On-line Measurement of Yarn Evenness

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Abstract— **The aim of this paper is to present an experimental procedure to measure yarn evenness in real-time using capacitive sensors; samples with several millimetres are analyzed, depending on the type of sensor used, to increase quality in production.**

The approach used allows a direct measurement in 1mm range, allowing real-time actuation when faults or other parameters exceed the maximum acceptable value.

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

I. INTRODUCTION

The quality of any textile product is strongly influenced by the type of its components, e.g., fibres and yarns. These must be manipulated in bulk and the resulting structure has many varying characteristics, which depend ultimately on the variation in mass per unit of length. It is thus important to determine the linear density variations and the total irregularity to predict the effect of the yarn's properties on the production and appearance of the finished fabric.

For detection of such irregularities it is still applied nowadays, electronic capacitance testers as a convenient and a reliable method of testing irregularity (determination of mass every 8 mm). The system signals when the mass value is greater or lower than pre-defined thresholds. These sensitivity thresholds are related to the mass average value, and allow the detection of yarn faults [1].

Yarn mass 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 length).

This paper presents a new system for direct measuring 1mm yarn mass using a capacitive sensor, defining by software different sensitivity regions for yarn classification.

II. THEORETICAL CONSIDERATIONS

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

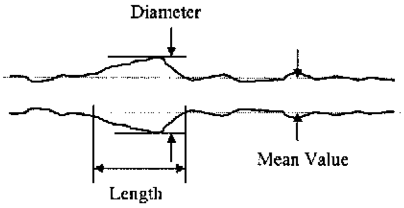

Fig. 1 Example of yarn configuration

In order to obtain yarn mass irregularity, electronic capacitance tests are established as a convenient method [2]. The basic requirement of this type of unevenness tester is that the output of the measuring circuit is directly proportional to the linear density; the relationship between capacitance and fibre mass must be linear. The changes of capacitance brought about by alteration of the total fibre cross-sectional area between the plates enables the automatic indication of the mean absolute deviation (U%) and coefficient of variation (CV%) [3].

In mathematical form, U% is defined by equation 1.

$$U = \frac{100}{\bar{x}T}\int_0^T \left|x_i - \bar{x}\right| dt \qquad (1)$$

Where, x_i – instantaneous value of the mass
x – average mass value (mean) during evaluation time
T – evaluation time

The irregularity U is proportional to the mass variation around the average, and is independent of the evaluating time (tested material length) if the mass variation is homogeneously distributed. In this case the mass variation fits approximately the normal distribution. The measure of the mass variation is the standard deviation, which is defined as the distance from the average value to the point of inflexion of the normal distribution curve. The CV% is related with the standard deviation and the mean value as defined in (2).

$$CV = \frac{100}{\bar{x}}\sqrt{\frac{1}{T}\int_0^T \left(x_i - \bar{x}\right)^2 dt} \qquad (2)$$

The number of faults and mass measurements enable a quality rating of the product. An accurate measurement of these properties is of major importance [4]. There are three kinds of yarn faults, classified as (Figure 2):

- thin places - a decrease (50%) in the mass during a short length (4 mm);
- thick places - an increase in the mass, usually lower than 200% and lasting more than 4 mm;
- NEP's - huge amount of yarn mass in a short length (typically from 1 to 4 mm).

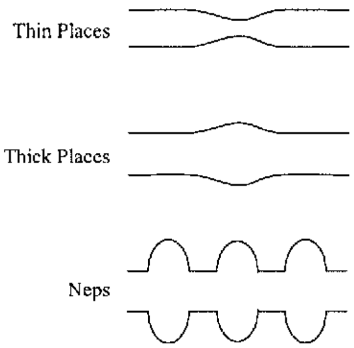

Fig. 2 Types of yarn faults

III. CAPACITIVE SENSORS

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

Capacitive sensors are traditionally formed with two plates (electrodes) of section S, separated by a distance d, where the final value of capacity depends on the plates section, their distance and the dielectric material. In this specific research the parameter changing will be the dielectric between the plates (yarn) that will vary depending on the yarn composition and diameter, allowing us to establish a relationship between the capacity and the mass value of yarn (figure 3) [8].

The capacity of a parallel plate capacitor is determined by (3).

$$C = \frac{\varepsilon_0 \varepsilon_r S}{d} \tag{3}$$

Where,

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

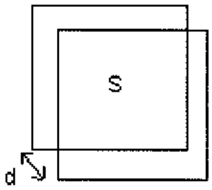

Fig. 3 Parallel plates capacitor

Using (3) we can verify that if the dielectric constant value (ε_r) is changed, the capacity also changes, phenomenon that occurs when we put the yarn between plates. A relationship is established between the capacity (C) and the yarn mass.

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

To overcome this problem we need to be careful when using capacitive sensors, using amplification circuits that auto-correct themselves. Furthermore, the software developed solves this problem using the value acquired without yarn as a calibration value. This task can be performed daily as humidity change has a low time constant.

Another problem was related to magnetic interferences. To solve that, a metal box was build and grounded. The sensor was placed inside (figure 4). The result was extremely positive because all the interferences disappeared.

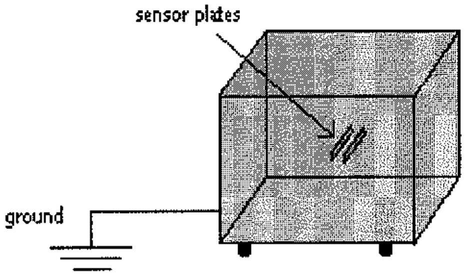

Fig. 4 Shielded Box

IV. YARN MASS FROM THE SENSOR TO THE COMPUTER

Capacitor plates were connected (1 to 8 mm width) to the MS3110 of *Microsensors*®.

This integrated circuit (IC) implements the functions related to transducer, amplification and signal conditioning; it is specific for capacitive sensors and has the following characteristics [9]:

- 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 analog channel of a data acquisition board (PCI-6024E from *National Instruments*). Some relevant characteristics of this board are: 16 input analog channels, 8 digital lines of I/O, an analog 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* 6.1 based software from (*National Instruments)* was developed for process monitoring (figure 5).

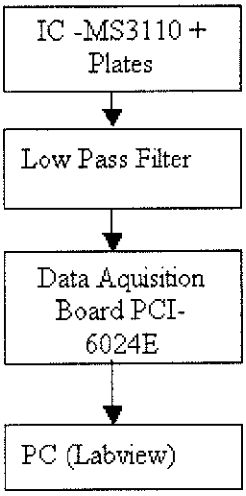

Fig.5 Diagram block schematic of acquisition

V. THE SOFTWARE

The customized program developed used *Labview* 6.1. 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(%) and using Fast Fourier Transforms (FFT) to extract some periodic faults.

A. 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 4 values of sensitivity (%)
- Location of the results files
- Type of sensor(mm)
- Sample length (m)
- Output digital channel

Although there are established sensitivity values for classification of yarn evenness, the user can define up to four sensitivities values, to perform a detailed analysis.

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

The output digital channel is used because the process of turning on/off the machine that controls the yarn speed is computer controlled, depending on the sample length to be analyzed and the yarn speed (4).

$$time(s) = \frac{sample}{speed} * 60 \quad (4)$$

Where,

sample = sample length to be analyzed (m)
speed = yarn speed (m/min)
time = acquisition time (s)

For turning on the machine, the computer activates a digital signal, turning on the machine during the time period considered.

B. 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 Graphic
- U (%), CV (%)
- Thin points, thick points for each value of sensitivity and neps
- Sample frequency (Hz) and period (s)
- FFT frequency peak and its power
- Sensor voltage without yarn (V)
- Average voltage level of yarn (V)
- Final and actual acquisition time (s)
- Machine state (on/off)
- Actual sample length (m)
- Result files

The mass yarn variation (%) is calculated for each sample (5).

$$mass(\%) = 100 * \frac{Vm - Xi}{Vsf - Vm} \qquad (5)$$

Where,

Vm = average voltage level of yarn (V)
Xi = actual voltage level of the sample (V)
Vsf = voltage of the sensor without yarn (V)

The expression used to calculate the sample frequency and period that takes one sample depending on the plates width is shown in (6) and (7).

$$f(Hz) = \frac{speed * \frac{1000}{60}}{n} \qquad (6)$$

$$T(s) = \frac{1}{f} \qquad (7)$$

Where,

n = type of sensor (1 to 8 mm)
speed = yarn speed (m/min)

The developed software calculates all the output variables on-line (using the buffer zero acquisition mode), except the FFT and result files that are evaluated and displayed at the end of the run.

The front panel software developed is shown in figure 6.

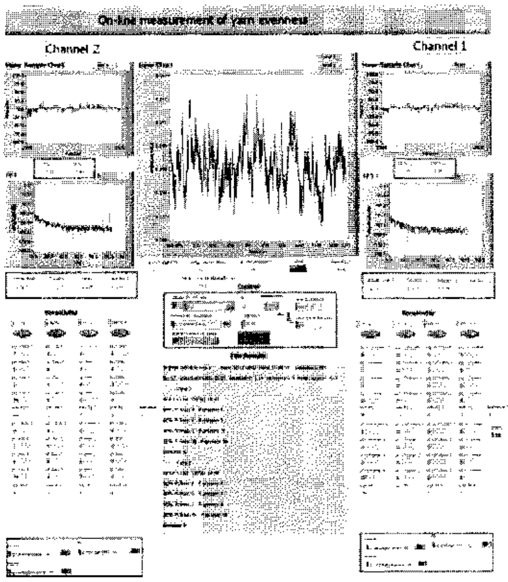

Fig.6 Front panel acquisition software

VI. RESULTS

Some tests were performed in order to evaluate the experimental setup. We present here two experiments using staple fibre yarn (cotton) and filament yarn (polyamide).

Test 1

The initial settings for polyamide yarn analysis are:

- Yarn linear mass = 76.5 tex
- Speed yarn (m/min) = 25
- Type of sensor (mm) =4
- Sample length (m) = 187.5
- Sensitivity (%) = 20,40,60,80

Table 1 presents the results obtained in terms of number of thin, thick points and neps in each sensitivity range considered, as well as U% and CV% values.

Table 1 Faults and evenness results (Test 1)

Sensitivity	Thin points	Thick points	Neps	CV (%)	U (%)
20%	6	13	0	12.5	10.0
40%	1	0			
60%	0	0			
80%	0	0			

Figures 7, 8 and 9 show the sample chart results in terms of FFT profile, linear mass variation (in %) and input signal (in V), respectively.

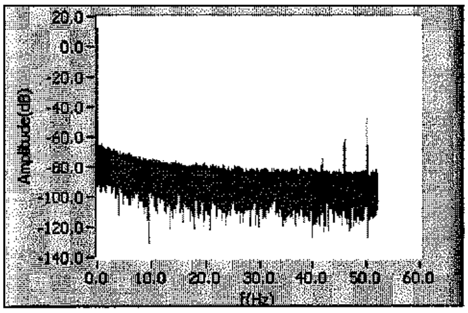

Fig.7 FFT test results

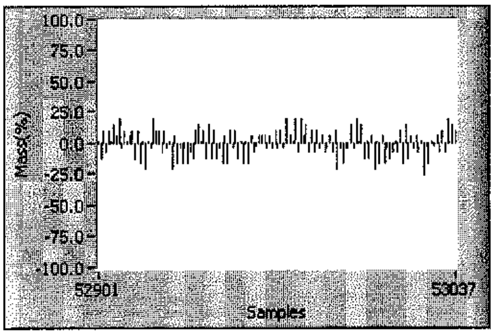

Fig. 8 Linear mass sample test results

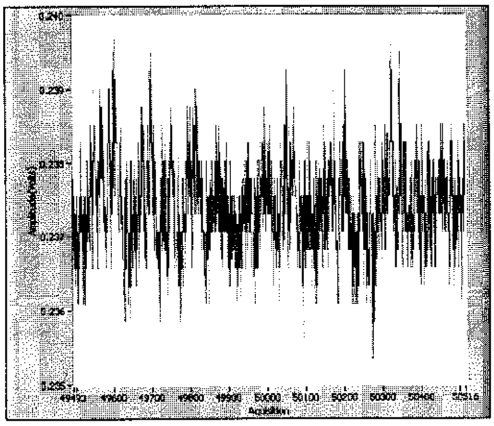

Fig.9 Input signal sample test results

Analysing the results we can conclude that the filament presents a good quality pattern because the values of U (%) and CV (%) are at low levels and just in the sensitivity scale of 20 % and 40 % we measured faults. However, these results were expected due it was a polyamide filament, which is very regular.

Test 2

The initial settings for cotton yarn analysis are:

- Yarn linear mass = 16 tex (carded yarn)
- Speed yarn (m/min) = 25
- Type of sensor (mm) =4
- Sample length (m) = 187.5
- Sensitivity (%) = 20,40,60,80

Table 2 presents the results obtained in terms of number of thin, thick points and neps in each sensitivity range considered, as well as U and CV values. It also displays the values obtained with Uster statistics (classification) regarding this type of yarn.

Figure 10, 11 and 12 show the sample chart results in terms of FFT profile, linear mass variation (in %) and input signal (in V), respectively.

Table 2 Faults and evenness results (Test 2)

Sensitivity	Thin points	Thick points	Neps	CV (%)	U (%)
20%	40 P(5)	558 (P50)	0 (P<5)	14.95 (P25)	11.96 (P50)
40%	1 (P<5)	15 (P<5)			
60%	0 (P<5)	1 (P<5)			
80%	0 (P<5)	0 (P<5)			

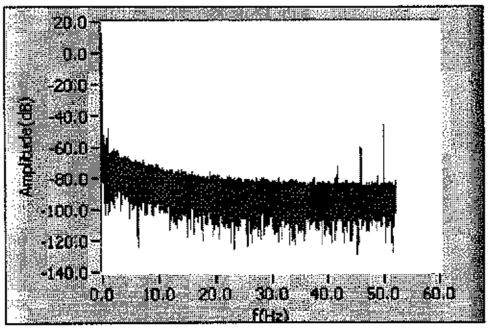

Fig.10 FFT test results

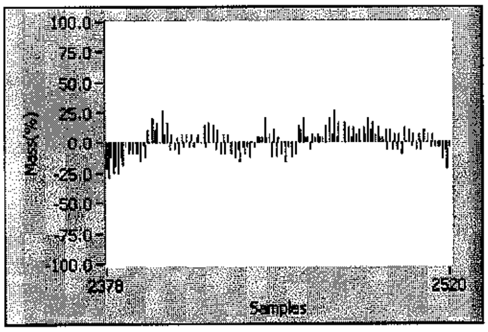

Fig.11 Linear mass sample test results

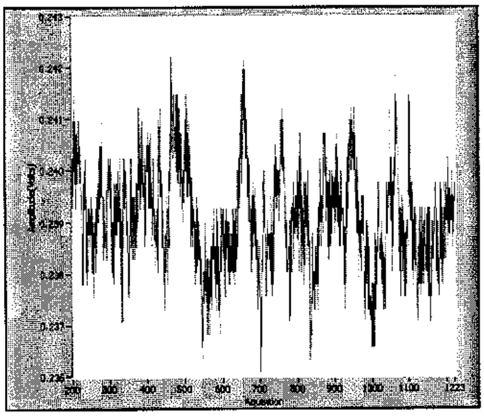

Fig.12 Input signal sample test results

Analyzing the results we can conclude that the measured yarn has poor quality. The values of U (%) and CV (%) are between 11.96 % and 14.95 % shown by the results of evenness. However, as we expected in terms of Uster values, the yarn is considered in medium range related to U (%) and CV (%) and a very good yarn concerning fault results.

VII. CONCLUSIONS

The results obtained so far with the system presented, show that the electronic devices and the signal processing techniques allow the same results as equipments with 8mm resolution.

In current quality yarn control only 8 mm sensors are used. The use of smaller length sensors (up to 1mm) contributes significantly to the improvement of the yarn quality control. Furthermore, the system is able to measure evenness, and common faults up to four values of sensitivity. The operator is able to choose the sensitivity level according to the production requirements. As presented in [VI] the system is also able of presenting the results with any resolution multiple of 1mm.

The spectral analysis allows the evaluation of a periodogram based on 1mm samples on the opposite of industrial system that use statistical approach to evaluate the result using 8mm sensors.

The present software is still undergoing improvements.

VIII. ACKNOWLEDGEMENTS

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