Development of a Yarn Evenness Measurement and Hairiness Analysis System

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Abstract — **This paper presents an automatic yarn characterization system, based on capacitive sensors for evenness measurement and on optical sensors for hairiness analysis. This approach enables direct yarn mass determination in 1mm range for evenness, an increase by a factor of eight over the most common commercial solutions (8mm), and will also enable hairiness measurement up to 1mm with high accuracy. This system determines all parameters commonly used in textile industry, for different sensitivity values defined by the operator. It also presents new parameters, not measured by commercial equipments (integral deviation rate-IDR, different signal processing techniques to detect error patterns (Fast Walsh-Hadamard Transform-FWHT) and other adapted parameters (Deviation Rate-DR, Spectrograms (Fast Fourier Transform-FFT), Coefficient of Variation-CV, Mean Deviation-U, number and length of faults).**

I. INTRODUCTION

An important feature to assess yarn quality is the irregularity measurement, evaluating several characteristic properties along a strand (yarns, roving, sliver or tops); unevenness measures the mean variation in linear density of a strand or part of it. Yarn processing efficiency influences final fabric appearance and there are levels of unevenness beyond which the yarn is unacceptable [1].

For detecting irregularities, electronic capacitance testers (determination of mass) are commonly used. Industrial systems use parallel plate capacitors with 8 mm width which allow measurements with 8 mm resolution. However, yarn mass determined in 1 mm range is important to correctly detect irregularities, as most of them have lengths between 1 and 4 mm [2].

Other important feature of yarn is hairiness. Its quantification is also relevant for the textile industry. The variations in yarn can significantly affect the appearance and handling of the woven and knitted fabrics. For measuring hairiness, optical sensors are generally used for samples of 2mm or less.

This paper presents a system based on a capacitive sensor that measures directly 1 mm yarn mass and on an optical setup for hairiness analysis. It also presents software developed for data acquisition and signal processing. Evaluation of all relevant yarn parameters is allowed. The main objective is to increase the quality of yarn and subsequently, the fabrics produced.

The solution being developed will enable online control procedures.

II. THEORETICAL CONSIDERATIONS

A. *Yarn configuration, faults and hairiness*

The most important parameters used to specify yarn quality are linear density, structural features and fibre content. An example of yarn configuration is shown in figure 1.

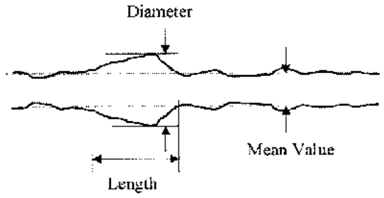

Fig. 1-Yarn configuration example

The number of faults and mass measurements enable a quality rating of the product. There are three kinds of yarn faults, classified as (figure 2).

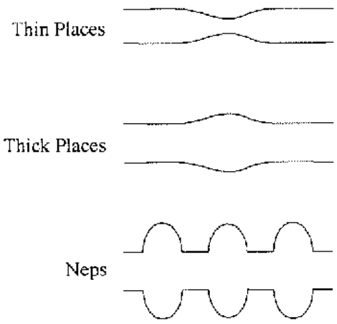

Fig. 2-Types of yarn faults

- 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).

As mentioned above, another important yarn characteristic is hairiness. Figure 3 presents the hairiness effect over a yarn. Hairiness is normally quantified by standard deviation, similar to CV (%). However, other parameters (U, DR, IDR) can also be considered.

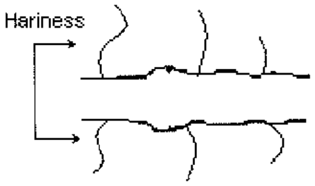

Fig. 3-Example of hairiness over a yarn

B. Statistical Parameters

The irregularity U is proportional to mass variation around the average and is independent of the evaluation time (overall tested material length), considering a mass homogeneous distribution. The irregularity CV%, for that case, is usually related with U (CV = 1.25 U).

The DR gives the yarn length that is not within the limits around the yarn mass average ($\bar{x}$). To obtain the deviation rate, a function p(n) is defined (1), which takes on the value '1' if a sample, $f(x)$, is above or below the limits (α) and '0' if not [3]:

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

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

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

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

$$L_{DR_{\alpha}}=DR_{\alpha}L_{sample} \tag{3}$$

The IDR represents 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):

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

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

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

This parameter determines the mass amount of a yarn segment that exceeds limits. According to the definition, if α is zero, IDR_{α} equals the value of U%. With IDR it is possible to quantify irregularity characteristics not only for 0%, as U, but for values in the range of [0,100] % giving a complete information of the regularity of the yarn for all limits.

C. Signal Processing Algorithms

FFT Approach

The first approach performed was based on the FFT transform, a sinusoidal based transformed, with narrow bands definition to aggregate the harmonics, due to the highly concentrated information of the spectrum. This could be considered a periodgram [4].

FWHT approach

The Walsh functions create an ordered set of rectangular waves presenting only two possible amplitudes, +1 and -1. Two series are presented, the CAL series and the SAL series, which are very similar to trigonometric series SIN and COSIN, respectively. The CAL(k, t) are symmetric in relation to the mean point of the definition interval, where the SAL functions SAL(k, t) are anti-symmetrical in relation to that same point. They are defined by (6) and (7):

$$CAL(k,t)=WAL(2k,t) \tag{6}$$

$$SAL(k,t)=WAL(2k-1,t) \tag{7}$$

where the k is defined as the major integer less or equal to (number of signal changes+1)/2. This transform can be seen as the FFT but for rectangular errors, also considering narrow bands.

D. Capacitive and Optical methods for mass detection

Capacitive Measurements

Parallel capacitive sensors are generally used to quantify yarn evenness by commercial systems. They are traditionally constituted by two electrodes (plates) of area *S*, separated by a distance d, with width w and length l. The final capacity value depends on the plate's area, their separation and the dielectric constant of the space between them [6]. For measuring the yarn mass variation, the variable parameter is the dielectric between the capacitor plates (where the yarn is positioned) that will vary depending on yarn composition and diameter, considering a constant air temperature and humidity during the test. This allows the establishment of a relation between the capacity and yarn mass (figure 4).

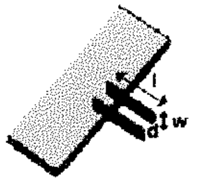

Fig. 4-Parallel plates capacitor

The capacity of a parallel plate capacitor is determined by (8).

$$C = \frac{\varepsilon_0 \varepsilon_r S}{d} \qquad (8)$$

where,

C – capacity (F);
ε_0 - 8.854 x 10^{-12} (F/m);
ε_r – relative dielectric constant, 1 for vacuum;
S (l×w) – area (m^2);
d – distance between capacitor plates (m).

Using equation 8 it is possible to verify that if the dielectric constant changes, ε_r, the capacity also changes. This phenomenon occurs when yarn is placed between capacitor sensor plates, establishing, as previous referred, a relation between capacity and yarn mass.

Optical Analysis

Optical sensors are mainly used by commercial systems to quantify yarn hairiness. There are two main methods that can be used to measure hairiness. The first method consists on using a light source and detector located on opposite sides and displaced by a distance from the yarn under analysis. When yarn hairs appear the light is partially blocked allowing their detection (figure 5). This method could be extended for several distances, allowing determination of hair lengths. Using a simple Led as a source and a photodiode as a detector this method can be made at low cost. However, as yarn traction causes a variation in the position of the yarn under analysis, this method has a high level of imprecision and uncertainty.

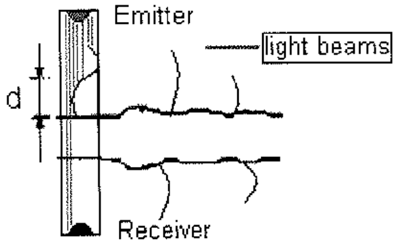

Fig. 5- First approach of hairiness detection

The second approach also employs a light emitter (laser)/ receiver (photodiode) pair, but with the addition of an optical setup to analyse yarn hairiness using a coherent optical signal processing technique [7-14]. A dark and red image is created. The red contrast gives information about yarn hairiness (figure 6), which is converted by the photodiode into a current intensity.

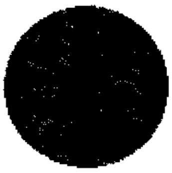

Fig. 6Example of an image plan of hairiness measurement using a coherent optical signal processing technique

This method quantifies with higher accuracy, the mass variation (%) caused by hairiness, considering as reference, the yarn mass linear density. This is a very precise method, relatively insensitive to variations in the exact yarn position. However the added complexity makes it a more expensive method. With both methods it is possible to use the information acquired to print out diagrams and spectrograms of hairiness variation.

III. FROM SENSORS TO COMPUTER

A. Capacitive Measurement

Capacitor plates were connected (1mm width) to the MS3110 of *Microsensors®*. This integrated circuit (IC) implements the functions related to transducer, amplification and signal conditioning, specific for capacitive sensors and has the following characteristics [15]:

- Capacitance resolution up to 4.0 aF/rtHz
- Single variable or dual differential variable
- On-chip dummy capacitor for quasi-differential operation and initial adjustment
- Gain and DC offset trim
- Programmable bandwidth adjustment 0.5 to 8 kHz
- 2.25 V DC output for ADC reference/ratiometric operation
- Single supply

- On-chip EEPROM for storage of settings

The sensor and the conditioning circuit (including amplification) are connected to low pass filter in order to filter some noise that could be introduced; the low pass filter calculates an average of inputs readings. Afterwards, the circuit is connected to an analogue channel of a data acquisition board (PCI-6024E from *National Instruments*) [16]. This board has an analogue to digital converter of successive approximation in 12 bits and a sample frequency in one channel up to 200 kHz. Finally, and after signal acquisition by the computer, a *Labview* based software from (*National Instruments)* was developed for process monitoring (figure 7).

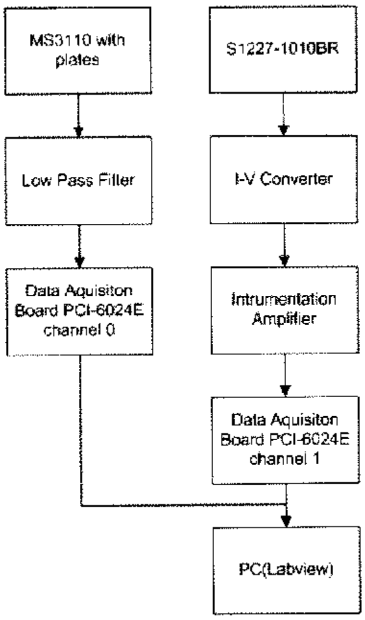

Fig. 7- Diagram block schematic of signal acquisition

B. Optical Measurement

Measurement of hairiness requires two distinct parts of hardware, electronic and optical. The electronic hardware, still being developed, uses, as a receiver, a photodiode (S1227-1010BR) [17] from *Hammamtasu* ®. Some of its characteristics are:

- Measurement area of 10x10mm
- Sensitivity for the emitter used (Laser) of 0.39 A/W
- Maximum dark current of 50pA
- Shunt resistance of 2GOhm
- Terminal capacitance of 3000pF

A conditioning circuit is being designed. This includes a current to voltage converter and an instrumentation amplifier to eliminate offset and noise, introduced by operational amplifiers of the circuit. The output of the instrumentation amplifier is connected to an analogue channel of the data acquisition board. Finally, software developed in *Labview* is used to acquire and process data.

Figure 8 presents the optical system used to obtain the hairiness information.

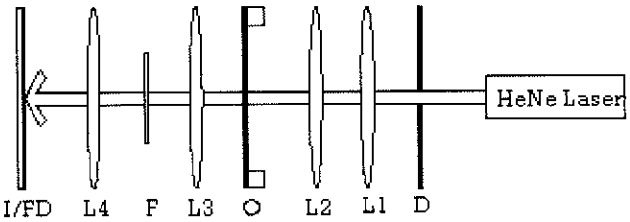

Fig. 8-Experimental setup of the optical system

Where,

I/PD – Image plane/Photodiode
L1, L2, L3 and L4 – Lens
F – Optical filter
D – Diaphragm
O – Object plan/Yarn

The objective of this setup is to quantify yarn hairiness, as the brighter elements of the final image. The setup presents the optical devices needed to obtain the image of yarn hairiness placed in the object plane. The first device is the light emitter (HeNe laser), followed by the diaphragm, to limit the laser beam to its core. After the diaphragm, the laser beam passes through a two lens beam expander (L1 and L2), and is directed to the yarn, placed in the object holder. The size of the object image is controlled by the lenses L3 and L4. A custom fabricated spatial filter (F) is placed in the Fourier plan of L3, to process the image, permitting only the high spatial frequencies in the image to propagate further. Essentially this is a high pass spatial Fourier filter [7, 8, 10]. This results in the contours of the edges of the yarn and associated hairs being highlighted while simultaneously eliminating the constant background (compare the images in figures 11 and 12 below) associated with the portion of the laser beam that was not obstructed by the sample. Through this method a much higher portion of the processed optical signal is associated with the presence of hairs on the yarn.

IV. RESULTS

A 30 Ne cotton yarn, for a length of 1 km at a speed of 50 meters/minute was used in this experimental work. This corresponds to an acquisition frequency of 833.33 Hz for a sample per millimetre, and 104.16 Hz for an average of 8 samples [18].

A. Capacitive Measurement Results

Table I shows the results of evenness and faults obtained with 1mm samples. As expected, the increasing in threshold (lower sensitivity), leads to small analysis results in DR, IDR, Thin and Thick Places; Neps were obtained for only one threshold value (100%), U and CV refer to all measured samples.

TABLE I
EVENNESS AND FAULTS IN 1 MM SAMPLES

Thres-holds (%)	DR (%) (m)	IDR (%)	Thin places	Thick places	Neps 100 (%)	U & CV (%)
20	25.23 252.34	5.71	50769	59360		
40	1.78 17.75	0.64	3639	5607	8	11.2
60	0.05 0.50	0.02	97	348		14.0
80	0.00 0.00	0.00	8	18		

Signal Processing Results

Fig 9 and 10 show the results of the spectral analysis performed with the FWHT and the FFT with 1 mm sensor, respectively [3].

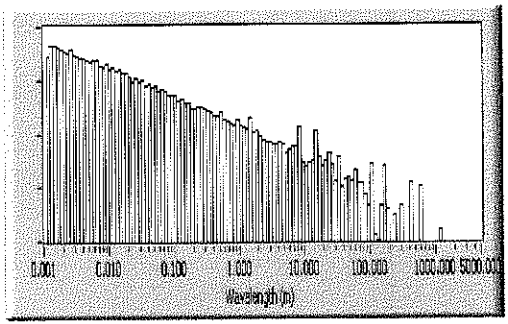

Fig. 9- FWHT for 1mm samples

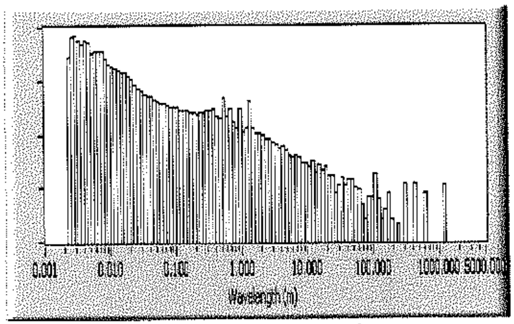

Fig. 10-FFT for 1mm samples

Analysing figure 9 and 10 it is observed that the major problem in the FFT is found close to the wavelength of 1 meter. Although the FWHT identifies also a problem at 1 meter, a major one is detected, close to 10 meters. Furthermore, the most important information that can be drawn from the results is the measurement of wavelengths at the range]2 mm, 2 cm[for the FFT and]1.2mm, 2 cm[in the FWHT. These results are not available in commercial products, which are only capable of detecting features at wavelengths of 2 cm and above. The data obtained for spatial distances of less than 2 cm is of utmost importance because it allows identification of raw materials used, in some types of yarns.

B. Hairiness Analysis Results

Figures 11 and 12 present the image of the yarn without and with the application of the coherent optical filter, respectively. Figure 13, corresponds to a photograph of the same yarn using the optical filter, but in this case the hairiness was greatly reduced by wetting the yarn with water.

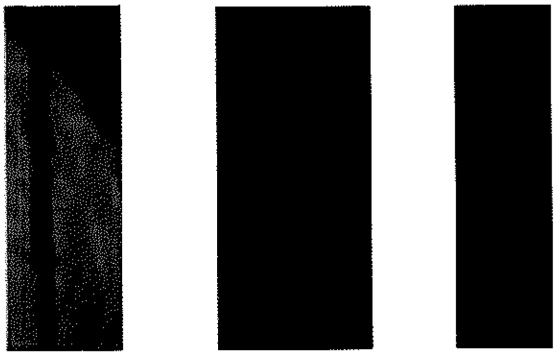

Fig. 4, 13 and 14 - Images of yarn with hairiness, without the high spatial frequency filter, with filter and increasing exposition time, respectively.

In figure 11, it is very difficult to identify yarn hairiness, because they are very thin, compared to the yarn. The resulting shadows are lost as a background in the high intensity of the unobstructed laser beam. Figure 12, taken using the same section of yarn but employing the coherent optical filter clearly highlights the previously hidden yarn hairiness.

Figure 13 is the image of the yarn, using water droplets to smooth the hairiness to the yarn. By doing this, it is desired to see the optical effect of the yarn itself, without the visualization of the yarn hairiness. In fact the signal from the yarn itself in the absence of hairiness is much reduced – to even obtain an image the exposure time had to be increased significantly. These preliminary measurements give us good reason to believe that it will be possible to develop an automated hairiness measurement procedure that is robust and precise.

IV. CONCLUSIONS AND FUTURE WORK

In comparison to 8mm commercial equipments, 1mm analysis has the advantage of enabling detection of faults for lengths of 1mm and above, specially important for neps [3], because they occur in up to ranges of 4mm length. This increase of resolution could contribute greatly to elevate quality requirements. Furthermore, new parameters were determined (DR and IDR) quantifying irregularity characteristic of yarn in the range [0,100] %, and not only for 0%, as U.

The signal processing techniques used (FFT and FWHT), with 1 mm samples are of utmost importance to the producer, because the measurement ranges are not available in commercial equipments (inferior to 2 cm), enabling, in some types of yarns, the detection of fibres constitution. As Signal Processing is extremely important for analysing data, future work will include spectral analysis based on Impulse Frequency Determination (DFI) to reduce its computational complexity [5].

Regarding hairiness analysis, there is a connection between the dimension of the filter applied in the set up and the frequency limit allowed. We are currently developing a technique to calibrate this signal to permit the determination of the ratio of hairiness mass compared to yarn mass.

The final goal of the project is to develop low cost system, which enables on-line control of yarn quality.

V. ACKNOLEDGMENT

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