQM3, were used in this study. Optical microscope has been also applied using cross sectional method and longitudinal method for evaluation of yarn diameter. The present investigation focuses on analysis of the data obtained from these commercial instruments as a stochastic process. It was found that a bimodal distribution can be applied to characterize the yarn diameter. The D-yarn program developed also supports this fact and deliveries much information about the characteristics of yarn diameter. Beside many other techniques, the autocorrelation function, spectrum analysis and fractal dimension was used.

Key words: Yarn irregularity, stochastic process, time series, bimodality, autocorrelation function, spectrum, fractal dimension.

1. Introduction:

Higher quality, lower cost of textile products always presents the difficult equation which has no solution. Wide adoption of quality management 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.

Principle of most used techniques

Uster evenness testers are widely used in textile industry for a long time. Uster tester 4 and 5 are a combination of capacitive type, and optical one. The OM module mounted on model, 4-SX [1,2], is capable of measuring yarn diameter with dual light beams perpendicular to each other. This design reduces shape error caused by irregular yarn cross-sections.

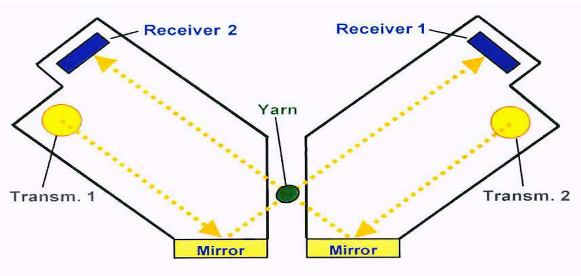


Figure 1 Principle of OM sensor of Uster 4

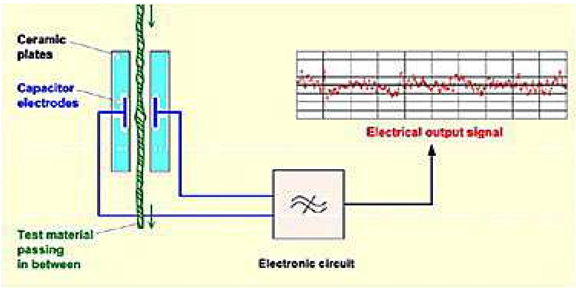


Figure 2 Principle of capacitive system of Uster 4

The irregularity of yarn is detected from the variations in electric capacitance generated by the movement of yarn specimen that passes through the gap of a fixed air condenser. On the other hand, using the photoelectric measurement, the irregularity is measured from the fluctuation of the light intensity or shadow on the sensor caused by the beam of light passing across the yarn cross-section.

Zweigle OASYS

The system operates with the principle of absolute optical measurement using infra-red light [3]. 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 uses an infrared light sensor operating with a precision of 1/100 mm over a measuring field length 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.

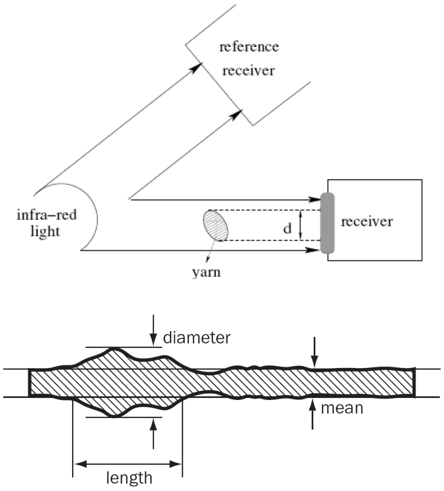


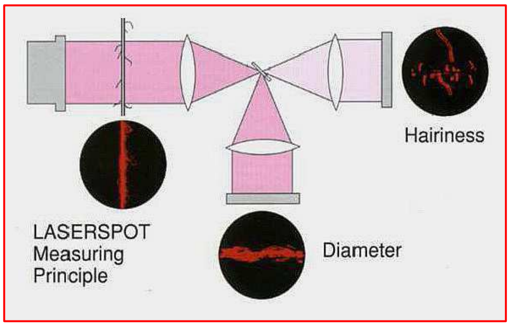
Figure 3 Principle of OASYS

Lawson-Hemphill YAS

The YAS is an important technology for measuring spun and air textured yarns. This system scans and measures diameter and diameter evenness of yarn, and automatically grades the yarn for appearance. It offers a tool for delivering yarn that gives consistent fabric appearance. Other features include hairiness testing, fabric simulation, yarn clearing simulation.

Figure 4 Laserspot principle

Keisokki KET-80 and Laserspot



Keisokki KET-80 and Laserspot LST-V [4] are wo 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 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. The Laserspot evenness and hairiness 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 at the same time.

The flying laser spot scanning system

The Flying Laser Spot Scanning System [5] 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.

QQM-3 yarn quality analyzer

QQM-3 is a portable device used for evaluation of yarn unevenness characteristics directly on OE & RS machines, provides measurements, analysis and data source for further investigation. It is a tool for identifying faults on spinning units, Provides measurement and analysis of CV% as well as imperfections and Spectrograph.

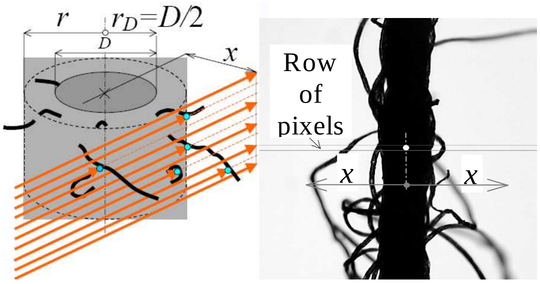


Figure 5 Assembly of QQM3 system 1- Measuring head 2- PSION work about terminal, 3- Battery charger

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.

Laboratory measuring systems:

A laboratory method was introduced by Prof. B. Neckar and Dr. D. Kremenakova from the Technical university of Liberec, where 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

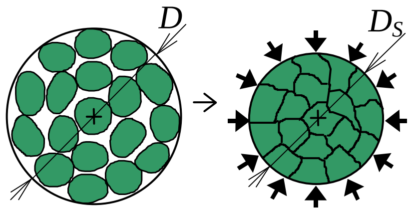


Figure 7 Maximum packing

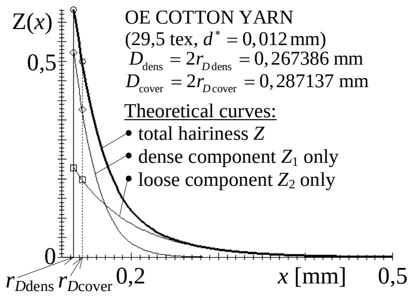


Figure 6 Principle of

pass at distance *x* without any problems, some others are "hindered" by the fibers. The longest section of black pixels 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 depending upon twist, fiber orientation and yarn fineness.

$$\frac{\left(\frac{\mu}{\mu_m}\right)^{5/2}}{\left[1-\left(\frac{\mu}{\mu_m}\right)^3\right]^3} = \frac{M[\mathrm{m}]\sqrt{\pi}}{2000\,\mu_m^{5/2}\sqrt{\rho\left[\mathrm{kgm}^{-3}\right]}} \cdot \left(Z\left[\mathrm{m}^{-1}\right]T^{1/4}[\mathrm{tex}]\right)^2$$

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. Experimental work

Twenty two different types of yarns, spun on different spinning systems were tested on Uster Evenness tester. The QQM-3 instrument was mounted directly on the Uster 4 apparatus. Thus we could get the signal from the Uster and the QQM simultaneously. Also the same yarns were tested on Lawson Hemphill instrument under constant tension transmission CTT, to measure the yarn diameter. The same yarns were measured under microscope, using a CCD camera; the images were analyzed according to the method of Neckar [6] to find the yarn diameter. The raw data from Uster tester 4 were extracted and converted to individual readings corresponding to yarn evenness, diameter and yarn hairiness.

3. Results and discussion

The raw data extracted from Uster tester 4, QQM and Lawson Hemphill instruments were adopted and converted to individual readings corresponding to yarn diameter. The data then are fed to a developed program D-YARN written in MATLAB code for analysis yarn diameter characteristics.

The program UNYARN in MATLAB is a complex system enables the analysis the data on the base of time series techniques. The program is divided into logical blocks, and can be used as standalone routines for data analysis.

Data Input

The data input block enables the entering of signal S(i) from USTER Tester in the form of external data file (ASCII and XLS format) or internal MATLAB file (.MAT format). The following types of artificial signals with prescribed properties can be simulated:

- white noise (Gaussian i.d random variables with selected value of variance and zero mean),
- autoregressive processes of first and second order corrupted by white noise,
- harmonic waves embedded in white or red noise,
- Fractional fractal processes for selected Hurst exponents with or without additive white noise.

The length of simulated series is selected to be 200 m and sampling interval is 0.01m.

Basic graphs

The mass diagrams for cut lengths 0.01, 1.5 and 10 m are presented. Thick and thin places are visualized on the special bar plots.

Basic assumption testing

These procedures for informal and more formal testing of stationarity or ergodicity, independence and linearity are available.

Structural unevenness

Two types of methods for overall characterization of unevenness are used. Basic are variance length curves for $CV_B(L)$ and $CV_N(L)$ in various variants (index plot, semi logarithmic plot). The deviation rate DR and integral deviation rate IDR are computed and graphically presented in the form of DR- mass variation curve and index plots.

Spectral and harmonic analysis

The core is computation of periodogram from autocorrelation coefficients and power spectral density estimator based on the discrete Fourier transformation (Welch method). From corresponding graphs in frequency and distance domain the major peaks (periodic sources of variability) are identified. The harmonic regression models with Fourier frequencies (linear least squares) and optimized frequencies (nonlinear least squares) are computed. The general spectral moments and central spectral moments are computed. Optionally the spectrogram plot is available.

Short-range dependences

The autoregressive models of optimal order are computed. For parameter estimation the approximate Yule Walker and more precise Levinson algorithms are used. The optimal autoregressive order is selected based on the criterion of MEP (mean error of prediction) and MDL (minimal descriptive length). The ACF graph and PACF (partial ACF) graphs are created.

Data stochastic nature

The various approaches for estimation of β and Hurst exponent are available. Logarithmic form of dependence of PSD on frequency is used for identification of persistency, stationarity and range of dependence. The range of dependence is evaluated from variogram and plenty of plots based on the aggregated data $y^{(L)}(i)$. Standard are plots of v(L) and R/S.

4. Data analysis:

The original print out from Uster tester protocol and the plot of the individual data of a 20 tex vortex yarn are given in fig. 8 a,b. It is seen clearly that both diagrams are completely identical. This means that the data is complete correctly processed.

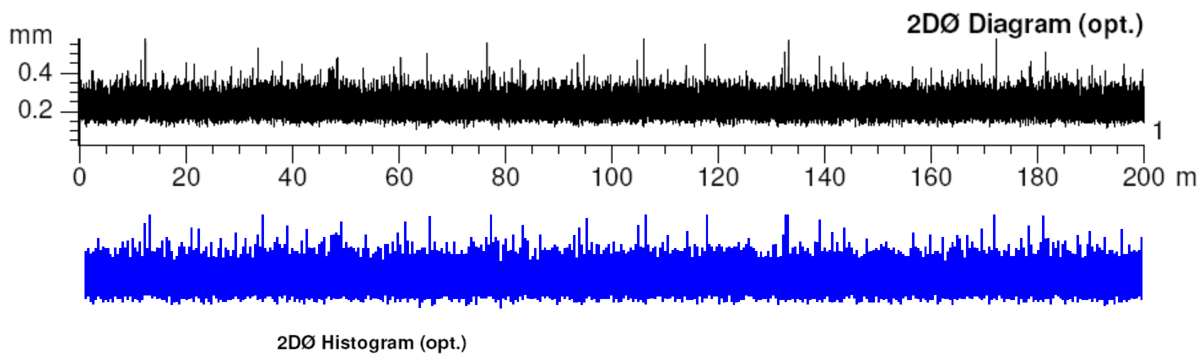


Figure 8 a & b Original diameter diagram & plot of individual data (rescaled to fit Uster) diagram)

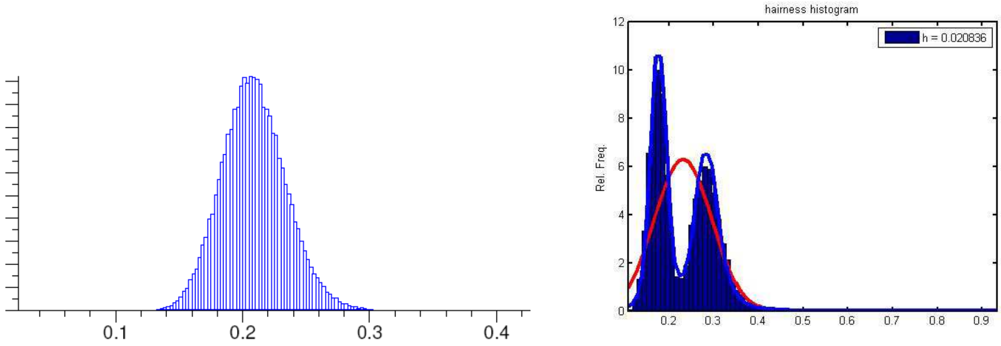


Figure 9 a & b Original histogram from Uster protocol & Plot from D-Yarn program

If we try to analyse this data by plotting the histogram, we find a great differences between the Uster original protocols and our analysis. The original Uster histogram gives a very smooth symmetrical normal distribution. In contrary to that the data is fitted to a two Gaussian distribution, and the bimodality is obvious. This leads us to go the basic rules of plotting histograms, and significant tests of bimodality.

Also the values of mean Diameter from Uster is(2Dφ=0.209), where according to normal statistical calculations, it gives 0.231453mm, which is fairly high, this is because all values have been taken in consideration. In contrast to those, Uster filters the data in some unknown way. The most near to Uster values is the median; median = 0.21123mm.

The coefficient of variation according to Uster is 10.7%, which is very low compared to our calculations, which is 27.44%. If we recognize the histogram, We cannot say that this yarn is so regular and actually has a bimodal distribution, this results in higher variation. Accordingly, from the UNYARN we can calculate the mean value of the smaller and bigger diameter, the standard deviations and the percentage (portion) of each component. The different significant tests for distinguishing the bimodality of yarn diameter are as follows:

Two Gaussians.

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

mean 1 = 0.283406.
mean 2 = 0.17703.
st dev 1 = 0.0281402.
st dev 2 = 0.0183086.
portion 1 = 0.458459.
portion 2 = 0.502085.
bimodal separation = 1.14509. Critical value << 2*0.0108=0.0216
T test of means .

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

T2 statistics = 298.366.
Critical value = 1.96009. Critical value 1.96

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

Likehood ratio test of fits .

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

Lratio statistics = 4134.68.
Critical value chi2, d.f.4 = 9.48773.

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

This means that the assumption that the diameter distribution is significant two Gaussian distributions, and the bimodality is confirmed. One important remark is, if we would like to assume that the distribution is an unimodal, and then we have to filter some values.

The QQM-3 gives the following values:
Mean diameter = 0.2214 mm, the coefficient of variation is 15.06%
The diameter is closer to Uster results, but the CV% is still higher than Uster, even when the sensor is 2mm.
The results from measurements applying image processing, and the evaluation algorithm of Neckar gives: The cover diameter =0.196 mm, and the dense diameter is 0.1802.

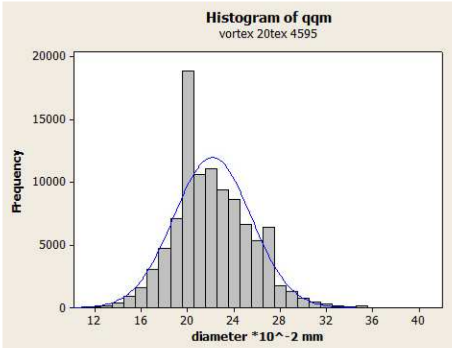


Figure 10 Histogram from

Therefore, we have developed the D-yarn program, which is a suitable system for evaluation and analysis of yarn diameter as a dynamic process, in both time and frequency domain. This also applies for the QQM data. The diameters measured by different systems are compared and plotted against the calculated diameter taking into consideration the yarn packing density. The most appropriate and accurate diameter is calculated after normalization with the Uster correction factor and using Savitzky Golay smoothing operation and setting the moving window at value 3. The figures 11 & 12 show the results.

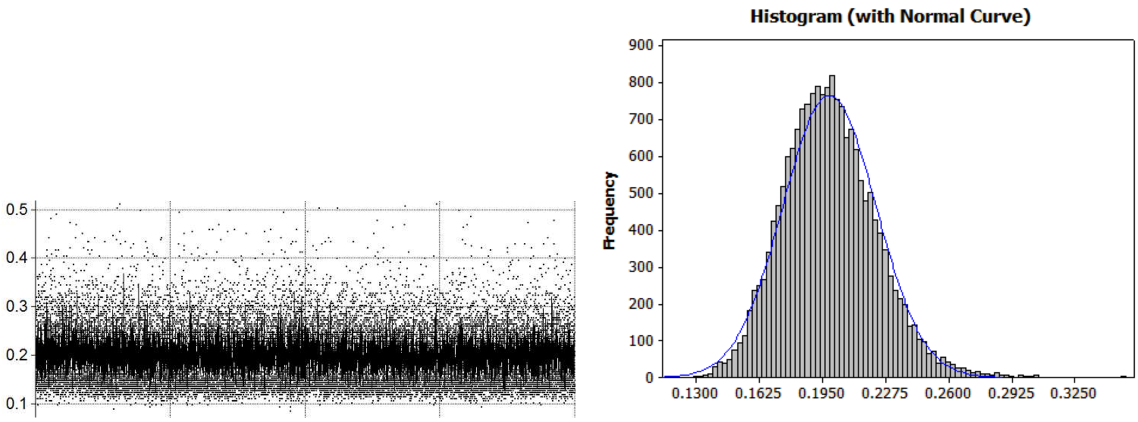


Figure 11 Savitzky Golay smoothing operation and histogram after

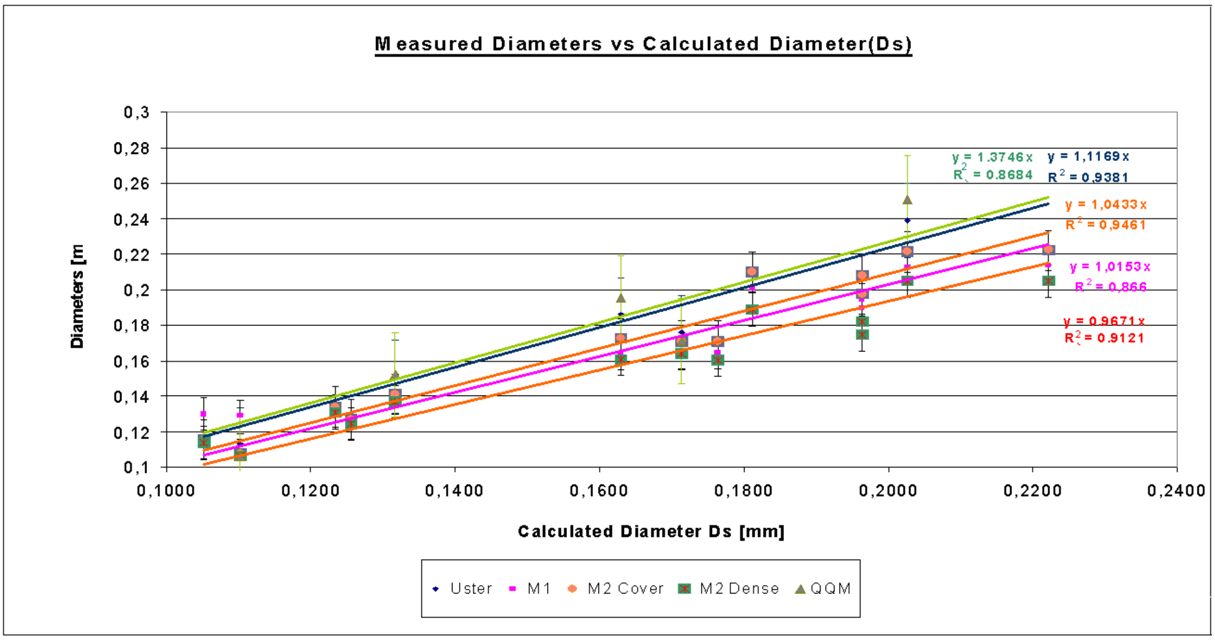


Figure 12 Diameters measured by different systems vs

The correlation matrix is shown in figure 13.

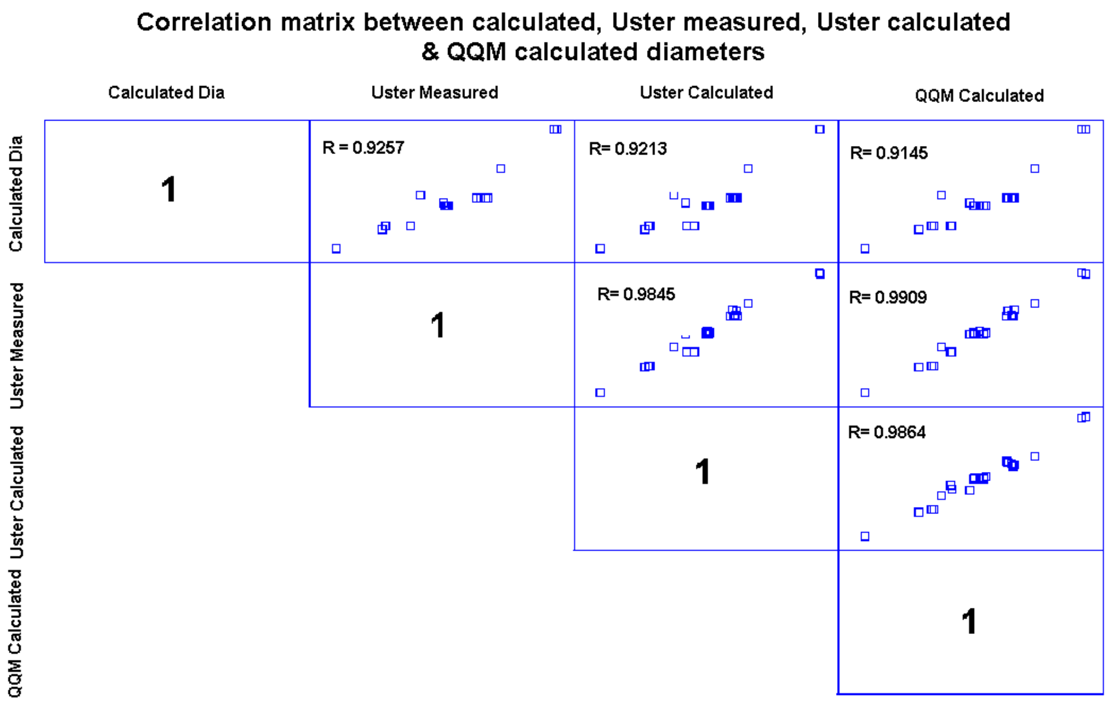


Figure 13 Correlation between different systems for diameter

5. Yarn diameter as a stochastic process

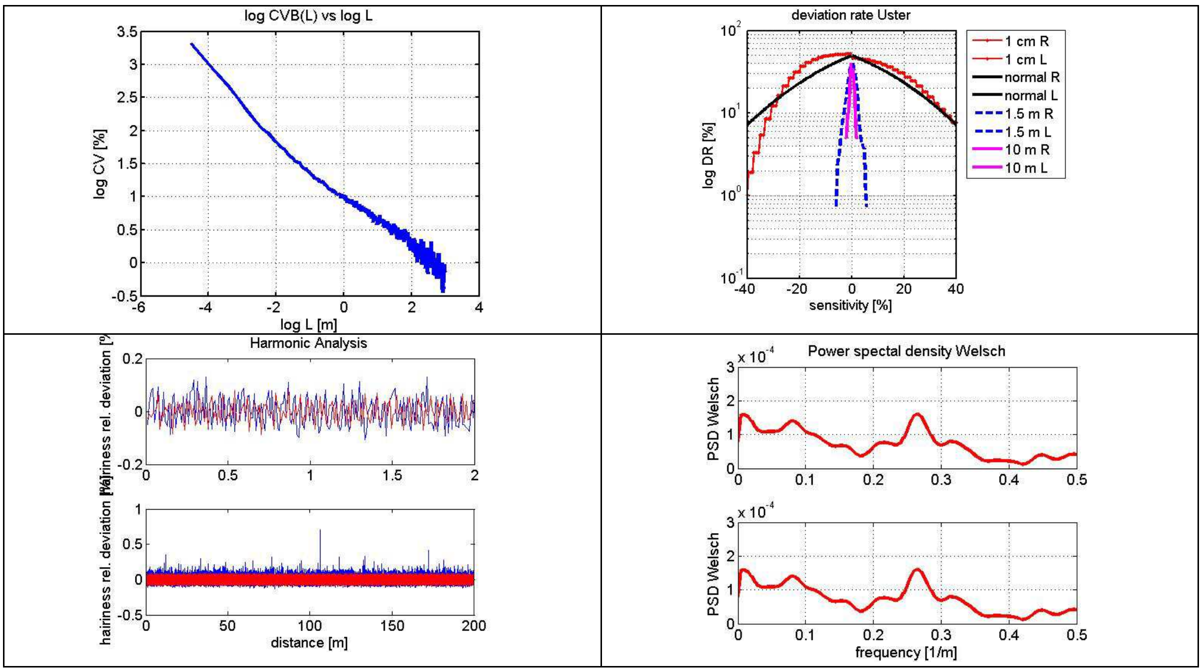
The data extracted from Uster is taken in equidistance (time interval), so that it can be used for more complex evaluation of hairiness characteristics in the time and frequency domain. The yarn hairiness can be described according to the:

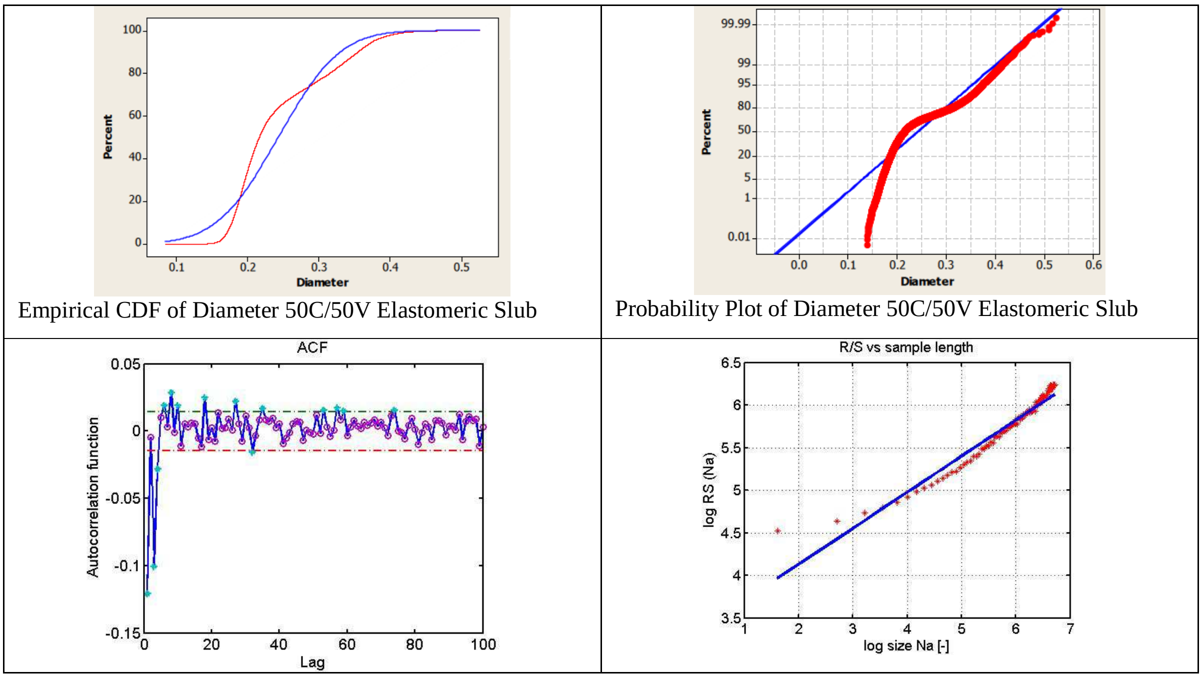
- *Periodic components*
- *Random variation*
- *Chaotic behavior*

For these goals, it is possible to use system based on the characterization of long term and short-term dependence of variance. The so-called Hurst exponent or fractal dimension can describe especially long-term dependence. Here we shall deal with a limited functions from many characteristics computed in our Un-Yarn Program. Details are found in [8].

As an example, the autocorrelation, which simply can be described as a comparison of a signal with itself as a function of time (distance) shift (lag) is illustrated in Figure (15).

Also, concerning frequency domain analysis, we demonstrate the FFT, which is also used for transforming time domain function into frequency domain and its inverse. The signal is decomposed to different sine waves. There are many types of spectrum, PSD, amplitude spectrum, and many other types. The power spectrum output from D-Yarn program is illustrated in figure (15). The cumulative of white identical distribution noise is known as Brownian motion or random walk. The Hurst exponent is a good estimator for measuring the fractal dimension. The Hurst equation is given by: $R/S= K^{*}(N)^{\wedge}H$. This can be seen in the same figure (last row). In figure 15, some sample of results are shown as length-variance curve, Deviation rate, Harmonic analysis, Power spectrum, Auto-correlation function and the Hurst exponent curve (H=0.57). A sample of the results obtained from D-yarn program is shown below.





Empirical CDF of Diameter 50C/50V Elastomeric Slub

Probability Plot of Diameter 50C/50V Elastomeric Slub

Figure 14 Sample results from D-Yarn program

Characteristics of QQM and Uster tester

Following are the printout of the data analysis for the QQM, Uster4 and CTT Lawson Hemphill. It is clear that the graphs obtained from these instruments are comparable. The individuals from these instruments has been treated at first, that the measuring distance should be the same to get fair comparison between the instruments. The uster tester measures at 10mm, whereas for QQM3 is 2 mm and for Lawson Hemphill is 0.5mm. These differences affect significantly the coefficient of the variation and all other characteristics. The data also were filtered using the Savitsky-Golay filer, to remove the noise from data. After that the data were processed using our developed program D-Yarn, which is written in Matlab code.

As it is seen from figure 15, all histograms are very similar and almost the mean diameters are comparable. T was observed that results obtained from Lawson Hemphill instrument are little bit smaller than those from the original Uster protocol, calculated from the raw data and QQM3. This is also the case for coefficient of variations.

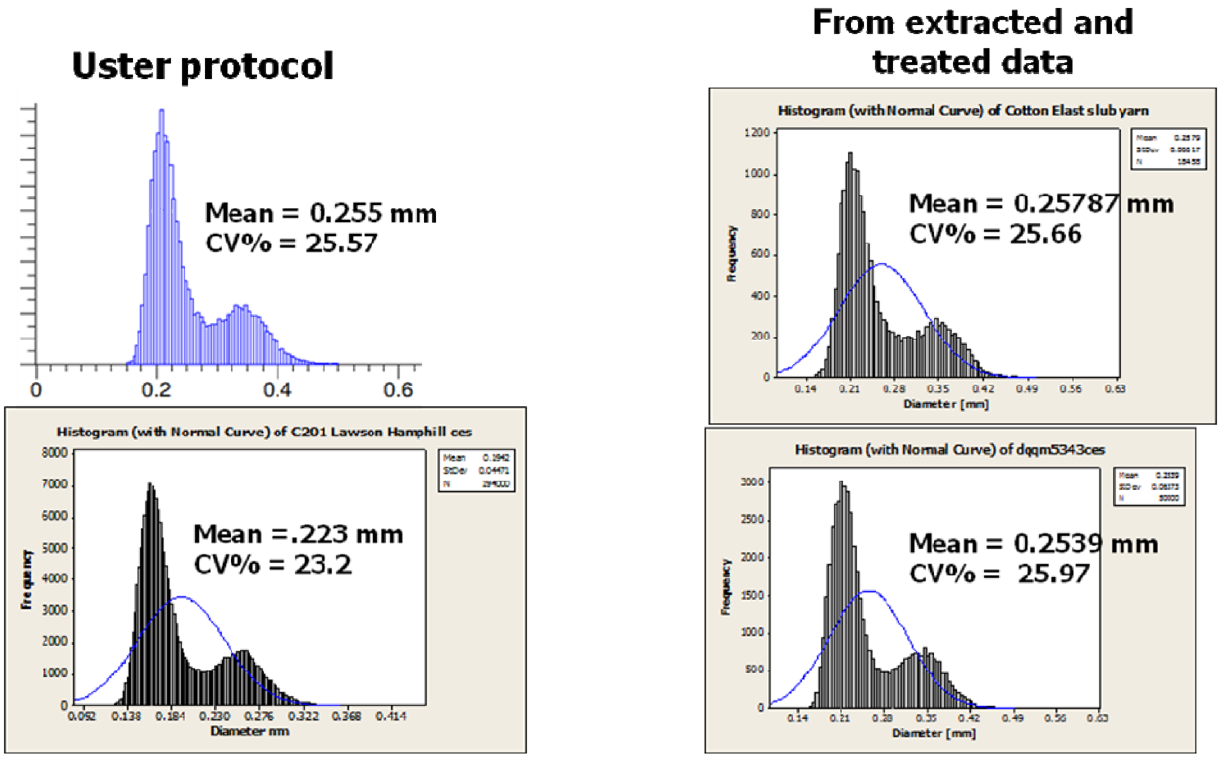


Figure 15, Histograms obtained from different instruments

SHORT RANGE DEPENDENCE

The autocorrelation structures are investigated by treatment of autocorrelation coefficients *R(h)* according to the following equation [8].

$$R(h) = \frac{\operatorname{cov}(y(0) * y(h))}{v} = \frac{c(h)}{c(0)}$$

The autocorrelation matrix associated with stationary process has the form

$$\mathbf{P} = \begin{bmatrix} 1 & R(1) & .. & R(N-1) \\ R(1) & 1 & .. & R(N-2) \\ . & . & .. & . \\ R(N-1) & R(N-2) & .. & 1 \end{bmatrix}$$

The positive definiteness of this matrix implies constraints on the values of correlation coefficients. Short range dependence can be simply modeled by autogeressive processes of *q* th order *AR(q)*

$$y(i) = \varphi_1 * y(i-1) + \varphi_2 * y(i-2) + .. + \varphi_q * y(i-q) + e_i,$$

where φ_i are autoregressive parameters and ε_i is uncorrelated white noise.

Mean value of *AR(q)* process is zero and autocorrelation function of order *h* is expressed by difference equation

$$R(h) = \varphi_1 * R(h-1) + \varphi_2 * R(h-2) + .. + \varphi_q * R(h-q)$$

For estimation of the autoregressive coefficients the Yule Walker set of linear equations has to be solved. These linear equations are result of substituting of *h=1,2,* q into eqn. (43). In the matrix notation has the Yule Walker system of equations form

$$\mathbf{R} = \mathbf{P}_q * \hat{\varphi} \quad \text{or} \quad \hat{\varphi} = \mathbf{P}_q^{-1} * \mathbf{R}$$

The matrix $\mathbf{P}_q$ is sub matrix of matrix **P** (where *N* is replaced by *q*). Vector **R** has *i-th* element *R(i)* and $\hat{\varphi}$ are estimated autoregressive coefficients.

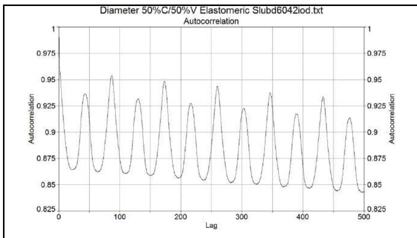
The simplest is **first order autoregressive** model *AR(1)*defined as

$$y(i) = \varphi_1 * y(i-1) + e_i$$

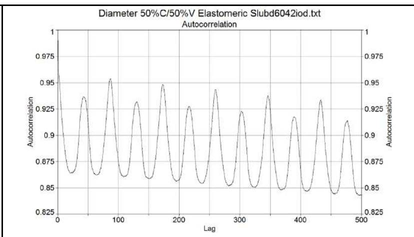
The autocorrelation function of this process is $R(h) = \varphi_1^h$ and therefore $R(1) = \varphi_1$. The autocorrelation of first order is then equal to the autoregressive coefficient of first order. The autoregressive models are special sort of regression models. The main task is to evaluate the optimal order q. For this purposes the criteria for optimal regression model selection.

Alternatively the partial correlation coefficients (PACF) $\hat{\phi}_{jj}$ can be evaluated. The standard method is successive fitting of autoregressive models of order *1, 2, 3..* and picking out the estimates of the last autoregressive coefficients $\hat{\phi}_{11}, \hat{\phi}_{22}, \ldots$

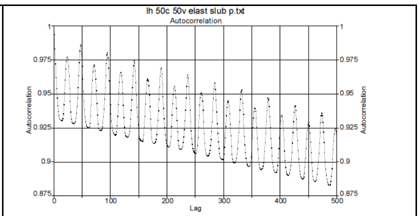
The following graphs show the autocorrelation function, it is also clear that the data obtained from different instruments have the same behaviour.



Autocorrelation from Uster data



Autocorrelation from QQM3



Autocorrelation from Lawson Hemphill

It clearly seen that the behavior of auto correlation function are similar, This supports the idea that by using a suatable evaluation system, results could be compared.

CHAOS DYNAMICS

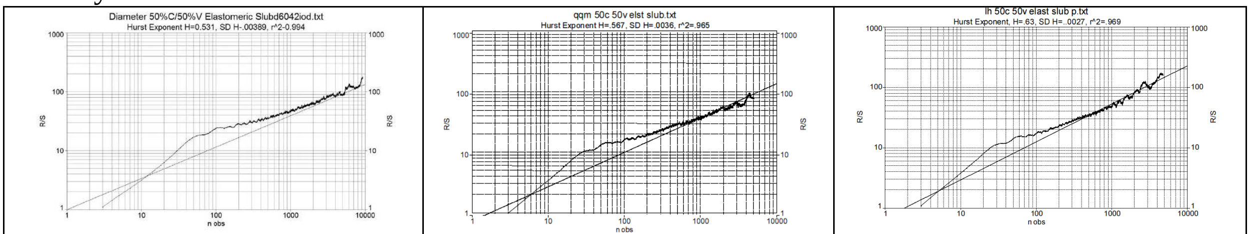
In the process of constructing a well-behaved phase space an important question is how to choose the delay *(τ)* and the embedding dimension *(D).* Usually, the procedure of determining the embedding dimension *D* is to increase *D* and to estimate the fractal dimension or the largest Lyapunov exponent for every embedding dimension until the fractal dimension or the largest Lyapunov exponent remains almost constant. The delay, τ is often chosen from the autocorrelation function of the original time series as the delay τ at which the autocorrelation function attains the value of 1/e. A justification for the above procedure in the deterministic case is given by Takens theorem [9]. According of this theorem is $D \geq 2A + 1$ where *A* is the attractor dimension. In practice, *A* is unknown. An estimate of the attractor dimension, *A*, may be obtained from the correlation dimension.

The various approaches for estimation of β and **Hurst exponent** are available. Logarithmic form of dependence of PSD on frequency is used for identification of persistency, stationarity and range of dependence. The range of dependence is evaluated from variogram and plenty of plots based on the aggregated data $y^{(L)}(i)$. Standard are plots of $v^{(L)}$ and *R/S.*

Chaotic behavior

The correlation integral and correlation dimension are computed and presented in graphical form.

The Hurst exponent shows very similar behavior for Uster and QQM, the Lawson Hemphill shows some haw difference, this is because, the nature of measurement is different than that of both systems.



From Uster data | **From QQM3** | **From Lawson Hemphill**

Figure 17 Hurst Exponent plots

7. Conclusions

- Yarn diameter is an important determinant of many fabric parameters and properties e.g. cover factor, porosity, thickness, air permeability etc. There are many established techniques and instruments to measure and analyze yarn irregularity, diameter and variability. These are all based on different principles governing the measurement methods and using different types of sensors. The evaluation of data is also different. They are accurate in performing the function efficiently in their own domain. However, there are a lot of algorithms for evaluation of yarn diameter. It is essential to investigate more deeply which of these methods is more reliable and to establish a relationship between the results obtained from different techniques.
- It is observed that, there is very good correlation between the diameters measured from Uster, QQM and by Image analysis with the theoretical diameter calculated taking into consideration the yarn packing density. There has to be a suitable filtering operation for the raw data of Uster and QQM to find out the most accurate diameter. Lawson Hemphill gives relatively smaller diameter than Uste instrument.
- The D-yarn system is a powerful program for evaluation and analysis of yarn Diameter as a dynamic process, in both time and frequency domain.
- D-yarn program is capable of estimating the complexity of this process.

8. Acknowledgements:

This work was supported by project of National Research Centre II No. 1M0553.

References

[1] I. S. Tsai and W. C. Chu. The measurement of yarn diameter and the effect of shape error factor (sef) on the measurement of yarn evenness. Journal of the Textile Institute, 87(3):496-508, 1996.

[2] Uster Technologies AG, Switzerland. Uster Tester 4-SX, 2004.

[3] B. P. Saville. Physical Testing of Textiles. Woodhead Publishing Ltd., Cambridge/England, 1st. edition, 1999.

[4] Keissokki Kogo Co. Ltd., Japan. Keisokki Laserspot Hairiness Diameter Tester and KET-80 Evenness Tester, 2004.

[5] You Huh and Moon W. Suh. Measuring thickness variations in fiber bundles with flaying laser spot scanning method. Textile Research Journal, 73: 767{773, 2003.

[6] Jana Voborova, Bohuslav Neckar, Sayed Ibrahim and Ashish Garg . Yarn properties measurements: an optical approach, the 5th international Engineering Conference of Mansoura University, Egypt, 2003.

[7] Meloun M., Militky J. and Forina M.: "Chemometrics for Analytic Chemistry vol.I and II, Statistical models building", Ellis Horwood, Chichester, (1992 and 1994).

[8] Militky J. and Ibrahim S.: “Yarn Hairiness Complex Characterization”, Proc. Annual Fiber Soc. Conf., St Galen, May 2005.

[9] Parzen E.: Statistical methods mining and non parametric quantile domain data analysis, Proc Ninth int. conf. on quantitative methods for environmental science, July 1988, Melbourne