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Sensors and Actuators A 115 (2004) 540–548

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SENSORS AND ACTUATORS A PHYSICAL

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Yarn parameterization based on mass analysis

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Received 10 October 2003; received in revised form 31 March 2004; accepted 5 April 2004

Available online 11 June 2004

Abstract

The aim of this paper is to present a new experimental procedure to evaluate yarn characteristics, in real time, using capacitive sensors with a width below 8 mm (commercial equipments use 8 mm sensors). The new approach allows a direct measurement in 1 mm range (increasing resolution eight times). Using software modules developed in this project, all yarn parameters commonly used in industry are evaluated, often with different percentiles. These percentiles are defined interactively with the operator. To increase the textile assessment of the yarn, new parameters were developed (integral deviation rate (IDR), fast fourier transform (FFT)-based analysis) and others were adapted (deviation rate (DR), spectrogram).

The final goal of the current project is to allow real time actuation on a ring spinning frame, based on the previous analysis of the yarn. This allows on-line control of the production according pre-defined quality requirements.

Keywords: Yarn evenness; Capacitive sensor; Signal processing; Spectral analysis

1. Introduction

Yarn irregularity is an important feature to assess its quality. A higher quality requires an arrangement of the fibres in which the number of fibres in each cross-section (longitudinal variation) is close to constant. Irregularity is used to evaluate variation in several characteristics along a strand (yarns, roving, sliver or tops) and unevenness measures the mean variation in linear density of a strand or part of it. Thus, for purposes of yarn processing efficiency that influences final fabric appearance, there are levels of unevenness beyond which the yarn is unacceptable [1,2].

For detection of such irregularities, nowadays electronic capacitance testers are still applied as a convenient and reliable method of testing irregularity (determination of mass). Industrial systems use capacitors with 8 mm length that allow mass measurements with 8 mm resolution. Mass yarn evaluated in 1 mm range is of utmost importance for a correct detection of irregularities, as most of them have a short length (between 1 and 4 mm) [3]. This paper presents a novel capacitive sensor that measures directly 1 and 4 mm yarn mass. It also presents a new software that, based on data acquisition and signal processing algorithms, allows the evaluation of all yarn relevant parameters.

The final achievement is to increase the quality specifying strict requirements. The use of the new solution developed improves quality control procedures during production.

2. Theoretical considerations

Some of the most important parameters used to identify specifications for yarn quality are linear density, structural features and fibre content [4]. The combination of different number of fibres per cross-section with varying forces, binding them together due to twist variation, leads to different yarn properties. An example of yarn configuration is shown in Fig. 1.

In order to obtain yarn mass irregularity, electronic capacitance testing is established as a convenient method [5]. The basic requirement of this type of unevenness tester is that the output of the measuring circuit is directly proportional to the linear mass (mass per unit length); the relationship between capacitance and fibre mass must be linear.

The changes of the total fibre cross-sectional area between the plates enable the automatic indication of the mean

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doi:10.1016/j.sna.2004.04.045

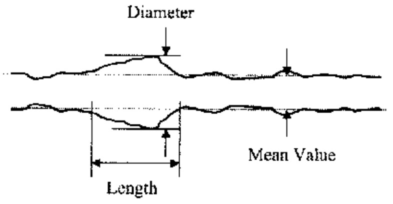

Fig. 1. Example of yarn longitudinal section and length of a defect.

absolute deviation, U (%) and coefficient of variation, CV (%), as well as the new defined parameter integral deviation rate, (IDR (%)) and the deviation rate, (DR (%)). The sensor plate's length defines the amount of mass considered per sample.

The irregularity U is proportional to the sample's mass variation around the average, and is independent of the evaluation time (overall tested material length), if the mass variation is homogeneously distributed. In this case, the mass variation fits approximately the normal distribution.

The irregularity CV (%), with this normal distribution, is usually related with U (CV = 1.25 U).

The deviation rate gives a result of the length of yarn that is not within the limits around the yarn mass average. To present the result of deviation rate, a function $p(n)$, which turns '1' if a sample is above or below these limits (α) and '0' if it is not, is defined as Eq. (1) [6]:

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

DR (%) as function of α is given by Eq. (2):

$$\mathrm{DR}_\alpha\,(\%)=\frac{\sum_{i=0}^{N-1}p(n)}{N}100 \tag{2}$$

The number of samples that exceeded the established limits for yarn mass is summed and divided by N (number of samples) obtaining the deviation rate result for a certain limit. The length of the analysed sample that is under the deviation rate calculated (3) (the amount of yarn that is under that pattern) is determined by multiplying the deviation rate by the sample length (L_{sample}):

$$L_{\mathrm{DR}_\alpha}=\mathrm{DR}_\alpha L_{\text{sample}} \tag{3}$$

Graphically, DR_α (%) is represented by Fig. 2.

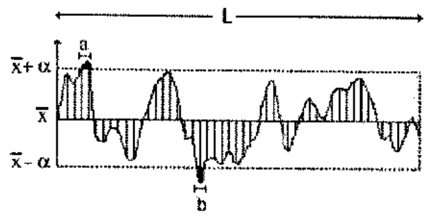

Fig. 2. Graphical representation of DR (%).

In this example (Fig. 2), a and b exceed the defined limit. Sample a due to an increase in mass average, and sample b to a decrease. As there are two samples out of the limits, the deviation rate by the sample length is $(2L_{\text{sample}}/N)\times 100\%$, where N is the number of samples acquired.

The integral deviation rate presents a result of the yarn mass that is not within limits around the yarn mass average. This parameter is measured using the function, $y(n)$, shown in (4):

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

IDR (%) gives information regarding the quality of the yarn for different requirements defined as a function of α (5):

$$\mathrm{IDR}_\alpha(\%)=\frac{\sum_{i=0}^{N-1}y(n)}{\bar{x}N}100 \tag{5}$$

This parameter determines the amount of mass of a segment of yarn that exceeds limits. For example, if the yarn must be very regular, IDR_α should decrease rapidly with the increase of α. Instead, for common quality yarns, IDR_α decreases slower with the increase of α. According its definition, if α is zero, IDR_α equals the value of U%.

The calculation of the mass variation can represent a true reflection of the mass or unit per length variation in a fibre assembly. This calculation is an indispensable auxiliary because it provides recognition of the more important deviations, tendencies and characteristic irregularities [7]. With IDR it is possible to quantify this characteristics not only for 0%, as U but also for values in the range of 0–100%, giving a complete information of the regularity of the yarn at all limits.

The number of faults and mass measurements enable a quality rating of the product. An accurate measurement of these properties is of major importance [8,9]. There are three kinds of yarn faults, classified as Fig. 3:

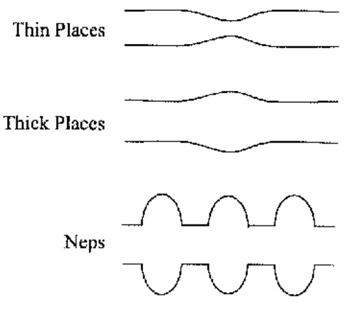

Fig. 3. Types of yarn faults.

- thin places—a decrease in the mass during a short length (4 mm);
- thick places—an increase in the mass, usually lower than 100% and lasting more than 4 mm;
- neps—huge amount of yarn mass in a short length (typically from 1 to 4 mm).

3. Capacitive sensors

The use of capacitive sensors has become very important to measure pressure, acceleration, fluid level and fluid composition.

Capacitive sensors are traditionally constituted by two plates (electrodes) of section *S*, separated by a distance *d* and a width *w*, where the final value of capacity depends on the plates section, their distance and the dielectric material [10]. In this specific research, the changing parameter will be the dielectric between the plates (yarn) that will vary depending on yarn composition and diameter. This will enable the establishment of a relationship between capacity and yarn mass (Fig. 4) [11].

The capacity of a parallel plate capacitor is determined by Eq. (6).

$$C = \frac{\varepsilon_0 \varepsilon_r S}{d} \tag{6}$$

Where C is the capacity (F); $\varepsilon_0 = 8.854 \times 10^{-12}$ (F/m); ε_r is the dielectric relative constant, 1 for vacuum; S $(d \times w)$ the area (m^2) and d is the distance (m).

Using Eq. (6), it is possible to verify that if the dielectric constant value (ε_r) is changed, the capacity also changes, phenomenon that occurs when the yarn is inserted between the plates establishing a relationship between the capacity (C) and the yarn mass.

The use of capacitive sensors has, however, some drawbacks. They are very sensitive to humidity, causing some troubles because the dielectric constant of humid air is inferior to the dry air. This is a daily situation confirmed by the voltage level of the sensor change without yarn, depending on the local percentage of humidity.

To overcome this problem, auto-corrected amplification circuits were used and the software developed employs the signal acquired without yarn as a calibration value. As humidity change has a low time constant, this task can be performed efficiently.

4. Sensor design

A new capacitive sensor with parallel plates was developed, together with the electronic conditioning circuit, which allows 1–4 mm yarn mass reliable measurements. Based on the results obtained with the 4 mm sensor, some improvements were made in the 1 mm length sensor. The studies undertaken show that a capacitance variation of 2,08E-17 F is expected when a 57 tex (0,057 g/m) yarn is used. Nevertheless, careful design of conditioning circuits was needed due to the low SNR (signal to noise ratio).

As radiation is a major problem, a solution with two sensors was used in a differential configuration (Fig. 5) [12]. With this technique it would also be possible to use the same equipment for two different yarn diameters (not simultaneously). The use of a differential set-up makes the electric circuit more robust to temperature and air humidity variations, which are particularly important in textile industries.

This system is to be used for on-line control of a ring spinning frame in order to evaluate the evenness of the yarn produced. Presently, in spinning mills this kind of evaluation is made off-line in laboratory using a small amount of yarn. The tests made with this system show good performance in laboratory environment. The experimental set-up used consists on a personal computer with a data acquisition system together with a 1 mm sensor and electronics.

Fig. 6 shows the system schematic diagram used in the project development.

In order to have two condensers with a common electrode, three metallic conductors placed in parallel were used in system design. The integrated circuit (IC) MS3110 from *Microsensors*, implements the functions related to transducer amplification and signal conditioning. Its use is specific for capacitive sensors and has the following characteristics [11]:

- capacitance resolution up to 4.0 aF/rtHz;
- single or dual differential variable;
- on-chip dummy capacitor for quasi-differential operation and initial adjustment;
- gain and dc off-set trim;
- programmable bandwidth adjustment 0.5–8 kHz;
- 2.25 V dc output for ADC reference/ratiometric operation;
- single supply;
- on-chip EEPROM for storage of settings.

The sensor capacitance variation is converted in a voltage signal and amplified. A second-order low-pass filter atten-

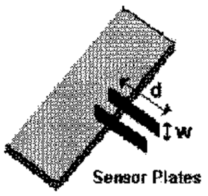

Fig. 4. Parallel plates capacitor.

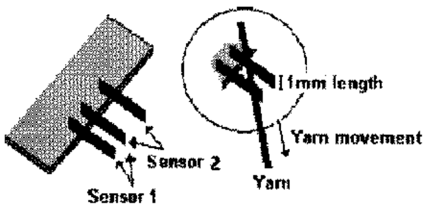

Fig. 5. Representation of the two sensors.

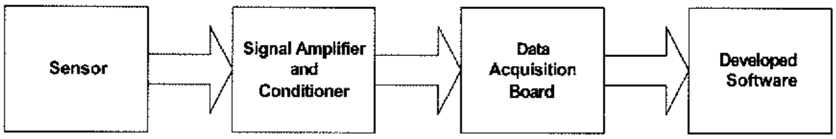

Fig. 6. System flow chart.

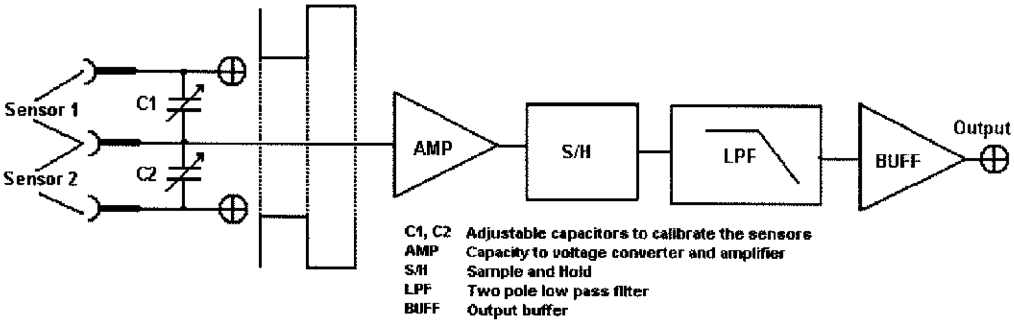

Fig. 7. Sensor plates and MS3110 block diagram.

uates the high-frequency interferences that come from the internal oscillator and other external noise sources. The filtered signal is then once more amplified (Fig. 7).

The signal output is converted in a digital signal using an ADC (analog to digital converter) included in the data acquisition board (6024E from National Instruments), which is monitored in a personal computer using the control software developed. This software allows the data storage, manipulation and processing for analysing the results obtained.

5. The software

The customized program was developed in *Labview* [13]. It implements the following on-line functions: yarn faults count (thin points, thick points and neps) up to four values of sensitivity, calculating yarn evenness U (%), CV (%), DR (%) and IDR (%) and using Fast Fourier Transforms (FFT) to extract some periodic faults [14].

5.1. Input variables

Input variables allow the operator to specify some acquisition characteristics, which are:

- sensor input analog channels;
- yarn speed (m/min) or sample frequency (Hz);
- linear mass of yarn (tex, Ne);
- set up to four values of sensitivity (%);
- width of sensor (mm);
- sample length (m).

Although yarn evenness classification has some standard sensitivity values, the user can define up to four sensitivity values, to perform a detailed analysis.

Sensitivity is the yarn mass value used to detect a particular fault, regarding yarn mass average. For instance, 80% sensitivity to detect thin points means that mass measurements below 0.8 of mass average is considered a fault, and for thick points, above 0.8.

5.2. Output variables

The output variables allow the analysis of the yarn characteristics regarding faults, statistics parameters, periodic faults and periodic characteristics.

The output variables are:

- voltage input graphic, of the sensors (V);
- mass yarn percentage variation graphic (%);
- fast fourier transform graphics;
- U (%), CV (%);
- DR (%) and IDR (%) graphics;
- thin points, thick points and neps for each value of sensitivity;
- sample frequency (Hz) and period (s);
- sensor voltage without yarn (V);
- average voltage level of yarn (V);
- actual sample length (m).

The mass yarn variation (%) is calculated for each sample (7).

$$\text{mass}\,(\%) = 100\frac{V_\text{m} - X_\text{i}}{V_\text{sf} - V_\text{m}} \qquad (7)$$

Where V_m is the mean voltage level of yarn (V); X_i the actual voltage level of the sample (V) and V_sf is the voltage of the sensor without yarn (V).

The expressions used to calculate the sampling frequency and period, depending on the plates width of the sensor are shown in (8) and (9), respectively.

$$f\,(\text{Hz}) = \frac{\text{speed}(1000/60)}{l} \qquad (8)$$

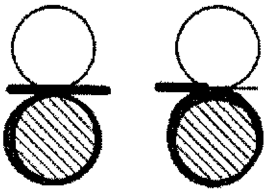

Fig. 8. Displacement of the roller axle.

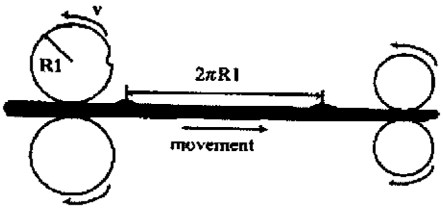

Fig. 9. Imperfections on the roller axle.

$$T\,(\mathrm{s}) = \frac{1}{f} \tag{9}$$

Where 1 is the width of sensor (1 to 8 mm) and speed is the yarn speed (m/min).

The developed software calculates all the output variables on-line, except the FFT, DR and IDR graphics.

The FFT result is showed in terms of wavelength (λ) (10), which is calculated considering the FFT results in frequency. Spectral information, in terms of wavelength, gives a more perceptive result to the yarn producer.

$$\lambda\,(\mathrm{m}) = l\frac{f_a}{1000 f_d} \tag{10}$$

Where l is the width of sensor (mm); f_a the acquisition frequency and f_d is the detected frequency for faults.

With the result of the spectral analysis, it is possible to detect periodical errors in the process, in which faults are included. But there are other two types of errors [3]:

- the first type (Fig. 8), typically occurs due to the accumulated dirt at the stretching rollers in the drafting systems, or the displacement of the roller axis, producing a sinusoidal imperfection in the spun yarn diameter.
- the second type (Fig. 9), generally due to imperfections in the surface of the rollers, generating a periodic impulse fault.

6. Experimental results

In order to evaluate the experimental set-up, several tests were performed using a 30 Ne staple cotton yarn. The initial settings for the analysis are:

- speed of yarn (m/min) = 50, which corresponds to a sample acquisition of 833.33 Hz;
- width of sensor (mm) = 1;
- sample length (m) = 1000;
- sensitivity thresholds for thin and thick points (%) = 20, 40, 60, 80;
- sensitivity thresholds for neps (%)= 100, 150, 200, 250.

6.1. *Faults and evenness results*

Tables 1 and 2 present the results obtained in terms of thin and thick points for each sensitivity value and length of faults, values of U (%), CV (%), number of neps for each sensitivity, DR (%), IDR (%) and length of yarn in terms of deviation rate.

A mathematical model was used to determine the values on 8 mm range in order to compare them with Uster values [15]. Such procedure allows the correct classification of the quality of yarn, which could be done considering a reference of 1 mm sample that would give a more accurate clas-

Table 1
Thin and thick points results considering 1 mm samples

Faults length (mm)	Sensitivity (%)							
	20		40		60		80	
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
1	38823	48013	3488	5229	97	313	8	18
2	7414	7875	132	233	0	26	0	0
3	2137	1917	13	49	0	5	0	0
>3	2335	1555	6	96	0	4	0	0
Total	50769	59360	3639	5607	97	348	8	18

Table 2
Evenness, neps, integral and deviation rate results considering 1 mm samples

Sensitivity (%)	DR (%)	Length (m)	IDR (%)	Sensitivity (%)	Neps	U (%)	CV (%)
20	25.23	252.34	5.71	100	8	11.23	14.04
40	1.78	17.75	0.64	150	0		
60	0.05	0.50	0.02	200	0		
80	0.00	0.00	0.00	250	0		

Table 3
Faults measured considering 8 mm samples

Faults length (mm)	Sensitivity (%)							
	20		40		60		80	
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
8	4125	1943	6	139	0	5	0	0
Total	4125	1943	6	139	0	5	0	0
Uster classification (%)	$P > 95$		$P = 25$		$P < 5$		$P < 5$	

Table 4
Evenness, neps, integral and deviation rate results considering 8 mm samples

Sensitivity (%)	DR (%)	Length (m)	IDR (%)	Sensitivity (%)	Neps	U (%)	CV (%)
20	4.87	48.70	1.09	100	0	8.26	10.33
40	0.11	1.10	0.04	150	0		
60	0.004	0.04	0.00	200	0		
80	0.00	0.00	0.00	250	0		
			Uster classification (%)		$P < 5$	$P < 5$	$P < 5$

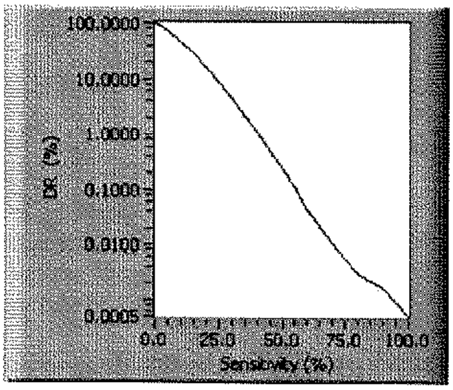

Fig. 10. DR results for 1 mm samples.

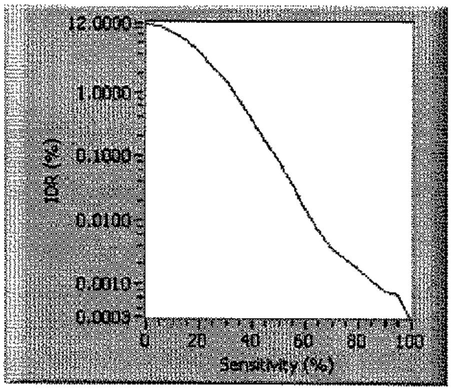

Fig. 12. IDR results for 1 mm samples.

sification. As there are no standard tables for 1 mm samples available, the data is transformed to 8 mm length samples. It is also aim of this project to build a data-base containing the classification of yarn regarding 1 mm samples.

Table 3 presents the faults results associating samples in groups of eight corresponding to 8 mm samples. Table 4 gives the same information as Table 2, but considering 8 mm samples. In these tables (3 and 4), there is also information about the classification of yarn quality obtained in terms of percentiles. The quality of yarn is in the inverse proportion of the percentile level (*P*).

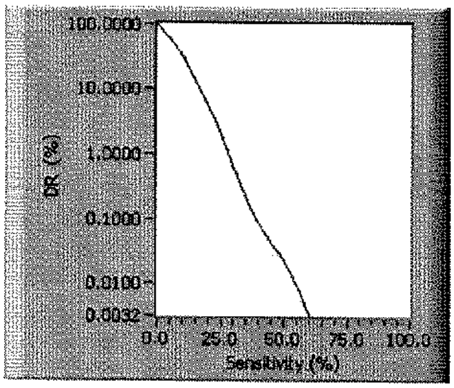

Fig. 11. DR results for 8 mm samples.

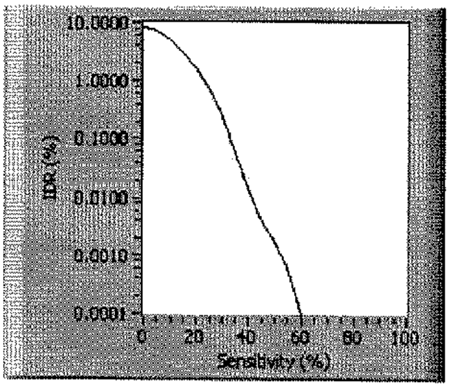

Fig. 13. IDR results for 8 mm samples.

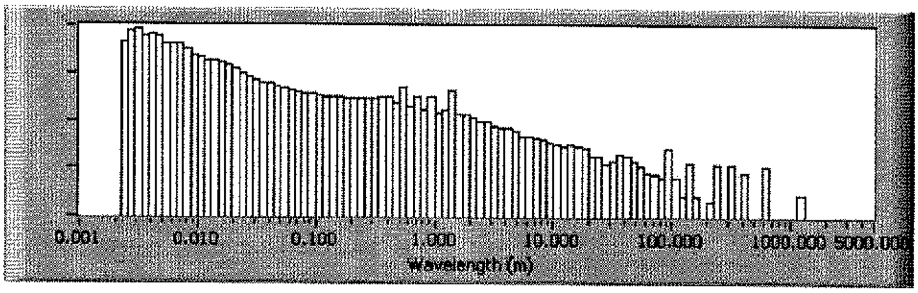

Fig. 14. FFT results with compression for 1 mm samples.

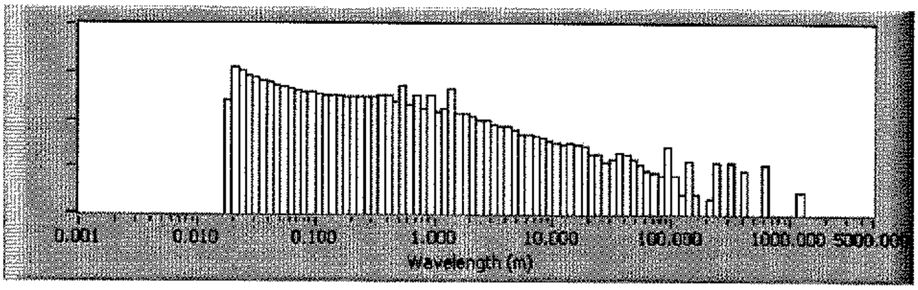

Fig. 15. FFT results with compression for 8 mm samples.

Comparing the results obtained with 1 and 8 mm samples, it is possible to observe that for 1 mm samples the detection of faults is much higher. These faults cause a decrease in values of U (%), CV (%), DR (%) and IDR (%). However, these results are explained because the resolution for 1 mm samples is increased eight times.

Using the Uster classification tables, the yarn is considered of high quality [14]. This is stated due to the low percentile levels obtained for most of the results, e.g. ($P < 5$ means that only 5% of the world companies produce with this quality level).

6.2. DR and IDR results

Figs. 10 and 11 show the results obtained for the DR (%) and Figs. 12 and 13 the results obtained for the IDR (%), considering 1 and 8 mm samples, respectively.

For the 1 mm graphics, a more precise result is obtained. Comparing both methods, it is possible to see that, as a consequence of the lower precision measurements, the values for 8 mm samples are in a lower range, for the same values of sensitivity, giving the impression that the yarn analysed is of better quality.

6.3. FFT results with the developed equipment

These spectrograms were evaluated based on a FFT model definition of narrow bands to aggregate the harmonics [16–18]. The initial FFT signal obtained was very highly concentrated, it becoming extremely difficult to extract relevant information [12]. So, the signal is compressed as seen in Fig. 14, for results obtained with 1 mm samples, and in Fig. 15 for results obtained with 8 mm samples (average of eight consecutive 1 mm samples).

Due to the higher acquisition frequency, used in 1 mm samples, more accurate information is reached. For 8 mm, the peak wavelength occurred around 2 cm, but for 1 mm around 3 mm. With the 1 mm sensor, it is possible to detect wavelengths in the] 2 mm, 2 cm [range, which are impossible with the 8 mm sensor. As cotton fibre lengths can be in this range, this new feature allows a more detailed quality analysis.

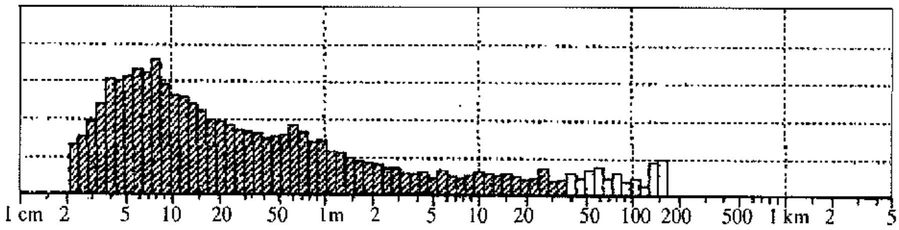

Fig. 16. FFT results with Uster Tester III.

6.4. FFT results with the Uster Tester III

In Fig. 16 is presented the yarn mass spectrum obtained with Uster commercial equipment.

Comparing the FFT results obtained with Uster Tester III and the developed equipment it is observed that the signals are very similar (mathematically). These slight differences are verified due to the fact that for different tests, with the same yarn, the number of faults varies in number and type. However, the main tendency of the spectrum should prevail as occurred.

7. Conclusions

The results point out that the evaluation of yarn mass with the developed sensor is feasible at 1 mm range. With this technique we are able to extract yarn mass values of 1 mm, which can be compared, using mathematical treatment, with Uster standard tables (8 mm yarn samples). It is also intended to build standard tables for 1 mm yarn samples allowing the automatic classification of the yarn quality.

With our new parameter IDR and the adapted DR, it is possible to have some numerical values to quantify mass diagrams, which are very useful to spinners as they represent a true reflection of yarn quality.

The main goal of this project is to develop a new technique that enables on-line measurement of 1 mm yarn mass in a spinning frame, in order to improve the precision of such measurements.

Future work will include the test of other signal processing techniques that has been shown to be feasible to give proper results. Some of those are the Walsh Transform and the DFI.

Acknowledgements

The authors are grateful to FCT project funding, contract no. POSI/P/EEI/13189/98.

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