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Characterizing Yarn Thickness Variation by Correlograms

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Abstract: The surface evenness and texture are closely related with the irregularity of yarn thickness. Besides, yarn thickness variation has an important role to influence the yarn performance and the textile process efficiency. Thus, the information not only on the yarn thickness, but also on the short- term irregular characteristics that have not been known before is required for enhancing the qualities of textile products. This paper reports the results of a study about the yarn thickness and its variation for various types of yarn on the basis of a new measurement system applying a laser slit beam as a light source. The new method delivers effective information on the irregularity. The analysis of the measured signal confirms that the visual shade created by the yarn doubling and twisting can be measured and the yarn thickness characteristics can be represented by correlograms. Depending on yarn types, correlograms have different shapes and can be approximated to an exponentially decaying function with or without fluctuating magnitude. In addition, the effective information on the yarn irregularity can be influenced by the sampling length interval of the measuring device used for tests.

Keywords: Yarn thickness, Laser slit beam, Correlogram, Short-term irregularity, Sampling length interval

Introduction

Yarn thickness is an important physical property influencing the efficiency of the consecutive processes and thus the mid-product quality. In addition the yarn thickness flaw comes out repeatedly accentuated in the visual surface texture of textile end product, which determines the quality of the textile on which customers decide whether to buy it or not. If mechanical properties of a textile product are so far in a level required as a quality product, which is the point most engineers have been concerning, the final decision for buying it in a market is even rather being made from the subjective point of view and on the basis of human senses, i.e., by color, pattern, texture, good looking, etc.. The surface texture of textiles is a factor defining the apparent quality. And that is closely related with the evenness of the constituent yarn thickness. Yarn irregularity is an eternal research theme for textile engineers not just from the point of view of process efficiency, but nowadays from the apparent quality of the product in markets as well. There have been many researches on yarn thickness and irregularity since long, especially to explain the causes and parameters affecting the yarn quality on a roll draft system. Since Balls suggested the existence of irregularity of sliver or yarn resulting from the drafting operation in 1928 for the first time, and called it "draft wave" [1], many prominent textile scholars as Martindale, Grishin, Rao, Grosberg, Backer, etc., performed their researches [2-6], mainly focusing on finding out the causes of the irregularity of yarn, analyzing the irregularity, developing new measuring methods and their assessment for yarn irregularity. But all these researches were targeted on improving the mechanical properties of yarn and the efficiency of the manufacturing processes. Therefore irregularity range was limited to about mid-term or long-term, namely, the wavelength longer than 15 mm.

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In general, there are two ways to represent the yarn thickness; i.e., in terms of the mass per unit length and the diameter of yarn cross-section. The mass per unit length (linear density) is closely related with the mechanical properties of yarn, while the diameter of yarn cross-section with the apparent quality of the products [7,8]. Among many methods for measuring the yarn thickness the capacitive method and the optical one could be technologically established and supplied in market. The capacitive method measures the yarn linear density. The optical method determines the diameter of the yarn cross-section. As well known, the capacitive type dominates the market because it outputs the results relating to the mechanical properties that play important roles for process efficiency. But from the point of view of apparent textile quality the optical method outweighs the capacitive one, because the yarn diameter and short wavelength of yarn diameter variation are more closely related with the apparent textile quality than the linear density of yarn is.

In this research we want to go further to the shorter wavelength range that seems to influence the apparent quality of yarn, which was difficult to realize earlier, but now looks possible to measure since the sensor technology has been so far developed. We try to obtain some basic information on the apparent thickness irregularity, especially in the range of the short-term wavelength that almost has been unknown but seems to play an important role to the visual textile quality. For reaching our research purpose we developed a new measuring system that operates on a laser slit beam. Three types of specimens including a single yarn, a two-plied yarn, and a three-plied yarn were applied to show the extent to which this method can measure the irregularity and to represent the short-term characteristics of yarn irregularity that depend of the yarn types.

Correlogram

Internal characteristics of a stochastic signal can be represented by means of the autocorrelation function that describes the correlation of the signal values at two points, positioning by a certain distance. Autocorrelation function $R_{XX}(\tau)$ of a stationary stochastic signal $X(t)$ can be given as an expected value of $X(t+\tau)X(t)$:

$$R_{XX}(\tau) = E[X(t+\tau)X(t)] = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x_1(t+\tau)x_2(t)f_{XX}(x_1, x_2; \tau)dx_1 dx_2 \quad (1)$$

The ergodic hypothesis let equation 1 transform into

$$R_{XX}(\tau) = \lim_{T \to \infty} \frac{1}{T}\int_0^T x(t+\tau)x(t)dt \quad (2)$$

Then, equation (5) in discrete form yields

$$R_{XX}(k) = \frac{1}{n}\sum_{j=1}^{n} x(j+k)x(j) \quad (3)$$

where $R_{XX}(k)$ denotes the autocorrelation function at $\tau = kT_s$, T_s means the sampling interval, and k takes integer values.

Eventually, correlogram $C(l)$ is defined as the autocovariance function of yarn thickness in length domain. Therefore, if we take the argument of the yarn thickness signal in terms of length, as $X(l)$ and can assume the yarn thickness as a stationary stochastic process, then the thickness correlogram of a yarn specimen that is running into the scanning zone with the speed v_f can be represented as

$$C(l) = R_{XX}(l) - X_{avg}^2 \quad (4)$$

where $X_{avg} = E[X(l)]$,

or in discrete form like

$$C(j) = R_{XX}(j) - \bar{X}^2 \quad (5)$$

while $\bar{X}$ stands for the mean value of $x(k)$ for $k = 1, 2, 3, \ldots n$, $C(j)$ for the correlogram at $l = jl_s$, and l_s denotes the sampling length interval $v_f T_s$.

Measuring System

A new system to measure the apparent thickness of yarn works on the basis of a laser slit beam, which is different from what have been published earlier [9,10]. The laser slit beam generating system employs a visible semiconductor laser of 670 nm in wavelength for its light source. The incident laser slit beam into the measuring area has the triggering rate of 1200 scans per second. For measuring the thickness a specimen is placed between the transmitter and the receiver as shown in Figure 1. Then, the laser beam creates a shadow, the size of which is proportional to the yarn diameter. The sensor consists of a CCD array that collects the width of the specimen shadow through an optical lens and outputs a signal.

Yarn feeding unit consists of a roller pair driven by a servomotor, a yarn guide which guides the specimen to the measuring zone where the laser slit beam is shot, and a frictional tension controller to stabilize the yarn tension.

A personal computer monitors and controls the total measuring procedure by using appropriate software programs, transferring

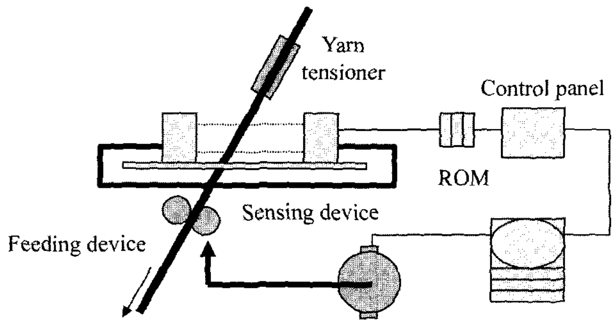

Figure 1. Schematic diagram of measuring system using a laser beam.

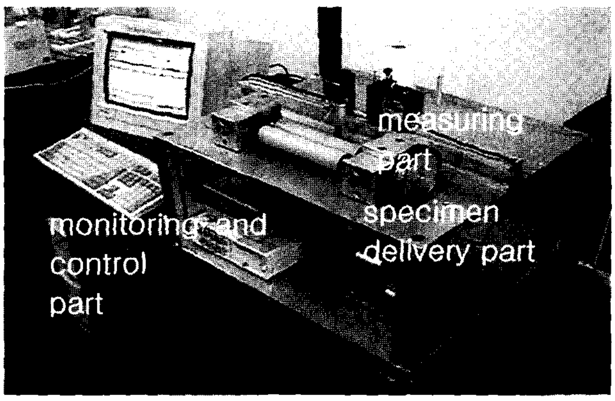

Figure 2. Photograph of yarn thickness measuring system.

Table 1. Specifications of measuring system components

Effective beam size	0.16 mm	Interface	RS-232 C
Light source	Red semiconductor laser (670 nm), 0.8 mW max., Class II	Output response time (max.)	2.5 msec.
Measuring accuracy	30 μm	Laser scan rate	1,200 scans/sec.

and processing the measured signal, and analyzing the data. Figure 1 shows the configuration of the total measuring system schematically. The system realized in this study is given in Figure 2. Specifications of the elements used for the measuring system are listed in Table 1.

Experiments

The factors causing human eyes to have different visual sensitivity to the yarn surface are the number of twists and the configuration of the cross-section. Thus, we selected three different types of yarn as specimen, i.e., a single cotton yarn, a two-plied rayon filament yarn, and a three-plied cotton yarn that show distinctly different visual effects of yarn thickness irregularity as given in Figure 3. The single yarn shows a more or less irregular surface distance between the neighboring yarns, and a harsh surface feeling with relatively many extruding fibers. But, the two-plied yarn shows alternating shade of dark and bright parts, which results from the rather a ribbon like yarn cross-sectional shape that makes the twist effect out. The irregular shape of the lateral surface of the two-plied yarn due to the twist becomes more noticeable than the other kinds of yarn. The three-plied yarn has a triangular configuration of yarn cross-section. Thus, the twist effects reduce visually. The specifications for the specimens and the experimental conditions are given in Table 2.

For a new measuring system it is important that the results can lead to a general statement about the measured object. Thus, the factors that can influence the measuring results have to be checked out. There are many factors that can affect the output signal of the measured yarn thickness. The specimen feeding speed is one of the factors on which the measuring results can depend. Given the data sampling time interval in the experiment constant, the sampling length interval is dependent on the specimen speed. In this research, the feeding speed of yarn is selected ranging from 0.11 m/min to 2.39 m/min to find out the feeding speed effect on the results. Being already mentioning about the effect of the speed on the measurement results, the new measuring device itself showed a very good linearity, which could be confirmed in the calibration procedure.

Results and Discussion

Figure 4 shows a typical raw signal obtained during the experiment.

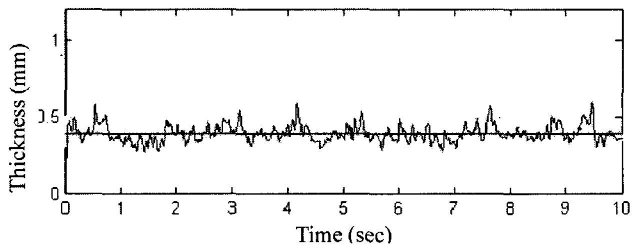

Figure 4. Measured signal of yarn thickness by means of a laser slit beam (x axis: measuring time in second, y axis: yarn thickness in mm, yarn speed : 1.19 m/min).

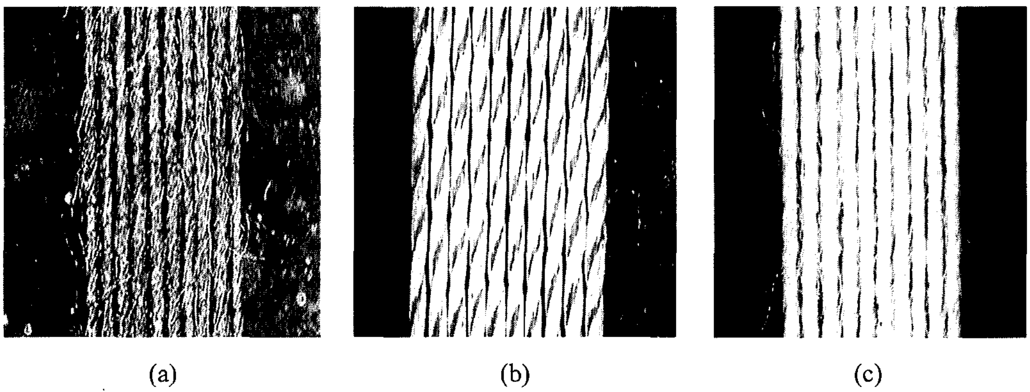

Figure 3. Visual susceptivity of yarn specimens: (a) single yarn, (b) two-plied yarn, (c) three-plied yarn.

Table 2. Specifications for the specimens used and the experimental conditions

Material	Single yarn : cotton Two-plied yarn : rayon Three-plied yarn : cotton	Twists/meter	Single yarn : 472 Two-plied yarn : 318 Three-plied yarn : 700
Fineness of the specimen (tex)	Single yarn : 42.41 Two-plied yarn : 173.21 Three-plied yarn : 60.6	Thickness irregularity CV(%)	Single yarn : 22.38 Two-plied yarn : 12.35 Three-plied yarn : 17.62
Sampling time interval (msec)	5	Yarn feeding speed (m/min)	0.11, 0.23, 0.54, 1.19, 2.39

Table 3. Standard deviation and mean of yarn diameter by experimental results

Feeding speed (m/min)	Single yarn	two-plied yarn	three-plied yarn
	diameter, SD/mean (mm), CV(%)	diameter, SD/mean (mm), CV(%)	diameter, SD/mean (mm), CV(%)
0.11	0.077/0.34, 22.6	0.061/0.68, 9.0	0.073/0.43, 17.0
0.23	0.078/0.37, 21.1	0.072/0.56, 12.9	0.073/0.43, 17.0
0.54	0.078/0.38, 20.5	0.082/0.56, 14.6	0.077/0.40, 19.3
1.19	0.087/0.39, 22.3	0.078/0.66, 11.8	0.080/0.45, 17.8
2.39	0.088/0.38, 23.2	0.092/0.57, 16.1	0.074/0.43, 17.2

SD: standard deviation, CV: coefficient of variation.

As Figure 4 shows, the measured signal consists of two parts; an effective signal part and a signal variation part with a relatively high frequency. But, an appropriate filter could eliminate the latter part of the measured signal and let only the effective signal remain.

Then, the mean and variance of the yarn diameter are calculated from the data. Table 3 shows the experimental results for various yarn feeding speeds. The measuring signal delivered almost invariant values of apparent yarn thickness and its variance independent to the yarn feeding speed. A slight difference of the results, even not significant, according to the yarn feeding speed is given in the case of 2-plied yarn, which, however, shows no tendency of the yarn diameter to depending on the yarn speed.

The characteristics of yarn thickness irregularity can be quantified in several ways, mostly by the coefficient of variation. But more detailed information on variation can be given by representing the irregular components in the form of correlation function with length argument, so called "correlogram". Figure 5 shows the diagrams representing the measured data from the specimens and their corresponding correlograms.

As seen from the Figure 5 above, the correlograms of the single yarn and the three-plied yarn have almost the same type of function, but the two-plied yarn shows a different correlogram function. The two types of correlogram can be described mathematically in a form as

$$R(l) = Ae^{\alpha l}(1 - B\sin\lambda l)$$

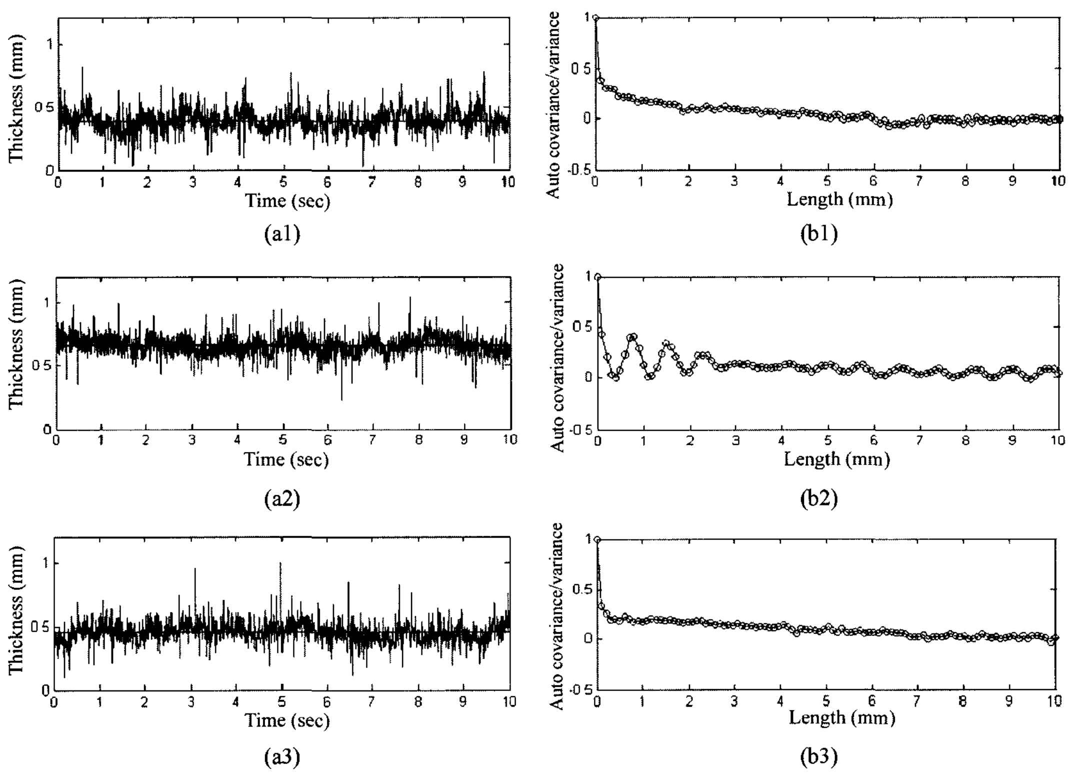

Figure 5. Measured signals for different types of yarns and their correlograms. (a1, a2, a3: diagrams of apparent thickness for single, two-plied, and three-plied yarn respectively, b1, b2, b3 : correlograms for single, two-plied, and three-plied yarn respectively, yarn feeding speed: 1.19 m/min).

Table 4. Parameters denoting correlograms for various types of yarn

Specimen	A	B	α	λ
Single yarn	0.0076	0	−7.2116	
Two-plied yarn	0.0068	0.8362	−1.2571	4.503
Three-plied yarn	0.0062	0	−7.514	

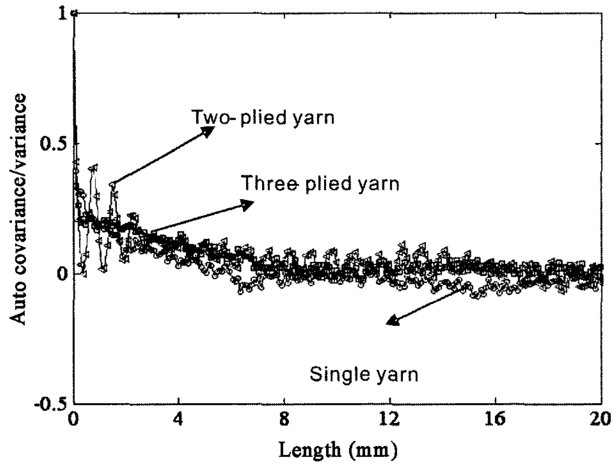

Figure 6. Correlograms for three different types of yarn.

where $R(l)$ denotes the correlogram function, A, B, α, and λ are parameters, depending on the yarn specifications. In fact A and B are the parameters representing the standard deviation of the yarn thickness, while α and λ the parameters, representing the characteristics of the irregularity of yarn. The values of the parameters obtained from the experiments are given in Table 4.

From the experimental results for the three kinds of yarn, the correlograms show that, for the single and three-plied yarn, the thickness correlation between the two points, positioning more distant than 0.5 mm, becomes rapidly low (Figure 6), while the two-plied yarn has still a relatively high correlation of thickness and shows a unique wave form in the amplitude reduction as the distance increases. The wavelength of the alternating thickness correlation corresponds to the half of the plying twist length. This result reveals that the new measuring device can detect very short thickness variation, e.g., up to the level of irregularity caused by doubling and twisting.

From the monotone decreasing thickness correlation in Figure 6, we can interpret this result as the attribute of the apparent irregularities of the single and three-plied yarns, i.e., the randomness with which the yarn cross-section changes irregularly takes place, just when the longitudinal points must be located at least more distantly than 0.5 mm. Thus, the neighboring points located more than 0.5 mm away each other can be supposed to have a significant freedom that the thickness can change, which means that a sampling length interval for measuring the yarn thickness should be greater that 0.5 mm, if the measurement results can be meaningful to providing the effective information on thickness variation. But, for the two-plied yarn, the sampling length interval for a random thickness change must be much longer than for the single yarn or three-plied yarn. Considering the decaying oscillation characteristics of the two-plied yarn, the correlation value of 0.25 which the points mutually distant by 0.5 mm can have for the single or three-plied yarn is given at least 6 mm or longer for the two plied yarn.

As a whole, the irregularity characteristics of yarn can be characterized by the correlograms that show different shapes according to the types of yarn, which suggests that the effective information on the yarn irregularity depends on the sampling length interval that should be adjusted to the yarn type and determined at least longer than that length where the rapid decrease of the correlogram begins to let up, e.g., 0.5 mm for the single or three plied yarn, 6 mm for the two-plied yarn.

Conclusions

Apparent thickness of yarn determines the visual quality of yarn and its products. However, the information on the apparent thickness is hardly to obtain when the conventional measuring method is applied. In this research we tried to apply a new measuring system to get the information on the characteristics of yarn irregularity that was lacking in the conventional methods. Results of the study show that the new measuring method allows to getting irregularity information up to the wavelength corresponding to the twist. The short-term irregularity can be characterized in terms of the correlogram. The irregularity of single yarn and the three-plied yarn can be described by a correlogram with an exponentially decaying magnitude, but the two-plied yarn has an exponential decaying correlogram with a periodically fluctuating magnitude. The single and three-plied yarn has a random cross-section change, as long as the longitudinal points are located at least more distantly than 0.5 mm.

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