Yarn-Mass Measurement With 1-mm-Length Samples

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***Abstract*—In textile production, measurement of yarn mass in the 1-mm range is of utmost importance to properly evaluate evenness, as several irregularities occur in 1–4-mm yarn length. Direct measurements in the 1-mm range are not available in commercial equipment. One of the most common, from Uster, is based on yarn samples of 8 mm. This paper presents a direct mass measurement in the 1-mm range system based on parallel capacitive sensors and signal-processing techniques for detection of periodical errors. Results point out that evaluation of yarn mass, with this approach, is feasible in the 1-mm range, allowing online measurement (1-mm yarn mass) in a spinning frame for real-time control. Despite low signal-to-noise ratio, it is possible to measure small variations of yarn mass (typical capacity variation of 2.08×10^{-17} F for 57 tex—0.057 g/m of yarn). As a spin-off of this project, a new low-cost control system is being prepared for detection of yarn break and bobbin end in knitting flat machines. Online quality classification is also feasible with the developed system.**

***Index Terms*—Capacitive sensor, signal processing, yarn evenness.**

I. INTRODUCTION

THE QUALITY of any textile product is strongly influenced by its components, e.g., fibers and yarns. These must be manipulated in bulk, and the resulting structures have many varying characteristics, which ultimately depend on variation in mass-per-unit length. It is thus important to find out linear-density variations and irregularity, to predict yarn properties' effects on production and fabric final appearance.

For the detection of such irregularities, electronic-capacitance testers are still applied nowadays as a convenient and a reliable method of testing irregularity (determination of mass variation). The system signals when a measured mass value is greater or lower than predefined thresholds. These thresholds are related to yarn-mass average value and allow detection of imperfections (thick points, thin points, or neps) [1].

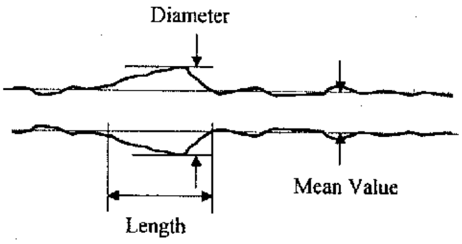

Fig. 1. Example of the yarn configuration.

Yarn mass evaluated in the 1-mm range is of utmost importance to a correct detection of defects, identification of periodical errors in wavelengths that start at 2 mm, which enable, in some cases, the characterization of fiber constitution of analyzed yarn and to perform an accurate classification of quality [2], [3]. This paper presents a new system for direct measurement of 1-mm yarn-mass length using a capacitive sensor.

II. TEXTILE PARAMETERS

Some of the most important parameters to identify yarn-quality specifications are linear density, structural features, and fiber content. An example of a yarn configuration is shown in Fig. 1.

Electronic-capacitance testers are established as an appropriate method to obtain yarn-mass irregularity [4]. The output of the measuring circuit is directly proportional to yarn linear density within the capacitor plates, that is, the relationship between capacitance and mass of the fiber between the sensor plates must be linear; changes of capacitance brought about by variation of the total fiber cross-sectional area between the plates enable automatic indication of mean absolute deviation ($U\%$) and coefficient of variation ($CV\%$) [5].

In mathematical form, U is defined (as a percentage) by

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

where

x_i instantaneous value of the mass;
$\bar{x}$ mean;
T evaluation time.

The irregularity U is proportional to the amount of mass variation around the average value and is independent of evaluating time or tested material length, if the material has a homogeneously distributed mass variation.

Standard deviation CV also measures mass variation and usually has a relation with $U (CV = 1.25\ U)$, considering that the yarn measured has an homogeneous fiber composition,

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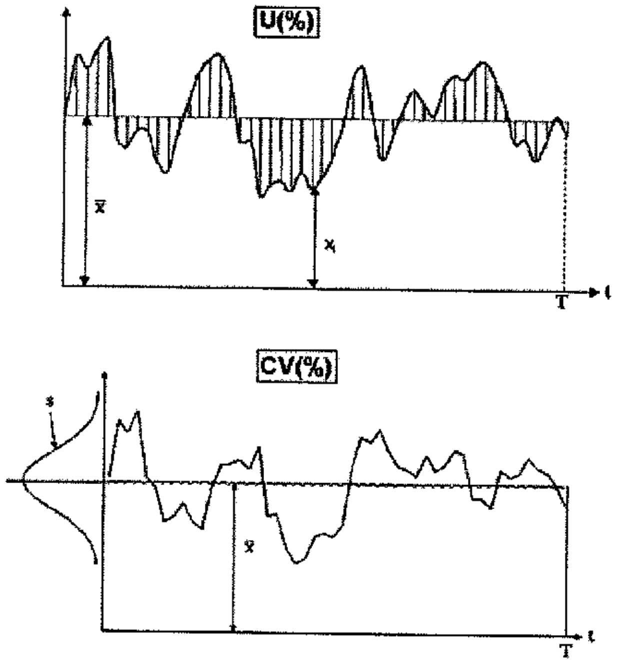

Fig. 2. Graphical representation of U and CV.

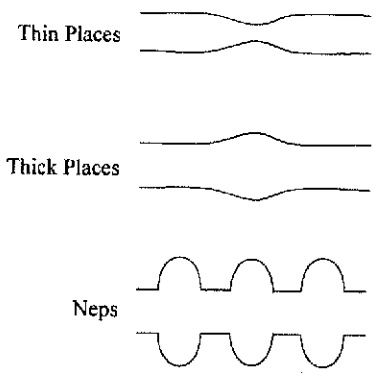

Fig. 3. Types of yarn faults.

which means a normal distribution in mass variation. The standard deviation is equal to the mean value as presented in

$$CV = \frac{100}{\bar{x}}\sqrt{\frac{1}{T}\int_{0}^{T}(x_i - \bar{x})^2 dt}. \qquad (2)$$

Irregularity $U\%$ and $CV\%$ can be described graphically according to Fig. 2 [5].

Apart from these yarn irregularities, it is important to provide data on the number and type of "imperfections" in order to produce a high-quality yarn. These are commonly named faults, namely (Fig. 3):

1) thin places—a decrease (50%) in the mass during a short length of about 4 mm;
2) thick places—an increase in the mass, usually lower than 200% and longer than 4 mm;
3) neps—huge mass of yarn in a short length, typically from 1 to 4 mm.

Number of faults and mass measurements (U and CV) enable a quality rating of a product. An accurate measurement of these properties is of major importance [6].

A. *Periodical Errors*

Analysis of yarn irregularity, which is known to contain a random component and eventually a periodic component, may be carried out with a frequency analyzer (spectrogram graphic) that performs harmonic analysis of periodic yarn irregularities. In the spectrogram, ordinates represent proportions of the irregularity associated with the wavelengths represented in abscissa. For a strand with fibers of uniform length, the relationship is given by the following [7]:

$$S(\log \lambda) = K\frac{\sin\frac{\pi l}{\lambda}}{\sqrt{\frac{\pi l}{\lambda}}} \qquad (3)$$

where $S(\log \lambda)$ is the amplitude of the spectrum corresponding to the wavelength λ plotted as abscissa, and K is defined by

$$K = \frac{1}{\sqrt{\pi\lambda}} \qquad (4)$$

where l is the fiber length and λ is the wavelength.

Maximum of ideal spectrum lays at about 2.3–2.7 of the mean fiber length.

Chimneys protruding above the smooth course of the spectrogram indicate regular periodic variations in the yarn, proportional to the ratio chimney height of to the height of the underlying curve at that point. Their wavelength is read off scale and processing details such as drafts, roller diameters, among others, may enable the deduction of the mechanical cause of the unwanted fault. Fig. 4 shows a typical spectrogram from commercial equipment based on an 8-mm capacitive sensor.

Observing Fig. 4, two main errors can be identified because of their higher amplitudes in relation to the surrounded wavelengths; one main error is between 5 and 10 cm and the other is between 50 cm and 1 m. With this information, the yarn producer should investigate the yarn fabrication process, at the errors distances, to determine their cause.

III. HARDWARE OVERVIEW

The first step of the work employed an experimental apparatus (Uster Tester I) based on a commercial 8-mm capacitive sensor and a Labview data-acquisition system to achieve yarn evenness.

After the validation of this experimental rig, comparing results with the ones obtained with a recent device, Uster Tester III equipment, the next research objective was to extract the 1-mm-mass values using measurements of 8-mm-length sensor. Using the signal-processing techniques described below, sequential samples of mass signal are acquired with length intervals in the 1-mm range [8]. A mathematical study allowed the extraction of the 1-mm-mass values, using measurements from an 8-mm-length sensor, acquired with a sample rate

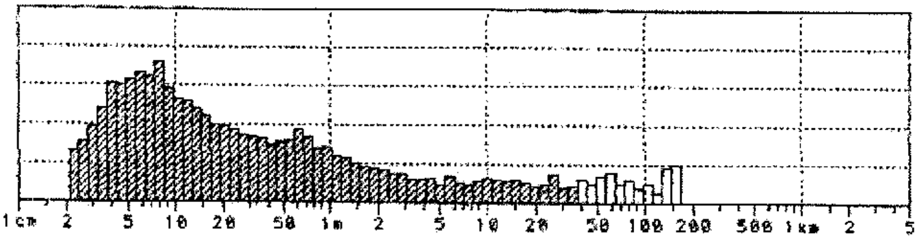

Fig. 4. Typical spectrogram from commercial equipment.

proportional to 1-mm yarn length (increasing in eight times the sample frequency).

In order to analyze the measurement-length influence (portions of 1 to 8 mm) in the evaluation of yarn evenness, a statistical study was carried out. The Scheffe method was used for pairwise comparisons of means. Pairs of means that were significantly different at 0.05 level were those obtained in comparison with the 1-mm range [9].

Commercial capacitive sensors with parallel plates with 1-mm length could not be found. Instead, a 1-mm-diameter cylindrical sensor was tested. The measurement sensor was tuned to get a maximum resolution. For that, the yarn should be placed as near as possible to the sensor, which also requires a specific and carefully designed electronic conditioning circuit. In this case, acceptable results were obtained. However, due to the yarn oscillations in industrial spinning frames, this kind of sensor could not be considered [10].

A capacitive sensor with parallel plates and the corresponding electronic conditioning circuit were developed. This setup allowed 4-mm yarn-mass reliable measurements, which were relevant for developing the 1-mm-length sensor.

Regarding accuracy, a theoretical study was undertaken to quantify capacitance variations due to the difference in the dielectric constant corresponding to an analysis with/without cotton yarn between the plates. An estimated variation of 2.08×10^{-17} F was considered for a 57 tex (0.057 g/m) yarn. The calibration process is taken, considering the output voltage of the sensor without yarn, as a reference or 0% mass measurement. Although it is possible with this equipment, to detect small variations, some difficulties, in terms of signal-to-noise ratio (SNR), were still present. These small variations of capacitance were translated in variations of microvolts voltage, resulting in a very small SNR. In order to reduce noise, some attempts were made using traditional high-pass filters, with relative success, as noise had its main component at the 50-Hz range (network energy frequency).

To overcome SNR problems, a study on the influence of electromagnetic interference was carried out, using two identical sensors, in a differential configuration but with different distances between the plates (Fig. 5). Due to the fact that both sensors vary almost in the same proportion as a result of electromagnetic interference, using one sensor as reference on the other as measuring sensor, their output difference eliminates most of the noise, increasing significantly the SNR. Also, with this technique, it was possible to use the same equipment for different yarn diameters. Furthermore, the use of the differential setup improved the electronic-circuit performance, making it more robust to temperature and air-humidity variations. These concerns are particularly important in textile industries.

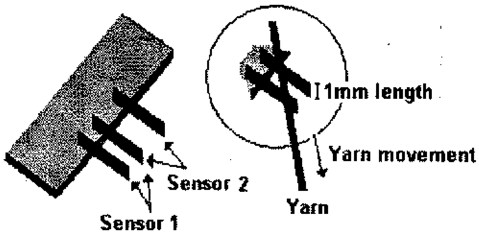

Fig. 5. Representation of the two sensors.

This system is aimed to be used for online control of ring-spinning frames in order to evaluate the yarn evenness produced. Currently, in spinning mills, this kind of evaluation is made offline in the laboratory using a small amount of yarn.

Tests made with this system showed good performance in the laboratory environment. The experimental setup used consists on a PC with a Labview data-acquisition system (National Instruments) together with two sensors and electronics.

Fig. 6 resumes, schematically, the components of the measuring system used in the project development. For having two capacitors with a common electrode in the system design, three metallic conductors were placed in parallel. Air and yarn make up the capacitor dielectric. Integrated circuit (IC) MS3110 from Microsensors implements functions regarding transducer, amplification, and signal conditioning. This is a specific IC for capacitive sensors and has the following characteristics (Fig. 7):

1) capacitance resolution of up to 4.0 aF/rtHz;
2) single variable or dual differential variable;
3) onchip dummy capacitor for quasi-differential operation and initial adjustment;
4) gain and dc offset trim;
5) programmable bandwidth adjustment from 0.5 to 8 kHz;
6) 2.25-V dc output for an anolog–digital-converter (ADC) reference/radiometric operation;
7) single supply;
8) on-chip electronically erasable programmable read-only memory for storage of settings.

Using the MS3110, the capacitance variations are converted into a voltage signal and amplified. Afterwards, a second-order low-pass filter attenuates the high-frequency interferences, which come from the internal oscillator and from other external noise sources. This filtered signal is then amplified using an output buffer. The MS3110 output voltage is filtered and converted to a digital signal with an ADC incorporated in the data-acquisition board used (6024 E from National Instruments).

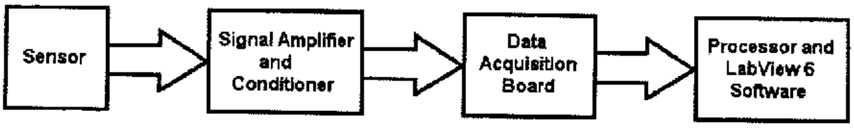

Fig. 6. System flowchart.

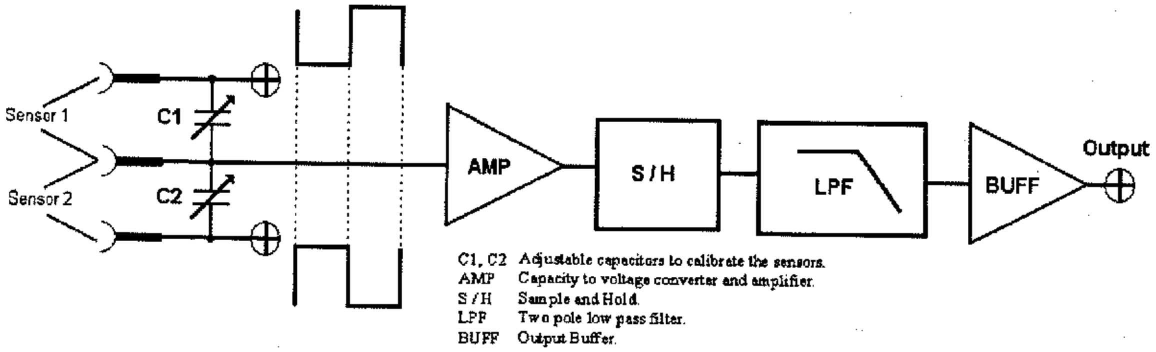

Fig. 7. MS3110 electric diagram.

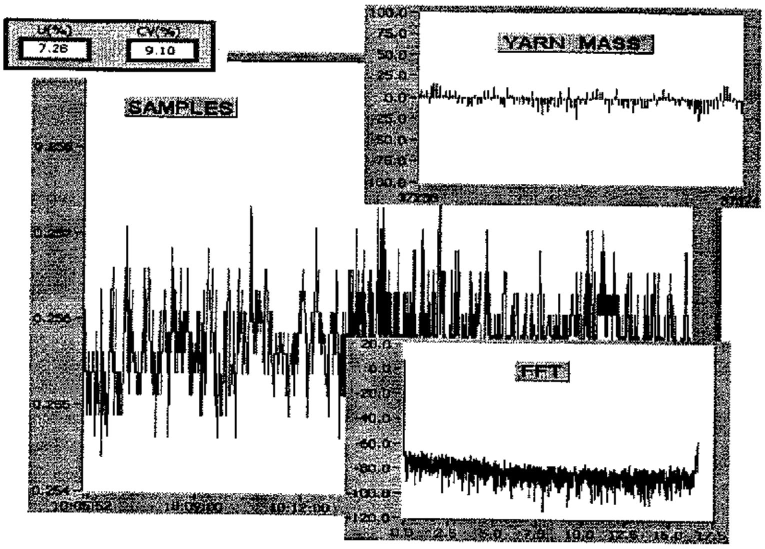

Fig. 8. Control-panel software components.

Finally, the acquired signal is monitored in a PC using a specifically developed software, based on National Instruments, Labview. This software allows data storage, manipulation, and processing for the analysis and evaluation of results.

Fig. 8 shows some examples of the results obtained with the software developed, namely acquired signal; the yarn mass in the top-right and in the left corner the values obtained for $U\%$ and $CV\%$. At the bottom, a spectral analysis based on the fast Fourier transform (FFT) algorithm is presented.

To allow an industrial use of the system, there is a need for several sensors and processor links in an industrial network. A new system, based on microcontrollers (RISC technology) that allows the use of advanced digital-signal-processing algorithms and distributed real-time control, is under development. The central unit monitors events (such as broken ends, neps, bobbin ends), report production data, and updates control algorithms. Final result is an alert display that signals events, for example, lamps indicating that a position needs presence of an operator.

IV. SOFTWARE OVERVIEW

The first attempt to extract 1-mm-mass values was implemented offline with postprocessing algorithms. This method is based on measurements of the 8-mm-length sensor acquired in real time, with a sample rate proportional to 1-mm yarn length. Fig. 9 displays, graphically, the method employed in order to obtain this measurement.

As already stated, sequential samples of the mass signal are acquired at length intervals of 1 mm. With this approach, each new sample includes a new segment with 1 mm length.

In order to obtain the yarn-mass values in steps of 1 mm, it is always necessary to know the mass of previous samples, using

$$a_i = \sum_{j=i-7}^{i} a_j - \sum_{k=i-8}^{i-1} a_k + a_{i-8} \qquad (5)$$

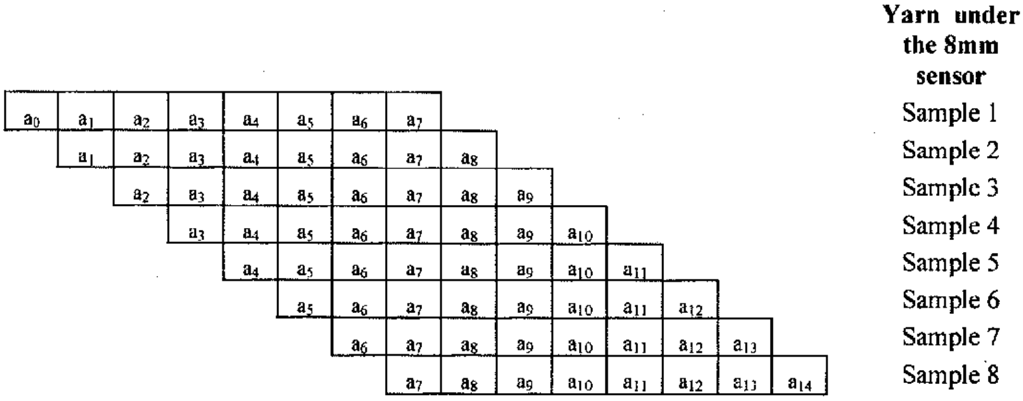

Fig. 9. Method used in the determination of mass in 1-mm yarn length.

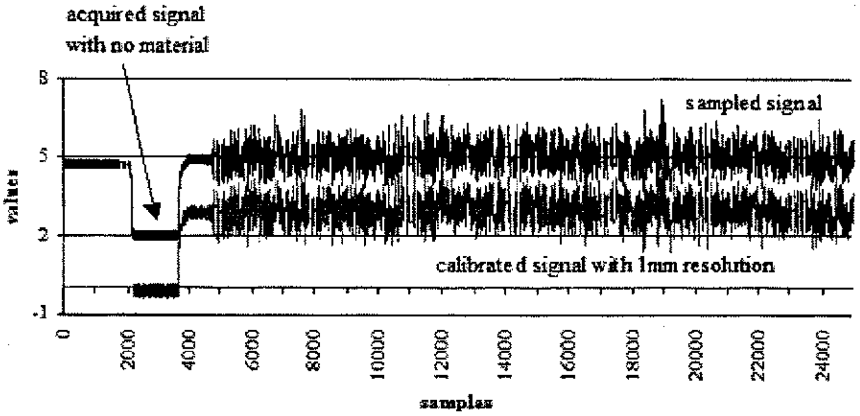

Fig. 10. Acquired signal with an 8-mm sensor and the evaluated signal with 1-mm length resolution.

TABLE I
CLASSIFICATION OF FAULT LENGTHS

Decimal Value	Fault Length (mm)
2, 10, 28 or 26	1xYarn Sample
6 or 22	2xYarn Sample
14	3xYarn Sample
15	Superior to 3xYarn Sample

where a_i are values in the 1-mm range (a_0 is the calibration value, without yarn). Fig. 10 presents the output-sensor-signal variation, with and without yarn. Observing Fig. 10, it is possible to conclude that during steady-state periods, some small variations due to some noise are present. However, peek-to-peek value is irrelevant if compared with the variation due to the presence or absence of yarn between the sensor plates.

Values acquired from the sensor allow the evaluation of mass variation around the mean value in the 1-mm range using

$$\text{mass}(\%) = 100\frac{Vm - Xi}{Vwy - Vm} \qquad (6)$$

where

Vm yarn mean voltage (in volts);
Xi sample voltage (in volts);
Vwy calibration voltage without yarn (in volts).

The methodology used for obtaining the number of faults in a tested yarn consisted of an analysis of the groups of five samples of the mass variation (as was intended to classify, using a 1-mm sensor, faults in lengths of 1, 2, 3, 4, and above 4 mm). These samples are then compared with the sensitivity threshold selected for the detection of thin and thick places or neps. If the comparison condition is true, a binary signal "1" is generated, otherwise this signal is "0." Afterwards, a decimal value is generated as the result of the binary word generated for the comparison of a group of five samples. As an example, consider a threshold value of 50% for detecting thick places, in a group of five samples, whose mass-variation values are: 0%; 45%; 55%; 75%; and 35%. The binary word generated is 00110, which corresponds to a decimal value of six that is classified as a thick place of 2 mm. This process is similar to thin places but considering the symmetric threshold value of thick places, and for neps, considering at least two times the threshold of thick places.

Table I presents the correspondence between the decimal values generated and the length of faults.

The results obtained by the system are saved on a file for offline analysis, namely quantification of yarn faults: $U\%$,

$CV\%$, and the number of points that are outside of a previously defined threshold. For instance, if a sample corresponds to a value of 150%, the number of thick points with a 50% threshold is incremented. Two consecutive samples with values more than 150% are quantified as only one fault.

It is also possible to calculate the mean values from eight consecutive samples, which corresponds to a sample of 8-mm yarn length.

These values, as well as the quantification of yarn faults based on them, make possible comparison with the conventional equipment that uses an 8-mm capacitive sensors. The second step in the software development task is online and real-time yarn analysis based on a 1-mm sensor. After the calibration (acquired signal without yarn), the data-acquisition system runs with a predefined sample rate. Statistical parameters are calculated, as well as FFT, using a Hanning window, fast Walsh–Hadamard transform (FWHT), and fast impulse frequency determination (FDFI). The FFT is used for the detection of sinusoidal errors (most common), the FWHT for the detection of rectangular errors, and the FDFI for the detection of impulse errors [2], [3]. This evaluation is very important for periodical fault detection responsible for fabric defects. As the signal is not fully periodic and the sample rate is not guaranteed to be a multiple of the sample period, use of windows does not solve the problem.

A method to solve this problem was applying energy bands, i.e., grouping neighbor spectral components in the same band. With this method, small speed variations in traction mechanism are solved. Results are displayed in a bar chart; corresponding to each bar an average energy of harmonics in interval. This periodogram graphic loses some resolution but eases result analysis, as well as allows a quicker identification of periodic faults (Fig. 4).

Currently , it is implemented the statistical parameter deviation rate (DR%) that gives information about the yarn fault length. DR% is calculated as the sum of yarn fault lengths divided by the overall yarn length analyzed. Another parameter that is also determined is the integral deviation rate (IDR%) that provides data of the amount of mass that is above or lower to a predefined mass threshold. The IDR%, for a threshold of 0%, provides the same information as that of $U\%$ [11].

V. RESULTS

With the yarn-mass evaluated signal, it is possible to calculate evenness values, which are of utmost importance to extract information regarding yarn quality.

Several tests were performed with different bobbins (from open-end-spinning system, ring-spinning system, and filament-type fibers) in order to detect the influence of linear mass.

Table II displays $U\%$ and $CV\%$ values in several yarn samples.

In order to evaluate yarn faults, previously defined as a mass decrease (50% during a short length, thin places), an increase in mass (usually lower than 200%, thick places), and a huge mass of yarn (above 200% in a short length, neps) at different thresholds were considered. Results show that a short difference in the irregularity threshold considered produces a strong change in the number of irregularities. These results are displayed in Table III. Nevertheless, note that neither the thin places can be obtained in a 182% threshold nor the neps in less than 182% range.

TABLE II
$U\%$ AND $CV\%$ VALUES

Fibre	Yarn Mass (tex)	U (%)	CV%
Cotton	57	14.96	18.69
Cotton	25	12.7	15.88
Cotton	37	11.28	14.09
Cotton	20	14.04	17.55
Cotton	20	21.35	26.68
Cotton	30	12.85	16.06
Polyamide	76.5	7.28	9.10

TABLE III
YARN FAULTS IN SEVERAL YARN SAMPLES

Fiber	Yarn Mass (tex)	Thresholds (%)	Thin places (1000 m)	Thick places (1000 m)	Neps (1000 m)
Cotton	57	182	-	0	2
		60	0	17	-
		40	7	47	-
		20	104	147	-
Cotton	25	182	-	0	0
		60	0	4	-
		40	12	18	-
		20	208	108	-
Cotton	37	182	-	0	0
		60	0	1	-
		40	1	10	-
		20	131	102	-
Cotton	20	182	-	0	0
		60	0	6	-
		40	34	31	-
		20	281	161	-
Cotton	20	182	-	0	12
		60	2	22	-
		40	109	42	-
		20	358	106	-
Cotton	30	182	-	0	0
		60	0	5	-
		40	10	20	-
		20	274	146	-
Polyamide	76.5	182	-	0	0
		60	0	0	-
		40	0	2	-
		20	59	27	-

The primary goal of the project was to analyze only cotton yarns, but in order to expand the system-application field, some tests were made to detect Lycra yarns with small linear mass [less than 6 tex (g/km)]. Although lycra has a higher dielectric constant, its small linear mass prevents good performance of the system.

At the moment, research work focuses on an adaptation of the developed system that enables the detection of Lycra yarns and all types of yarn with less than 6 tex.

VI. CONCLUSION AND FUTURE WORK

The system developed allows direct yarn-mass measurements in the 1-mm range, using parallel capacitive sensors. Periodical errors are determined by signal-processing techniques. However, large-scale tests are needed to allow a total correlation of results with those obtained by commercial solutions.

The system under development should integrate yarn-mass measurements based on capacitive sensors (as presented) and yarn-hairiness measurements based on optical sensors. A solution including image processing is also being considered.

The main objective of the project is to perform online measurements of 1 mm in a spinning frame by using feedback control to obtain a yarn with specified characteristics previously defined by the operator.

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