Yarn Mass Analysis with 1 mm Capacitive Sensors

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Abstract— This paper presents the advantages of analysing yarn evenness, based on mass variation, using a capacitive sensor which allows the measurement of 1 mm yarn length [8][9]. The variation of capacity is due to the dielectric change and is proportional to the quantity of yarn mass between the sensor plates. Available commercial equipment uses a solution of 8 mm with the drawback of decreasing the resolution eight times. This limits the correct detection of Neps and other parameters. This type of fault (Nep), usually has a length between 1 and 4 mm, which can be measured directly with the new sensor. Commercial equipment detects this fault based on estimation.

This paper also presents the spectral analysis of the yarn mass. This is important for textile quality control. Two approaches are presented, one based on a FFT model definition of narrow bands to aggregate the harmonics and other based on the Walsh - Hadamard Transform. They show the wavelength detection of the sample taken into test, enabling the detection of the most common faults and errors, namely: fibre wavelength, and production faults. Furthermore, with the resolution presented it is possible to measure wavelengths in the range [2mm, 2 cm], which is impossible with commercial available solutions. The information obtained in this interval, is of utmost importance as it allows the characterization of the fibres in some types of yarns.

The main objective of the project is to increase the quality specifying strict requirements allowing, in the near future, real-time actuation on a ring spinning frame.

Index Terms— Yarn Evenness, Capacitive Sensor, Signal processing.

I. INTRODUCTION

Yarn properties assessment has been subject to a considerable amount of work. There are many characteristics, which combined, give distinct properties of an individual yarn. Yarns can vary in properties such as strength and twist as well as some mass variation per unit length: yarn irregularity. Variations in the factors mentioned are to a large extent, secondary or tertiary effects of variations per unit length. It is important to recognize that all spun yarns are to some extent irregular, and it is the degree of irregularity, which determines whether it is acceptable, or not for a particular end-use. Because the appearance of many fabrics is influenced by yarn irregularity, this is frequently regarded as one of the most important yarn characteristics [7].

For detection of such irregularities electronic capacitance testers are to a great extent still applied nowadays, as a convenient and reliable method of testing irregularity (determination of mass every 8 mm). Variations of mass are classified in three types of faults: thin points, for mass decreases, thick points, for mass increases lower than 100 % and Neps for mass increases 100 % over [1]. The developed system allows the configuration of pre-defined thresholds for classification of these faults [2].

The first method was based on digital signal processing to extract 1 mm mass values, using measurements of 8 mm sensor length, acquired with a sample rate proportional to 1 mm yarn length [6]. Sequential samples of the mass signal are acquired in such a way that the length interval is in the 1 mm range. The method proposed determines the yarn mass variation in portions of 1 mm, from 1 to 8 mm, using an 8 mm experimental measure. However, to guarantee the measurement in the 1 mm range it is necessary to have, periodically, some calibration procedures. This fact did not allow the use on production systems [9].

In order to obtain reliable and accurate 1 mm measurements without mathematical models, we intend to use a 1 mm capacitive sensor. As capacitive sensors with 1 mm width parallel plates show small voltage variations, some tests had been made with a cylindrical sensor with a central electrode of 1 mm of diameter. After the failure of the general purpose approach with this sensor, some improvements in the electronic conditioning allowed obtaining acceptable results. Preliminary tests and the comparison with 8 mm length industrial equipment proved that the system works correctly.

A capacitive sensor of parallel plates with respective amplification and conditioning electronic was developed [3]. This equipment allowed achieving good results with 4 mm length plates. Based on these positive results, an improvement in the electronic circuit was made that allows the use of a new sensor, with only 1 mm length. After these changes and calibrations in the electronic circuitry, experimental work was performed. Regarding accuracy, a theoretical study was undertaken to quantify the capacity variations as a result of the variation in dielectric constant due to the cotton yarn in the air volume between plates. As a result of the study a value of $2,08E-17$ F for variation is estimated for a yarn of 57 tex. Afterwards, a study of the influence of

radiation on the capacitive sensor was done. To eliminate the effects, a differential configuration of two capacitors with a common plate was used (Fig. 1). One of the capacitors is used for calibration and the other for the mass measurements, itself.

Fig. 1 Differential configuration sensor

II. NEPS DETECTION

A Nep fault is characterized by an huge increase of mass (usually more than 200%) and occurs typically in quantities of yarn length less or equal to 4 mm (Fig. 2).

Fig. 2 Nep fault representation

Commercial equipment, using 8 mm capacitive sensors, obtains its results based on estimation techniques, specifying the uncertainty of each of measurement; sometimes the results converge even to a wrong classification. The developed system with the 1 mm sensor, detects this fault directly because the analysis is performed on 1 mm length samples. So, is possible to detect these high variations of mass in their interval of appearance [1mm, 4mm], resulting in its identification and measurement with certainty and accuracy.

Fig. 3 and fig. 4 show the mass variation analysis performed on a 30 Ne (linear mass) cotton yarn for the 1 mm sensor (performed directly) and for the 8 mm sensor (performed statistically with the average of 8 samples with 1 mm), respectively.

Fig. 3 Mass variation diagram for 1 mm samples

Fig. 4 Mass variation diagram for 8 mm samples

Comparing both figures it can be observed that for the 8 mm sensor the mass variation occurs in the interval $[-50, +70]$ % of the average mass and for the 1 mm sensor in the interval $[-80, \text{more than } +100]$ %. In this test only, with the higher resolution sensor it was possible to detect Neps. The 8 mm sensor works as a 1 mm sensor with a low-pass filter (average effect). In this type of filters frequencies above the "cut" frequency (f_c) are attenuated, as seen in fig. 5.

Fig. 5- Example of a bode diagram in a low -pass filter

Fig. 6 and fig. 7 present the frequency mass diagrams for 1 and 8 mm samples, respectively.

Fig. 6 Mass frequency diagram for 1 mm samples

Fig. 7 Mass frequency diagram for 8 mm samples

With the 8 mm sensor a "straighter" curve is obtained. This could be seen as if the yarn analysed has a lower variation tendency over 0 % of the mean (more regular), in comparison with 1 mm results, where a more wether curve is observed.

Regarding faults, table I shows its variation and the irregularity detected with the 1 mm sensor in comparison with the 8 mm sensor.

Table I -Faults and irregularity variation on 1 mm samples is compared to 8 mm samples

Thres-holds	Thin points	Thick points	Neps	CV (%)	U (%)
20%	+46644	+57417	+8 (0 for 8 mm) (8 for 1 mm)	+3.71	+2.97
40%	+3633	+5468			
60%	+97	+342			
80%	+8	+18			

From table I, it is observed that greater quantities of faults are detected with the 1 mm sensor. These results were expected because this sensor has an eight times higher resolution. Furthermore, as already stated, the 8 mm sensor works as a 1 mm sensor with a low-pass filter (all high-frequency changes are attenuated). As this is the case of faults, this detection is not so accurate with the 8 mm sensor.

As a direct consequence of the number of faults detected, the irregularity values [10], U (mean deviation - which is proportional to the sample's mass variation around the average) and CV (coefficient of variation- which is related to U for normal distributions and its equal to 1,25U) also present a positive variation between 3 and 4 % respectively (the test was performed for a sample of 1000 meters at a speed of 50 meters/minute, which corresponds to an acquisition frequency of 833.33 Hz for a sample per millimetre, and 104.16 Hz for an average of 8 samples (8 mm sensor)).

It must be emphasised that with the 1 mm sensor it is possible to simulate the 8 mm sensor used in industry.

III. SPECTRAL ANALYSIS

A. Periodical Errors

The existence of a constant frequency of yarn irregularities is one of the causes for the appearance of imperfections in the production material (e.g. fabrics). These defects appear as visible high energy peaks in the frequency analysis.

So, 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 [4]:

1. 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.

Fig. 8 Accumulated dirt error

2. The second type (Fig. 9), generally due to imperfections in the surface of the rollers, generating a periodic impulse fault (imperfections in the raw material are seldom periodic).

Fig. 9 Imperfection in the surface rollers error

As spectral information, in terms of wavelength (λ), give a more perceptive result to the yarn producer, the results are performed in the 1 mm to 5 Km range. Wavelengths are calculated considering the results in frequency as (1).

$$\lambda(m) = l \frac{f_a}{1000 f_d} \quad (1)$$

Where,

l = width of sensor (mm)

f_a = acquisition frequency (Hz)

f_d = detected frequencies for faults (Hz)

B. FFT Approach

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

In (2) is shown the DFT one-dimensional determination.

$$F(K) = \frac{1}{N} \sum_{m=0}^{N-1} f(m) e^{-j \frac{2\pi}{N} km} \quad k = 0, 1, \dots, N-1 \quad (2)$$

The multiplicative constants can be grouped arbitrary, so the DFT expression can be written as (3).

$$F(K) = \sum_{m=0}^{N-1} f(m) W_N^{Km} \quad k=0,1,\dots,N-1 \quad (3)$$

Where,

$$W_N^{Km} = e^{-j2\pi / N} \quad (4)$$

By (3) is seen that there are necessary N complex multiplications and N complex sums, or as the same, $2N^2$ arithmetic complex operations. By this reason the FFT algorithm is based on the decomposition of the DFT calculus, in a sequence of longitude N, decreasing each step by half.

Fig. 10 shows the FFT algorithm for 8 samples. The first step consists of calculating four DFTs of 2 points, the second step, two DFTs of four points and the last step one DFT of 8 points, always based on the previous results.

Fig. 10 FFT algorithm for 8 samples

The final analysis is performed considering the magnitude spectrum (5) using energy bands.

$$\text{Magnitude spectrum} = |F(K)| \quad (5)$$

The intervals of the energy bands, for each decade, are calculated by (6).

$$\text{int}(j) = \sum_{i=0}^{j=n-1} 10^{\frac{i+j}{n}} \quad (6)$$

Where,

- n= number of intervals
- i= decade index (-3,..., 4) for [1 mm, 10km]
- j= interval index (0,..., n)

Then, all the wavelengths detected, at the corresponding energy band, are summed and then multiplied by its number, obtaining the final value of the energy band (7).

$$e(j) = n \sum_{w=1}^{w=k} \lambda(w) \quad (7)$$

Where,

- k= number of detected wavelengths in the band
- w= index of detected wavelength
- $\lambda(w)$ = wavelength amplitude at the index w

C. FWT approach

The Walsh functions create an ordered set of rectangular waves presenting only two possible amplitudes, +1 and -1 [5]. They are defined over a limited interval and, as in the case of trigonometric functions; two parameters are necessary for its total identification. Walsh functions are denoted by WAL (n,t), where t represents the position in the defined interval and n is the order number which is related with the frequency and is equal to the sign changes.

For the classification of Walsh functions is commonly used a notation in terms of odd and even symmetries. Two series are presented, the CAL series and the SAL series, which are very analogue with the 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 (8) and (9):

$$CAL(k,t) = WAL(2k,t) \quad (8)$$

$$SAL(k,t) = WAL(2K-1,t) \quad (9)$$

where the k parameter is defined as the major integer less or equal to $(n+1)/2$.

Three main types of ordering the Walsh functions are known: the sequential, the natural or Hadamard and the dyadic or Paley. In the sequential order, functions are ordered in terms of the sign changes of each wave (Fig. 11); the Hadamard order, which is the one used in this work, is computationally the most efficient, and is related with the Hadamard matrix. The smallest Hadamard matrix that can be generated is shown in fig. 12. All the other matrices are formed recursively by (10), where n is number of bits of the sample to analyse (2^n samples).

Fig. 11 The first 8 Walsh functions

$${}^1WH = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

Fig. 12 Hadamard smallest matrix

$${}^{n+1}WH = \begin{bmatrix} {}^nWH & {}^nWH \\ {}^nWH & -{}^nWH \end{bmatrix} \quad (10)$$

Fig. 13 shows the first 8 Walsh functions ordered by the natural or Hadamard form.

Fig. 13 Hadamard or natural order for 8 samples

The result is an 8x8 matrix.

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

Fig. 13 Hadamard matrix for 8 samples

Finally, the Walsh-Hadamard transform is given by (11).

$$FWT = [x(0) \ x(1) \ \dots \ x(n-1)]^k WH \quad (11)$$

Where,

x = array of mass variation (0, 1,..., n-1)
 $n= 2^k$ samples

D. Results

Fig. 15 and fig. 16 show the results of the spectral analysis performed with the FFT and the FWT with 1 mm sensor.

Fig. 15 FWT for 1 mm samples

Fig. 16 FFT for 1 mm samples

Analysing the results it is observed that the major problem in the FFT is found close to the wavelength of 1 meter. Although the FWT 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 FWT. These results are not available in commercial products, because they only present results for wavelengths of 2 cm and above. The data obtained before this level is of the utmost importance due to the fact that it allows the identification of the fibres constitution in some types of yarns.

E. Comparison between approaches

The Walsh approach has the advantage of being computationally simpler than the sinusoidal transforms because no complex multiplications need to be made, maintaining the resolution and the wavelength below 2 cm. However, it is more difficult to analyse, because it requires taking all the samples to perform the spectrogram.

The FFT approach is easier to analyse because only half of the samples are needed, due to the symmetrical characteristic of the spectrogram, but has the drawback of the need for heavy mathematical processing considering the complex multiplications. The relation with the yarn production is easier as it has several sinusoidal defects.

IV. CONCLUSIONS

The results obtained with the developed system (1mm resolution), showed proper results.

Due to the fact that there are no standard tables for 1 mm sensors to classify the quality pattern of the yarn, mathematical treatment for comparison with the available tables [11] (8 mm sensors) has to be done. So, the intention to build those ones prevails as an objective of the project.

FFT and FWT analysis with 1 mm samples allow results of the utmost importance to the producer, because the ranges of measurement are not available in the commercial equipment. As Signal Processing is extremely important for analysing the data obtained, future work will include spectral analysis based on the Impulse Frequency Determination (DFI).

The final goal of the project is the on-line control of yarn quality, using information based on 1 mm results.

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VI. REFERENCES

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