Determination of Yarn Hairiness Using Optical Sensors

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Abstract: This paper introduces a new module of the automatic mass parameterization system (MPS1), based on optical sensors. The electronic instrumentation used before in MPS1 enabled the yarn evenness measurement using capacitive sensors, with eight times increased resolution (using samples of 1mm). The new module performs hairiness measurement using a coherent signal processing technique for high accuracy. MPS1 system determines all relevant parameters commonly used in textile industry and proposes the quantification of new others.

Keywords: Hairiness, Optical Analysis, Signal Processing.

INTRODUCTION

Yarn quality highly depends of the level of homogeneity of yarn – unevenness, which quantifies the mean variation in linear density of a strand or part of it. These irregularities are detected using capacitive sensors which, in commercial equipments, perform yarn analysis in steps of 8mm; MPS1 performs 1mm analysis. The increase in resolution enables direct detection as most yarn irregularities occur in lengths between 1mm and 4mm [1].
Another important feature of yarn is hairiness, which can also significantly affect the appearance of fabrics. Its measurement is usually undertaken using optical sensors for samples of 2mm or less; MPS1 upgrade performs hairiness yarn analysis in 1mm samples.
It is possible to determine all important yarn parameters for evaluating yarn quality using capacitive and optical sensors measurements, together with signal processing techniques.

THEORETICAL CONSIDERATIONS

An important yarn characteristic which greatly influences the appearance of fabrics is hairiness. This phenomenon appears as a result of yarn released fibers over the strand. Figure 1 presents an example of hairiness.

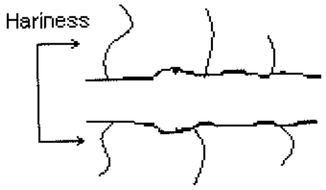


Figure 1. Example of hairiness over a yarn

Measurement of yarn mass and hairiness, allows the determination of several yarn statistical parameters and the application of signal processing techniques.
Although, commercial equipments statistically quantify hairiness using standard deviation (sH) and coefficient of variation (CVH) all the other parameters quantified in mass measurements can be applied to hairiness mean determination, namely mean deviation coefficient (U), deviation rate (DR) and its integral (IDR) [1, 2].
In general, commercial equipments use signal processing techniques, over the measured signal, based on FFT. MPS1 applies also FWHT and FDFI techniques [1].
Hairiness analysis employs a light emitter (laser) / receiver (photodiode) pair with the addition of an optical setup to analyze yarn hairiness using a coherent optical signal processing technique [2, 3, 4] with Fourier analysis (1).

$$F\{g\} = \int\int_{-\infty}^{\infty} g(x,y) e^{-j2\pi(f_x x + f_y y)} dxdy \qquad (1)$$

where, $g(x,y)$ is the signal function of two dimensions, f_x and f_y are spatial frequencies (m^{-1}). Spatial frequencies are determined by (2).

$$K_n \approx \frac{\lambda . f}{n} \qquad (2)$$

where, K_n is the spatial frequency (m^{-1}), λ is wavelength (m), f is focal distance (m) and n is the distance between light constructive points (m).
Using Fourier analysis it is possible to build an optical high pass filter which extracts the non desired frequencies (spatial yarn linear density frequencies), leaving the spatial frequencies in hairiness range. This analysis results in a dark and red image where, the red contrast gives information about yarn hairiness (figure 2), that is converted by a photodiode into a proportional current intensity [2].

Figure 2. Example of an image plan of hairiness measurement using a coherent optical signal processing technique

MEASUREMENT SETUP

Measurement of hairiness requires two distinct parts of hardware, electronic and optical. The electronic hardware employs, as a receiver, a photodiode (S1227-1010BR) 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 and terminal capacitance of 3000pF.

A conditioning circuit is designed. This includes a high precision current to voltage converter, based on a *Burr-Brown* operational amplifier OP277P. As the operational amplifier offset and dark photodiode current are extremely reduced, they can be neglected, compared to the signals magnitude. The output of the operational amplifier is connected to an analogue channel of the data acquisition board (PCI-6024E from *National Instruments*) and the software developed in *Labview* acquires and processes the data.

Figure 3 shows the optical system developed for hairiness determination.

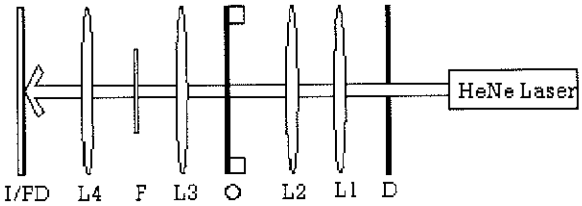


Figure 3 - Experimental setup of the optical system

Where, *I/PD* is the image plane/photodiode, *L1, L2, L3* and *L4* are lenses, *F* is the optical filter, *D*, the diaphragm and O is the object plan/yarn.

The objective of this setup is to quantify yarn hairiness, as the brighter elements of the final image [2]. The set up presents the optical devices needed to obtain the image of yarn hairiness placed in the object plane. A custom fabricated spatial filter (*F*) is placed in the Fourier plan of *L3*, to process the image, allowing only the high spatial frequencies in the image to propagate further. Essentially, this is a high pass spatial Fourier filter [3-10]. The result is the contours of the edges of yarn and associated hairs being highlighted, while simultaneously eliminating the constant background associated with the portion of 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.

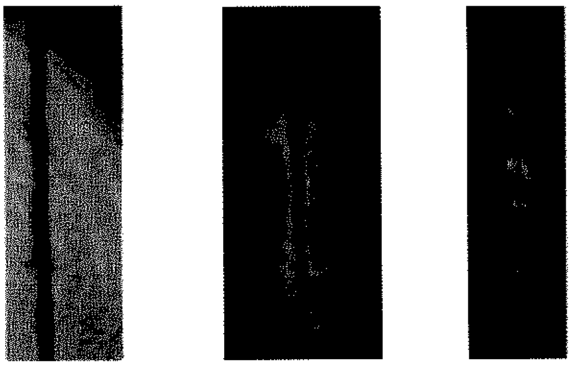
Determination of hairiness variation is calculated by (3).

$$Hairiness(\%) = \frac{Vm - Xi}{Vwh - Vm} 100 \qquad (3)$$

where, V_m is hairiness mean output voltage (V), X_i is hairiness sample voltage (V) and V_{wh} is yarn output voltage without hairiness, reference signal (V).

RESULTS

Figures 4 and 5 present yarn image without and with the application of the coherent optical filter, respectively. Figure 6, corresponds to the same yarn using the optical filter, but in this case, the hairiness was greatly reduced by wetting the yarn with water.



Figures 4, 5 and 6 - Images of yarn hairiness, without the high spatial frequency filter (4), with the filter (5) and with exposition time increased (6), respectively.

In figure 4, 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 5, refers to the same yarn section but employing the coherent optical filter, clearly highlights the previously hidden yarn hairiness.

Figure 6 is the yarn image, 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 – the exposure time had to be increased significantly [2].

Using the described setup, five 100% cotton yarns were tested online (figure 7).

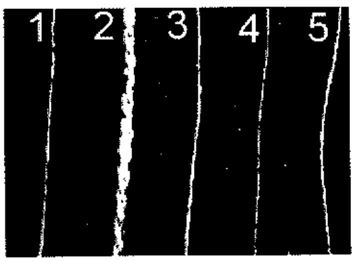


Figure 7 - Image of yarns used in the test

The experiments considered a total sample length of 6 meters at a traction speed of 6 meters/minute which corresponds to an acquisition frequency of 10 Hz. Table 1 characterizes the linear mass and diameter of the yarns tested.

Table 1. Description of yarns tested

Yarn number	Linear Mass (tex = g/Km)	Diameter (0.037*√tex) (mm)
1	36.88	0.23
2	295.00	0.64
3	62.00	0.29
4	19.67	0.16
5	49.17	0.26

For determination of hairiness variation, it was measured the voltage without yarn (similar for all yarns), the reference voltage (voltage without hairiness) and mean hairiness voltage under test (specific for each yarn), as presented in table 2.

Table 2. Voltage without yarn and without hairiness for each yarn tested

Yarn number	Voltage without yarn (V)	Vwh (V)	Vm (V)
1		2.039	2.488
2		2.290	4.224
3	1.841	2.176	3.428
4		2.480	3.410
5		1.875	2.769

Analyzing table 2 is possible to distinguish three levels of voltage considering hairiness measurement: level one, which presents the lower voltage results and is constant (voltage without yarn); level 2, which presents the middle voltage results (voltage without hairiness) and level 3, which presents the higher voltage results (mean hairiness voltage or hairiness voltage) (Figure 8).

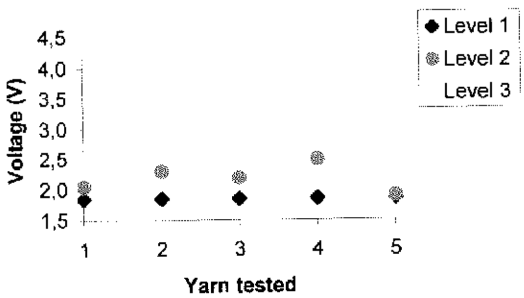


Figure 8 – Steps of voltage in hairiness measurement

Figure 9 presents the signal to noise ratio (SNR) determination for the values presented in table 2, considering as noise the constant DC component (voltage without yarn).

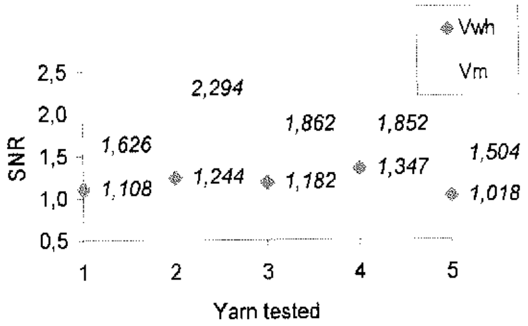


Figure 9 – SNR results

Under figure 9 it can be stated that the SNR, in the yarns tested, is always superior to 100%, reaching up to 229% for mean voltage of yarn 2. These results allowed to conclude that they have a good level of precision.

Figures 10 to 14, present the hairiness variation(%) results for yarns 1 to 5 , respectively, using equation 3.

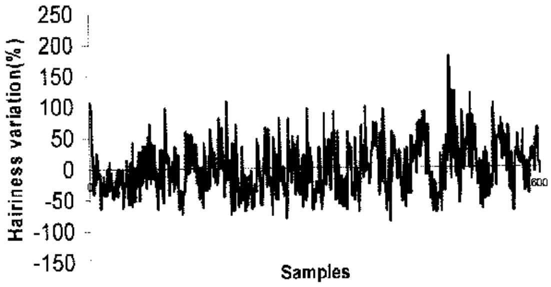


Figure 10 – Hairiness variation for Yarn 1

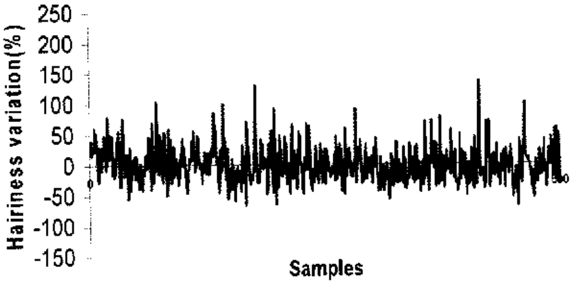


Figure 11 – Hairiness variation for Yarn 2

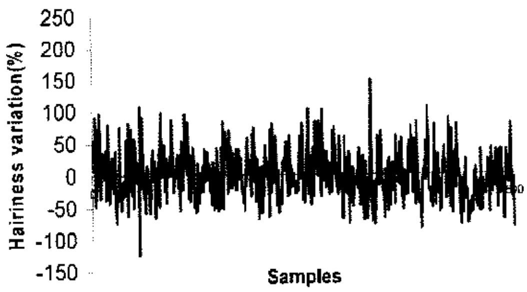


Figure 12 – Hairiness variation for Yarn 3

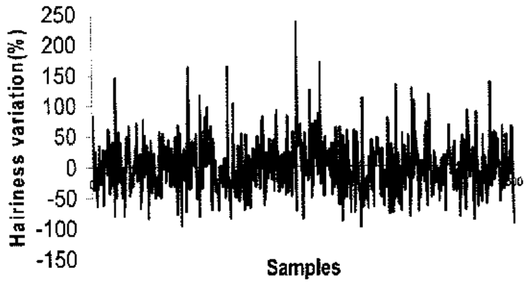


Figure 13 – Hairiness variation for Yarn 4

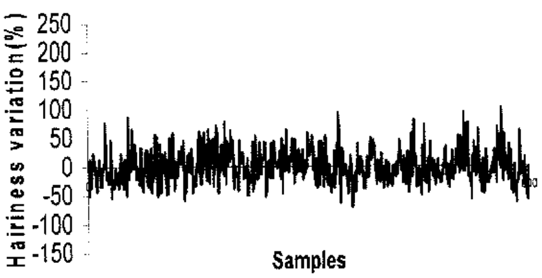


Figure 14 – Hairiness variation for Yarn 5

Table 3 presents the hairiness standard deviation.

Table 3. Standard deviation results

Yarn number	Standard Deviation (%)
1	42.03
2	30.69
3	39.58
4	45.04
5	29.68

Analyzing figures 10 to 14 and table 3 is possible to conclude that, considering hairiness, the most regular yarns are numbers 5 and 2 proved by the high concentration levels of figures 14 and 11, respectively and supported by their low standard deviation values. In the opposite, the most irregular yarns are numbers 4, 1 and 3 due to the high dispersion levels showed in figures, 13, 10 and 12, respectively and supported by the high standard deviation results.

CONCLUSIONS AND FUTURE WORK

The measurement technique used for determination of hairiness (%) showed proper results. It causes a significant variation of signal between yarn with and without hairiness and without yarn. There are established three levels of voltage. This is also proved by the high SNR (>100%) determined, for values of voltage without and with hairiness, considering as noise the level of voltage without yarn.

Actually, with the developed setup, is already possible to infer qualitatively over yarn quality, considering hairiness regularity.

As there is a relation between the dimension of the applied optical filter and the frequency limit allowed, a technique is being developed to calibrate this signal in order to allow the determination of hairiness mass ratio compared to yarn mass. Furthermore, it is also being studied the inclusion of a polarizator, in the optical setup, to reduce significantly the voltage without yarn (DC component) and subsequently increase the SNR which will allow the achievement of even higher precision results.

At last, a study for comparing two methods of conversion of a yarn with hairiness to without hairiness will be realized.

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