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Yarn Evenness Parameters Evaluation: A New Approach

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Abstract This paper presents MPS1 (Mass Parameterization System), an automatic system for determination of mass characteristics of textile yarn. It is based on 1 mm parallel capacitive sensors, working online or offline. This new approach allows direct measurement of yarn mass in the 1 mm range (increasing the resolution by eight times) [Pinto, J. G., Dissertação de Mestrado, Minho University, 2004; Baxter, L. Capacitive sensors: design and applications, IEEE Press, 1997]. Acquisition and data processing are performed in Labview^{TM} from National Instruments. All parameters commonly used in the textile industry are determined for different values of sensitivity defined interactively by the operator. In MPS1, the new parameters were used (integral of deviation rate [IDR%], signal processing techniques based on the fast Walsh–Hadamard Transform and on fast impulse frequency determination [FDFI]) and others adapted (deviation rate [DR%], spectograms, frequency and mass variation diagrams, coefficient of variation [CV%], mean deviation [U%], faults counting and extension). A new feature of this system is also the online automatic quality classification of mass parameters.

Key words yarn evenness, signal processing, capacitive sensors

Yarn evenness, defined as the variation of mass per unit length, can affect several properties of textile materials, especially, the final appearance of the woven/knitted fabric. This problem is particularly important when it appears at regular intervals along the yarn length, causing imperfections in the final product. For its detection, commercial equipments use capacitive sensors in the 8 mm range or optical 2 mm sensors together with a signal processing technique. In this newly developed system (MPS1), a 1 mm capacitive sensor is used with several signal-processing techniques that are adequate to identify the type of faults: fast Fourier transform (FFT), for determination of faults with sinusoidal characteristics; fast Walsh–Hadamard transform (FWHT), for determination of faults with rectangular characteristics; and fast impulse frequency determination (FDFI), for determination of pulse faults. Therefore, yarn evenness is one important characteristic that is used to quantify the quality of the final product. High-quality yarn requires an arrangement of fibers in which the number of fibers in each transverse section (longitudinal variation) is approximately the same. For its detection, the yarn production process needs to be appropriately controlled. Consequently, the MPS1 system enables the online control of production, according to quality requisites predefined by the operator (Figure 1).

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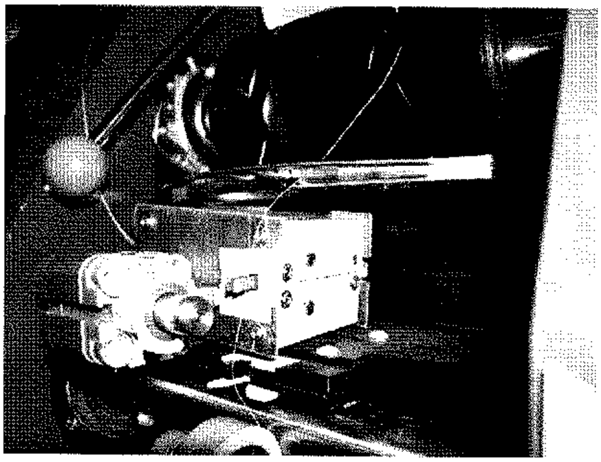

Figure 1 Online system insertion.

New Textile Parameters

Some of the most important parameters used in the specification of yarn quality are: linear density (linear mass), structural characteristics and composition of fibers [1–4]. In addition to the mean deviation (*U%*), the coefficient of variation (*CV%*), the fault classification and frequency diagrams (8 mm), determined in commercial systems, MPS1 provides new parameter information, namely the deviation rate (*DR%*), its integral (*IDR%*) [5], and mass–frequency diagrams (1 mm range), which are described below.

Deviation Rate

The parameter *DR%* indicates the yarn length that is out of limits around the mean value of mass. For the calculation of this parameter a function $p(n)$ is defined, which takes the value '1' if the sample is outside limits (α) and '0' if not. Mathematically it is defined by equation (1).

$$p(n) = \begin{cases} 1 & \text{if } f(x) \geq \bar{x} + \alpha \\ 0 & \text{if } \bar{x} + \alpha < f(x) < \bar{x} + \alpha \\ 1 & \text{if } f(x) \leq \bar{x} - \alpha \end{cases} \qquad (1)$$

Samples that exceed the mass limits established are summed and divided by the total number of samples (N), obtaining the deviation rate for a certain limit.

The deviation rate (*DR%*), as a function of α is given by equation (2).

$$DR_\alpha(\%) = \frac{\sum_{i=0}^{N-1} p(n)}{N} \times 100 \qquad (2)$$

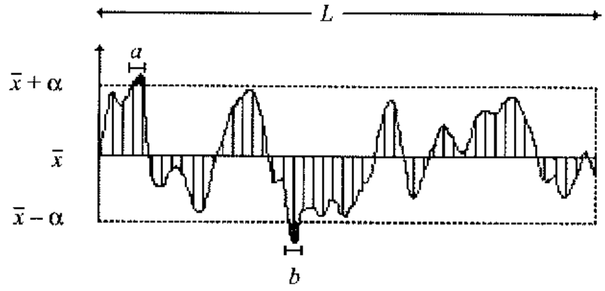

Figure 2 Graphical representation of DR%.

To determine the sample length in accordance with the deviation calculated (equation (3)) (length of yarn that is under that pattern), the deviation rate is multiplied by the sample length (L_{sample}).

$$L_{DR_\alpha} = DR_\alpha L_{\text{sample}} \qquad (3)$$

The parameter ($DR_\alpha\%$), is represented in Figure 2. In this example, samples *a* and *b*, exceed the defined threshold (sample *a* by excess and sample *b* by shortage). As there are two samples outside the limits, the deviation rate per length of sample is ($2\ L_{\text{sample}}/N$) × 100%, where N is the number of samples acquired.

Deviation Rate Integral

The deviation rate integral (IDR%) shows the yarn mass that is not contained within established limits around the mass mean value. This parameter is calculated using function, $y(n)$, presented in equation (4).

$$y(n) = \begin{cases} |f(x) - (\bar{x} + \alpha)| & \text{if } f(x) \geq \bar{x} + \alpha \\ 0 & \text{if } \bar{x} - \alpha < f(x) < \bar{x} + \alpha \\ |f(x) - (\bar{x} - \alpha)| & \text{if } f(x) \leq \bar{x} - \alpha \end{cases} \qquad (4)$$

The *IDR%* gives information relatively to yarn quality for different sensitivities, defined as a function of α (see equation (5)).

$$IDR_\alpha(\%) = \frac{\sum_{i=0}^{N-1} y(n)}{\bar{x}N} \times 100 \qquad (5)$$

According to its definition, if α is zero, IDR_α equals *U%*. So, with IDR it is possible to quantify yarn regularity, not only for 0%, as *U%*, but for values in range zero to 100% allowing complete information on yarn evenness.

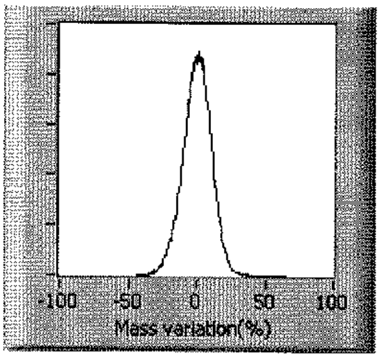

Figure 3 Example of an regular yarn frequency diagram.

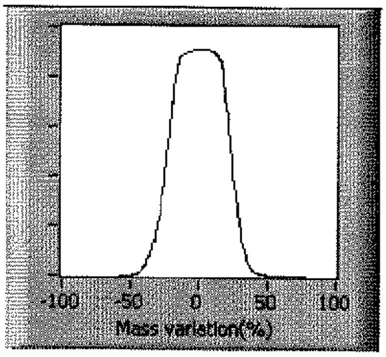

Figure 4 Example of an irregular yarn frequency diagram.

Mass–Frequency Diagrams

The mass–frequency diagram determines frequency as an interval of mass variation. Predefined mass intervals are obtained in variation intervals [*min*, *max*]% (histogram) using 1 mm samples (*min* corresponds to the minimum value of acquired mass and *max* to the maximum). As an example, a regular yarn presents a straight curve (Figure 3), centered on 0%, since a large concentration of values presents a reduced deviation relatively to null mass variation; an irregular yarn presents a more enlarged curve (Figure 4), because it will have a higher deviation of mass values in comparison with the mean value [3].

The variation of each interval of mass frequency is determined by equation (6).

$$delta\_x = \frac{(max - min)}{m} \tag{6}$$

where *max* is the maximum value of the data sequence; *min* is the minimum value of the data sequence; and *m* is the number of intervals.

MPS1 Apparatus

To determine the yarn linear mass characteristics a new system, MPS1 (Mass Parameterization System) was developed. This system integrates by using capacitive sensors of 1 mm together with a data acquisition board and data processing [6, 7]. The software used was developed in Labview from National Instruments (graphical programming) [8] and is divided into four distinct modules [3]: online acquisition, *DR%*, *IDR%*, frequency and mass variation, spectral analysis and automatic quality classification of yarn. Figures 5 to 8 display the front panels of the respective modules.

Table 1 summarizes the parameters obtained in MPS1.

Table 1 MPS1 functions.

U%: mean deviation	Value of percentage area that exceeds the mean value of yarn mass.
CV%: coefficient of variation	Percentage value of standard deviation that exceeds the mass mean value
Thin places	Number of reductions of the mean mass value, for four values of sensitivity defined by the operator
Thick places	Number of increases of the mean mass value (< 100%), for four values of sensitivity defined by the operator
Neps	Number of increases of the mean mass value (≥ 100%), for four sensitivity values defined by the operator
Length of faults	Length of imperfection for 1, 2, 3 and more than 3 mm for thin and thick places
DR%: deviation rate	Deviation rate for the interval [0–100%]
IDR%: integral of deviation rate	Integral of deviation rate for the interval [0–100%]
Mass variation diagram	Measurement of mass values in steps of 1 mm
Spectograms	Based in FFT, FWHT and FDFI, for sinusoidal errors, rectangular errors and pulse errors, respectively
Quality classification	In five values of percentile (P5; P25; P50; P75; P95) (Based on Uster tables)
Mass frequency diagrams	Mass frequency diagrams obtained in the interval [minimum value, maximum value]

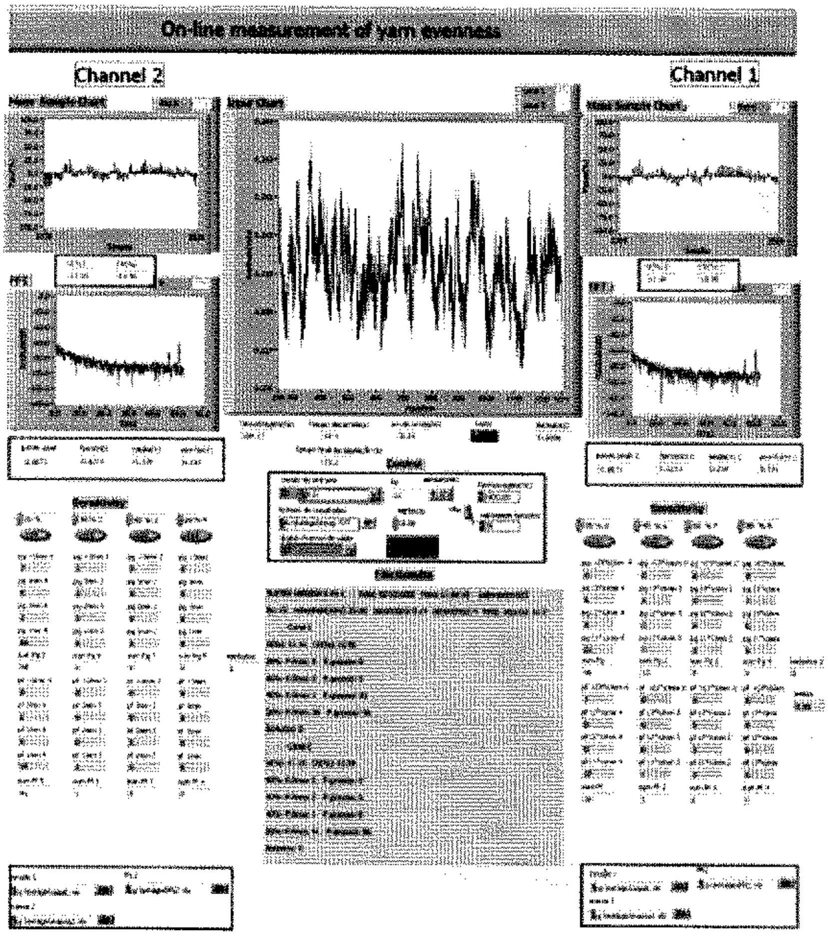

Figure 5 Online acquisition module frontal panel

Experimental Results and Discussion

During system development several tests were performed considering different yarn types and linear density ranges [3, 6, 7, 9–11]. In order to validate these measurements, several tests were carried out using items of commercial equipment and our system in a parallel and real-time set-up. These studies led to the conclusion that measurements tendencies were the same. For that reason one study is presented which reflects the main results.

A 20 Tex 100% carded cotton yarn, with a twist coefficient of $\alpha_{tex} = 4020$ was tested in MPS1 and in a commercial equipment (Uster Tester III).

The following MPS1 parameters were used in the analysis.

Yarn traction speed (m/min) = 50, which corresponds to a sample rate of 833.33 Hz;
Sensor plates width (mm) = 1;
Sample length (m) = 1000;
Sensitivity values for thin and thick places (%) = 35, 40, 50, 80;
Sensitivity values for neps (%) = 100, 140, 200, 250.

The commercial equipment used the following configurations:

Yarn traction speed (m/min) = 400, which corresponds to a sample rate of 104.16 Hz;
Sensor plates width (mm) = 8;
Sample length (m) = 1000;
Sensitivity values for thin and thick places (%) = 50;
Sensitivity values for neps (%) = 200.

In order to confirm 1 mm measurements with 8 mm commercial equipment, a comparison was performed using 1 mm samples (directly measured), 8 mm samples (mathematically calculated) and 8 mm samples (directly measured with commercial equipment). Although the measurement speed reduction used in MPS1 is eight times lower than

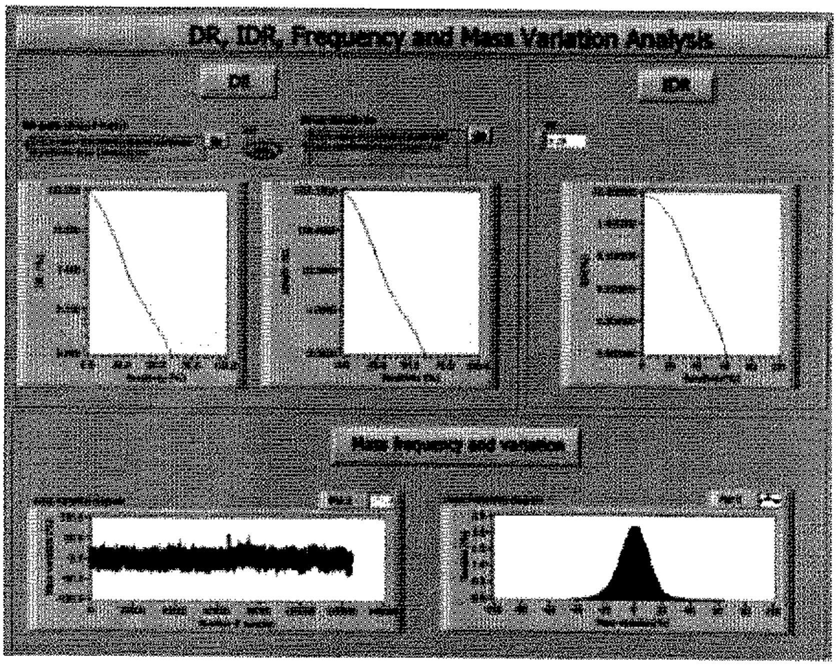

Figure 6 Determination of *DR*, *IDR*, frequency and mass variation front panel.

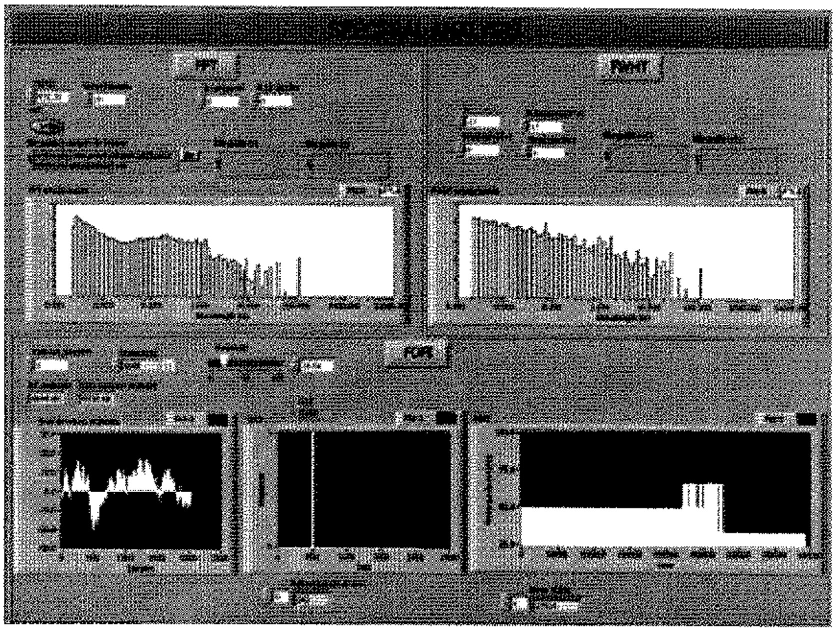

Figure 7 Spectral analysis module front panel.

commercial equipment, this factor is equally compensated by increasing the sampling frequency eight times in MPS1, which allows a reliable comparison of values. As speed (s) is inversely proportional to sampling frequency (f), the relationship between the two systems remained the same (MPS1: s = 50 m/min, f = 833,33 Hz; commercial equipment: s = 400 m/min, f = 104.16 Hz).

Table 2 shows the mathematical difference between the results for the two samples (1 mm versus 8 mm) in MPS1 parameters and Table 3 shows the mathematical difference between the results for the samples (8 mm (MPS1) versus 8 mm (commercial equipment).

In Table 2, as a direct consequence of the number of imperfections detected with the 1 mm samples, values of

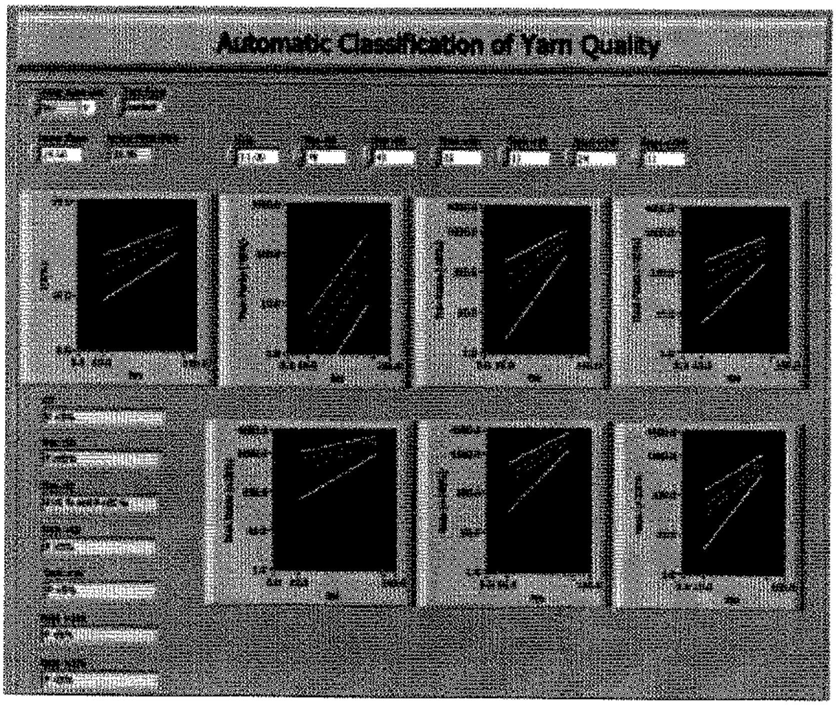

Figure 8 Automatic yarn quality classification module front panel.

Table 2 Mathematical difference between the two samples results (1 mm versus 8 mm)

Sensitivities (thin and thick places)	Thin places	Thick places	*DR* (%)	*IDR* (%)	Length (m)	Sensitivities (neps)	Neps	*U* (%)	*CV* (%)
35%	+10315	+7916	+1.63	+0.7059	+16.3	100%	+6	+2.9	+3.63
40%	+4427	+4045	+0.77	+0.3624	+7.7	140%	0		
50%	+701	+1021	+0.16	+0.0768	+1.6	200%	0		
80%	+9	+15	$+2.4 \times 10^{-3}$	+0.0017	+0.024	250%	0		

Table 3 Mathematical difference between the samples results of 8 mm (MPS1 versus commercial equipment)

Sensitivities (thin and thick places)	Thin Places	Thick Places	*DR* (%)	*IDR* (%)	Length (m)	Sensitivities (Neps)	Neps	*U* (%)	*CV* (%)
50%	−8	−31	Not measured by commercial equipment (not comparable)			200%	−69	−2.8	−3.7

irregularity, *U*% and *CV*%, present a positive variation of 2.9 and 3.63%, respectively. The values of *DR*% and *IDR*% show a variation between 2.4×10^{-3} and 1.63% and between 0.0017 and 0.7059%, regarding the values of sensitivity, respectively.

This was caused by increasing the resolution eight times, leading to highly accurate detection and, as the 8 mm sensor works as a low pass filter for the 1 mm sensor, all high frequencies are attenuated, causing a less precise detection (sample rate in 8 mm samples is reduced eight times, from 833.33 to 104.16 Hz), resulting in a lower number of faults.

In Table 3, the number of imperfections detected with samples of 8 mm in MPS1 is inferior to commercial equipment, for the same threshold, which results in a negative variation of irregularity values, –2.8 and –3.7, for *U*% and *CV*%, respectively. However, the variation of *U*% and *CV*%, for comparison of 1 and 8 mm samples in MPS1 (Table 2) and for 8 mm samples in MPS1 versus commercial equipment, is almost the same (differ only by 0.1%)

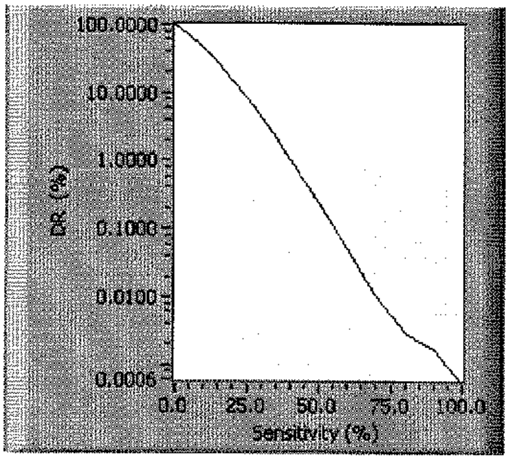

Figure 9 *DR* results for samples of 1 mm.

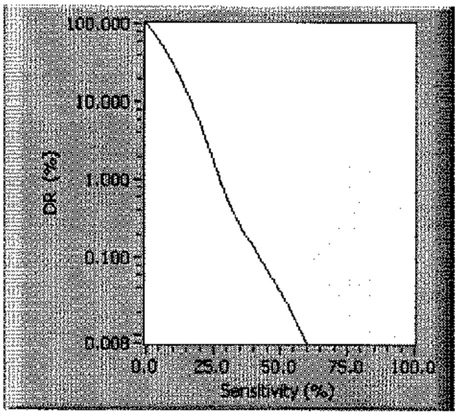

Figure 10 *DR* results for samples of 8 mm.

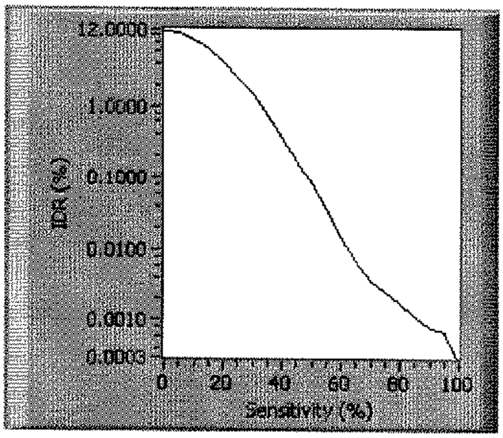

Figure 11 *IDR* results for samples of 1 mm.

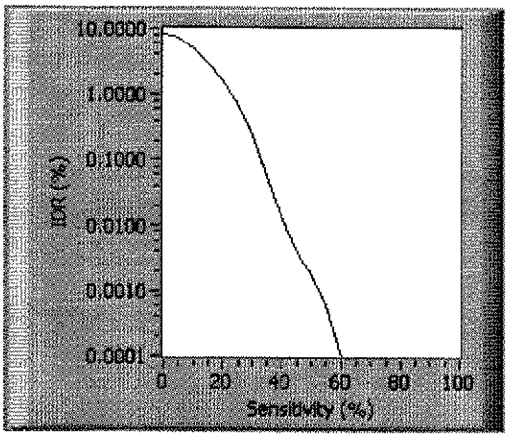

Figure 12 *IDR* results for samples of 8 mm.

which supports the statement that the influence of frequency of measurement is compensated by measurement speed, and thereby explaining the lower detection. As neps are characterized by lengths up to 4 mm, data acquisition with 8 mm sensors could only be performed by estimation methods. MPS1 is able to detect these imperfections directly for 1 mm samples, leading to more reliable results.

Figures 9 and 10 present the results obtained for *DR%* and Figures 11 and 12 give the results obtained for *IDR%*, considering samples of 1 and 8 mm in MPS1, respectively.

As a consequence of less accurate measurements, 8 mm samples (commercial equipments and MPS1 mathematical algorithm) show a reduced range of variation, for the same sensitivities in comparison with 1 mm samples. By using the data obtained for 8 mm samples, the yarn is classified as a regular yarn.

Using the FFT model in energy bands to aggregate the harmonics and attenuate the effects of overlapping, spectrograms were achieved [12–15]. As the FFT signal was concentrated, becoming difficult to extract relevant information, it was compressed. Figures 13, 14 and 15 show the FFT results obtained with 1 and 8 mm samples (MPS1 and commercial equipment), respectively.

For MPS1 8 mm samples, the wavelength data peak occurs around 2 cm and with the 1 mm samples this occurs around 3 mm. These values could be explained by the fact that with a 1 mm sensor it is possible to detect wavelengths in the range 2 mm to 2 cm, which are not available in the 8 mm sensor. Due to a higher sample rate, more detailed information is obtained for samples of 1 mm, although the entire remaining spectrum characteristic is similar.

Comparing the 8 mm spectrum results for MPS1 and commercial equipment (Figures 14 and 15), respectively, it

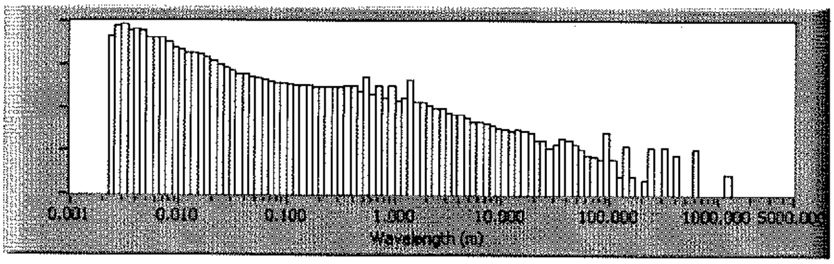

Figure 13 Compressed FFT results for 1 mm samples.

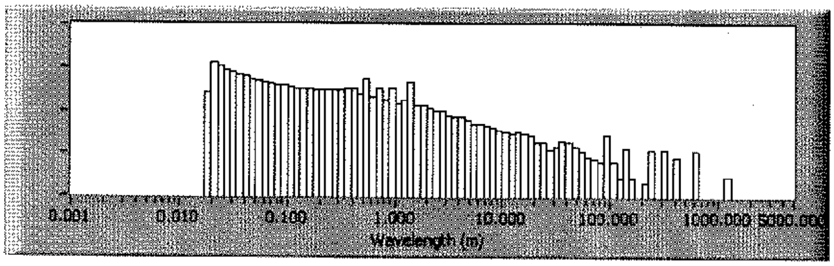

Figure 14 Compressed FFT results for 8 mm samples (MPS1).

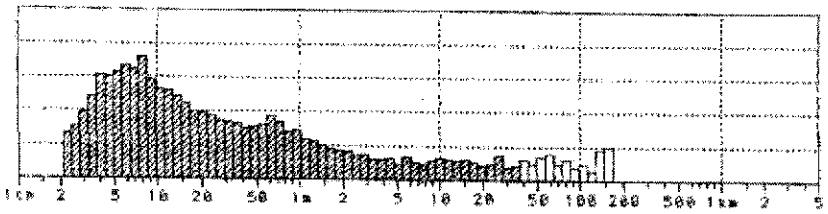

Figure 15 Compressed FFT results for 8 mm samples (commercial equipment).

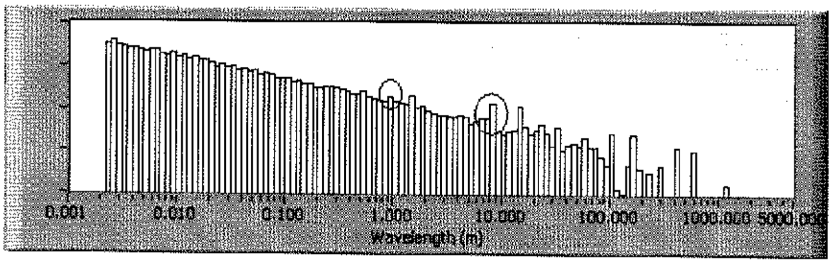

Figure 16 FWHT results for 1 mm samples.

is observed that the signals are very similar. Small differences occur due to the number and type of imperfections obtained in different tests, although the signal tendency remains the same.

Figure 16 presents the results of FWHT, considering 1 mm samples. As in FFT, FWHT for 1 mm samples has similar characteristics to those obtained in the 8 mm samples, differing only for values inferior to 2 cm.

Comparing the plots of FFT and FWHT, a periodic error occurs for a wavelength around 1 m in both graphs, albeit with less amplitude in FWHT. This fact is due to sinusoidal errors being better detected by sinusoidal transformation (FFT) rather than the rectangular characteristics of FWHT [15]. However, an error was detected around 10 m that was not detected with FFT, leading to the conclusion that the evaluated yarn has irregularities with rectangular characteristics in this wavelength.

Conclusions and Future Work

The MPS1 apparatus performs yarn mass parameterization in the 1 mm range. This new approach allows the correct identification of faults, especially neps, which can be measured directly with accuracy, and the detection of periodical errors from 2 mm wavelength, in contrast to the 2 cm of traditional systems. Spectral information below 2 mm could give, for cotton as an example, information about fiber constitution. With the determination of two new parameters (*DR%* and *IDR%*), as well as diagrams of mass variation and mass frequency, *U%*, *CV%*, and number of faults, is possible to obtain numerical values to quantify mass diagrams, that are very useful for yarn producers.

The signal processing techniques used, FFT (sinusoidal transform) and FWHT (rectangular transform), are important tools for periodical error determination. As a vast number of faults in yarn production have sinusoidal characteristics, FFT is the most important and adequate method. However, with FWHT, rectangular errors become more evident and could be detected clearly. Commercial equipments only perform FFT analysis.

MPS1 also performs the online automatic yarn quality evaluation using Uster tables (based on 8 mm samples). Due to this fact, MPS1 converts 1 to 8 mm samples (mean of consecutive eight 1 mm samples) to assess yarn quality.

In conclusion, MSP1 is a low-cost system that allows the yarn producer to quantify yarn faults and the statistical values presented, including the new *DR* and *IDR*, as well as two forms of main spectral analysis and one for pulse errors (FDFI), still under development, which can contribute to increase yarn quality.

For future work the following tasks are planned: automatic yarn quality implementation (for all of the Uster database) [16]; new standard tables for 1 mm samples, allowing real time automatic yarn evaluation; and finally, the development of a new module for hairiness assessment to be inserted in MPS1.

Acknowledgements

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