Techniques for Unveiling Faults During Knitting Production

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***Abstract*— Detection of faults during production of knitted fabric is crucial for improved quality and productivity. The yarn input tension is an important parameter that can be used for this purpose.**

This paper will present and discuss a computer-based monitoring system which was developed for the detection of faults and malfunctions during the production of weft knitted fabric, using the yarn input tension. In particular, it will present the method used to unveil the appearance of faults, based on two different approaches: comparison with a previously acquired waveform and a particular pattern matching technique - Average Magnitude Cross-Difference.

***Index Terms*— Monitoring, Fault Detection, Knitting Machine, Signal Processing, Average Magnitude Cross-Difference.**

I. INTRODUCTION

Whenever a fault occurs during the production of knitwear, the machine has to be stopped, thus promoting some loss in productivity. The faulty element needs to be located in order to be removed, and some repairing procedures are required, depending on the severity of the damage. Due to the importance of this problem, preventing measures were taken, namely a periodic exchange of the entire set of knitting elements, which is time consuming and expensive. Producers are also concerned with extracting more useful information from the knitting production, which led to more instrumented machines [1,13].

On the field of fault detection, the most widely used systems are based on mechanical devices and optical devices for detecting needle faults [5,6], optical devices for detecting knitwear faults, which basically search for a pattern on the knitwear [7], and yarn detectors made from mechanical systems [8]. Last proposals in the biggest textile world fair ITMA 2003 from some industry manufacturers tend to replace the present yarn detectors by optical devices.

These solutions are very specific on their task, are very efficient but they lack in integration and valuable information that can be transmitted to the technician. For example, the solutions presented do not give any information concerning the average ***yarn input tension*** (*YIT*) which is a crucial parameter for maintaining the knitting machine at work in good conditions. Some manufacturers introduced a force sensor for measuring in real time this force. However, it seemed at that time that the return in value added information does not compensate the investment on this kind of equipment. This is due to fact that one sensor is needed for each yarn used, and one knitting machine can have more than one hundred yarns.

Previous research showed that the *YIT* is indeed a valuable resource of information concerning in particular the knitting process, and in a more general term, the overall behavior of the knitting machine, since *YIT* directly reflects the influence of the different mechanisms involved in the production of the knitted fabric [9,11,12,14]. In fact, this approach does not only detect the presence of a fault, as well as allow its exact location. Moreover, it is possible to distinguish between the fault's natures and experiments using mathematical techniques such as clustering and discriminating analysis were used to evaluate the capability of fault identification [12,13]. It was also observed that this approach allows the detection of the same and some more faults that the previously mentioned sensors do, each one separately. These facts can be an excellent reason for an investment on this approach for future knitting machines. Research was also made in order to develop a cost effective force sensor which would allow the installation of one sensor per feeding system [10].

II. MEASURING SYSTEM

The developed system will be shortly described in this section. The measuring system is based on encoders, strain gauge force sensor and optical sensor. These sensors are installed on the knitting machine as Fig. 1 shows. The biggest advantage of this system is the fact that it can be easily assembled on an industrial machine, without the need of any kind of modifications on the referred machine.

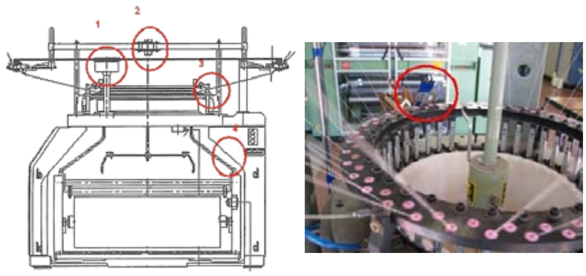

Fig. 1. Sensors location on the knitting machine. Detail of the force sensor location.

The encoders are responsible of generating the signals necessary to calculate the yarn consuming rate, the rotation speed and synchronizing signals. On the other hand, the optical sensor is used to mark the spot where each revolution of the knitting cylinder starts. This sensor is used whenever the knitting cylinder vertical axis is inaccessible for assembling one of the encoders. Finally, the force sensor is placed near the knitting zone in order to measure the *YIT*, which is the base instrument for detecting the faults and malfunctions related with the knitting elements, yarn and systems directly involved with the knitting process.

All sensors are connected to a data acquisition board by means of a conditioning board (Fig. 2). The conditioning board main features are: software programmable gain from 1 up to 8000, programmable elliptical anti-aliasing filter up to 5000 KHz, and a programmable sampling frequency multiplier from 1 to 256 times the base frequency. All subsystems of the conditioning board are tuned through the data acquisition board and, at a higher level, through the developed software. The data acquisition board is a general purpose one from *National Instruments* and the programming environment used was *LabVIEW 6i*.

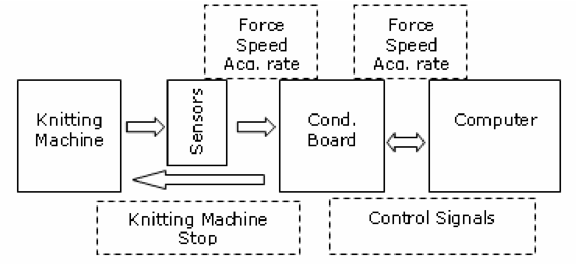

Fig. 2. General structure of the monitoring system.

The knitting machines used for the experiments were: a sample making circular weft knitting machine with one positive feeding system, one cam, 168 needles and sinkers, 3.75” diameter cylinder, with speeds up to 200 rpm; one industrial weft circular knitting machine with 36 positive feeding systems, 36 cams, 756 needles and sinkers, 12” cylinder diameter, and a top speed of 45 rpm.

The *YIT* signal is sampled through the use of an external frequency signal. This signal is obtained from the square waveform generated by the encoder assembled on the vertical axis of the knitting cylinder. When needed, the encoder signal is multiplied in order to generate a required number of sampled points per revolution. Usually the number of points per revolution is expressed in number of points per needles instead, in order to be independent from the knitting cylinder diameter. This approach allows excellent space accuracy and surpasses the need of calculating the correspondent sampling frequency if it was intended to use an external clock independent of the knitting machine’s rotating movement. Nevertheless, the system allows the use of absolute time-based frequency sampling.

The developed software – *KnitLab* - is a package capable of acquire, save to file, retrieve from file, analyze and manipulate the waveforms with different processing tools, like digital filtering, spectral analysis, correlations, etc. One of the included tools of the developed software is the monitoring tool that will be described on the following paragraph.

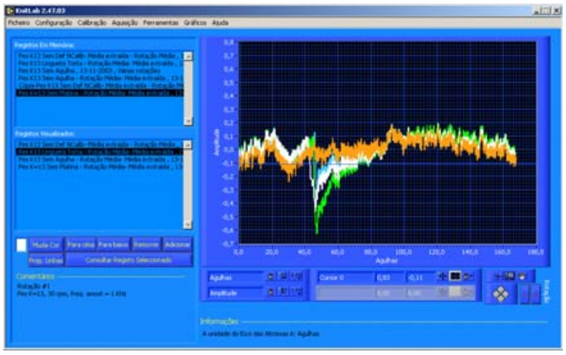

Fig. 3. KnitLab at work with four different waveforms of YIT, Each one represent a different situation.

The monitoring system is organized as Fig. 4 illustrates.

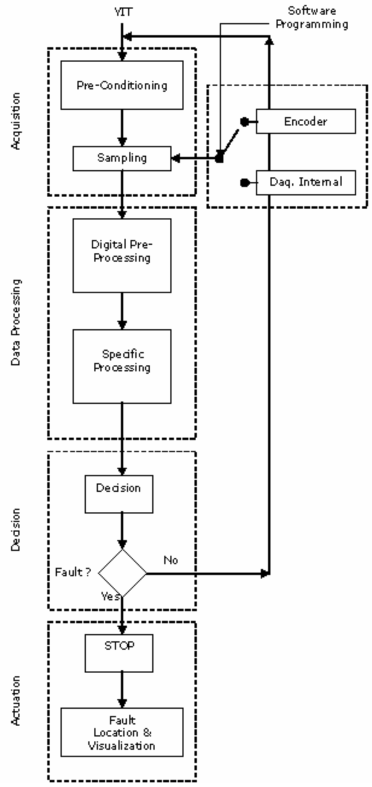

Fig. 4. MonitorKnit block structure

The software, called as *MonitorKnit*, receives the previously conditioned signal and processes it in order to obtain a reference waveform for one entire cylinder revolution. This operation is crucial for locating purposes in the case of a fault during the production of knitwear. Afterwards, the signal is passed through a module responsible of further processing and the resulting signal will be analyzed by a decision module. In case of fault, the knitting machine will receive a signal to stop immediately and the fault will be easily located.

It is important to mention that each *YIT* waveform corresponds to an entire course of knitted fabric and there exists a significant variability in *YIT* for each course as seen in Fig. 5.

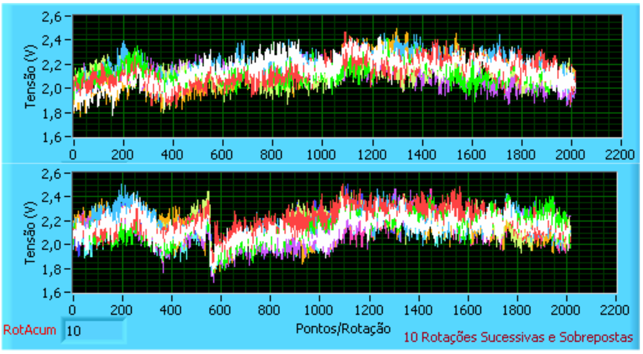

Fig. 5 . Representation of several fault-free waveforms of *YIT*, extracted from consecutive courses (above), and faulty waveforms of *YIT* (below).

III. TECHNIQUES FOR FAULT DETECTION

Two different approaches for detecting abnormalities or faults during the knitting process will be described in this section. Although different in their concept, both can identify the presence of a fault.

YIT monitoring through one single parameter

The measures presented in this section intend to represent the behavior of the knitting process in one single parameter. This approach has obvious advantages for the technician point of view, since it can be easily represented and observed by him during the production of the knitted fabric. Moreover, one can use the measure for representation in process control charts.

To accomplish that goal, the most convenient method would be the comparison of the waveform that is presently under surveillance (i.e. the presently acquired waveform) with a standard waveform, considered as fault-free. The implemented algorithm can be described by Fig. 6, which reflects its organization after the acquisition stage, represented on Fig. 4.

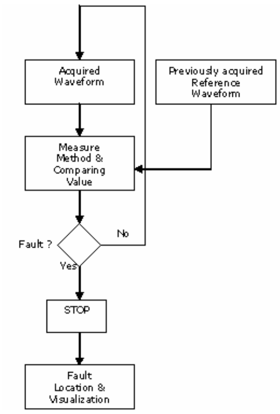

Fig. 6. Representing *YIT* through one single value.

Three different measures were attempted, which modify the "Measure Method & Comparing Value" module in Fig. 6. The general expression is:

$$Measure = \frac{k}{N}\sum_{i=0}^{N-1} d_i^{\,p} \qquad (1)$$

, where $\boldsymbol{p}$ and $\boldsymbol{d_i}$ will differ depending on the method of difference used, and $\boldsymbol{N}$ stands for the number of *YIT* acquired points per revolution. Since the total sum can be a very small number, a constant $\boldsymbol{K}$ is multiplied. The comparison between the standard and the recently acquired waveform is made on a point-to-point basis, i.e. the i-th acquired point is compared with i-th standard point. The standard waveform is the result of a point-to-point basis average of 50 fault-free revolutions, as expressed below:

$$\bar{y}_i = \frac{1}{50}\sum_{j=1}^{50} u_j \qquad (2)$$

The first measure used was called as **SQD**, which stands for *Sum of Quadratic Difference* measure, uses p = 2 and

$$d_i = \left[\left(x_i - \frac{1}{N}\sum_{k=0}^{N-1} x_k\right) - \left(\bar{y}_i - \frac{1}{N}\sum_{k=0}^{N-1} \bar{y}_k\right)\right] \qquad (3)$$

This measure returns a typical number for each simulated situations, thus giving an idea of how well the overall knitting process is running. When there is no fault, **SQD** gives a typical value, which is different from the other situations, i.e., when some fault occurs. Table 1 shows the results for some simulated faults in a particular experiment conditions and yarn used.

Table 1. **SQD** average results for polyester continuous filament, 240 dtex.

	N=2016, K=100		N=1, K=1	
	Mean	Stand. Dev.	Mean	Stand. Dev.
Fault-free	0,49	0,12	9,84	2,43
Without Needle	1,90	0,26	38,20	5,31
Without Hook	1,81	0,30	36,39	5,97
Damaged Latch	1,18	0,32	23,80	6,43
Without Latch	0,76	0,16	15,20	3,15
Without Sinker	0,72	0,16	14,40	3,20

The second measure was called as **S4D**, standing for *Sum of 4th power Difference*, uses the same $\boldsymbol{d_i}$, however, p = 4. This was used in order to try to stand out the fault-free behavior from the faulty one. The results obtained for the same experiment conditions are showed on Table 2.

Table 2. **S4D** average results for polyester continuous filament, 240 dtex.

	N=2016, K=100		N=1, K=1	
	Mean	Stand. Dev.	Mean	Stand. Dev.
Fault-free	0,01	0,005	0,18	0,08
Without Needle	0,2	0,06	5,15	1,75
Without Hook	0,19	0,06	5,21	1,67
Damaged Latch	0,07	0,04	1,38	0,8
Without Latch	0,03	0,01	1,04	0,54
Without Sinker	0,02	0,01	0,47	0,21

Finally, the third approach is called **SAD**, which means *Sum of the Absolute Difference*, uses p =1 and

$$d_i = \left| \left(x_i - \frac{1}{N}\sum_{k=0}^{N-1} x_k \right) - \left(\bar{y}_i - \frac{1}{N}\sum_{k=0}^{N-1} \bar{y}_k \right) \right| \qquad (4)$$

Table 3 illustrates the results obtained using this measure.

Table 3. **SAD** average results for polyester continuous filament, 240 dtex.

	N=2016, K=100		N=1, K=1	
	Mean	Stand. Dev.	Mean	Stand. Dev.
Fault-free	5,57	0,72	120,04	17,02
Without Needle	10,01	0,87	202,26	16,73
Without Hook	9,67	0,9	195,46	18,87
Damaged Latch	8,35	1,27	180,44	27,58
Without Latch	6,91	0,78	197,55	35,55
Without Sinker	6,64	0,76	143,58	16,54

YIT monitoring through transformed waveform inspection

This approach, by means of proper pre-processing and further mathematical transformation of the waveform, tries to emphasize the appearance of faults, resulting in a new waveform. The malfunctions or faults result in an increased value during a determined period, which can be detected with a decision module, as showed in Fig. 4. The major advantage of this approach is to allow the possibility of locating the faulty element. These techniques are widely used for pursuit of a specific pattern on a signal, in particular in areas like medicine (ECG). One method was experimented in order to evaluate his performance [16,17].

a) Average Magnitude Cross-Difference (ACMD)

The general expression is as follows:

$$y(i) = \sum_{k=0}^{N-1} \left| x_t(k) - X_t - [x(k+i) - X_i] \right|, \quad i = 0,1,..M-1 \qquad (5)$$

where $\boldsymbol{x_t(k)}$ are samples of the selected template, $\boldsymbol{x_t(k+i)}$ are samples of the *YIT* waveform under analysis, $\boldsymbol{i}$ is the shift parameter, $\boldsymbol{N}$ is the size of the template window, $\boldsymbol{X_t}$ and $\boldsymbol{X_i}$ are the mean value for the template window and the waveform window under analysis, respectively,

$$X_t = \frac{1}{N}\sum_{k=0}^{N-1} x_t(i) \qquad (6)$$

$$X_i = \frac{1}{N}\sum_{k=0}^{N-1} x_t(k+i) \qquad (7)$$

M stands for the total number of points per entire revolution. In this technique, blocks of pre-processed *YIT* waveform are compared with a previously selected template with length ***N***. This template is a slice from an arithmetic average of at least 30 *YIT* fault-free waveform revolutions. Whenever the two signals are similar in shape, the Average Magnitude Cross-Difference value becomes a minimum.

Fig. 7 illustrates the result of this technique applied to a fault free waveform of the *YIT*. The raw material used was a polyester continuous filament yarn with 240 dtex, which is a yarn with a very low irregularity. Also, the speed of the knitting machine was 30 r.p.m., meaning a linear velocity of 0.15 m/s. The magnitude of the force applied does not have a significant importance when is intended to detect faults. However this does not happen when one is concerned with tuning the knitting process for proper functioning.

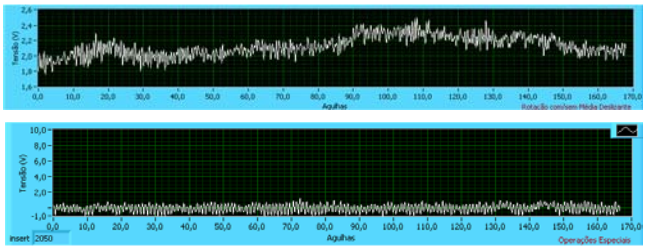

Fig. 7. Fault-free waveform. The picture above shows the *YIT* as it was acquired, and the second picture shows the processed wave-

Fig. 8 illustrate a situation when a fault occurs (a missed hook). This particular situation can happen due to the ageing of the needle and/or exceeding *YIT*. The experimental conditions are the same.

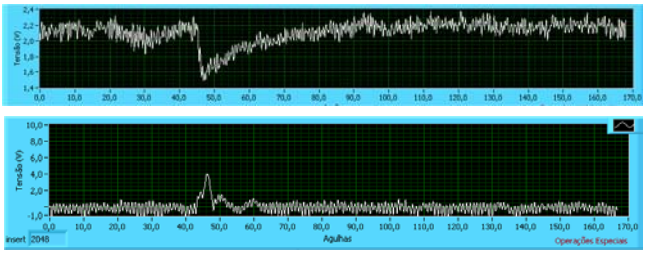

Fig. 8. Needle without hook. The picture above shows the *YIT* as it was acquired, and the second picture shows the processed wave-

Fig. 9 illustrate another situation, this time with a missing sinker.

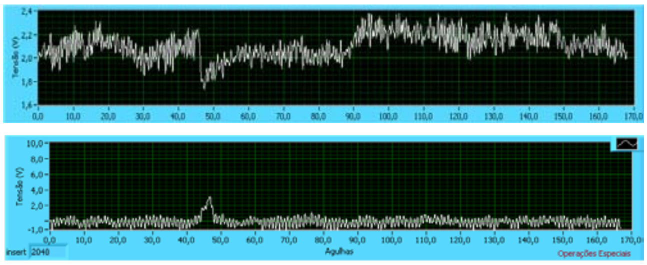

Fig. 9. Missing sinker. The picture above shows the *YIT* as it was acquired, and the second picture shows the processed waveform.

Fig. 10 illustrate two detected faults during production on an industrial knitting machine, for cotton yarn 24 tex. The speed was 42 r.p.m., meaning a linear velocity of 0,65 m/s. Note that this kind of yarn is much more irregular than continuous filament.

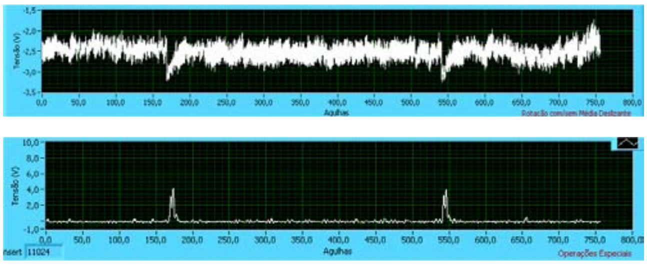

Fig. 10. Two missing needles. The picture above shows the *YIT* as it was acquired, and the second picture shows the processed wave-

IV. DISCUSSION OF RESULTS

Monitoring though a single parameter

This approach represents an excellent tool for the technician, since it is very straightforward for inspection. The experiments made show that there is no risk of misinterpreting between the fault-free waveform from a faulty waveform. Moreover, this approach can be plotted in a control chart for the knitting process. However, in case of detecting a fault, there is no chance to locate the origin of the fault by direct observation of the parameter. Nevertheless, inspecting the original waveform, the technician can determine the exact place where the problem occurred.

It is also difficult to correctly identify the cause of the fault using exclusively this parameter. The observed variability inside each simulated situation is significantly high to produce misinterpretations. From the three measures presented, **S4D** seems to be the measure that best distinguish the simulated faults, at the cost of more power processing.

On the other hand, this approach requires a previously acquired fault-free pattern, which is obtained from the average of several waveforms. Finally, the nature of the raw material can also influence the value of this parameter. More irregular yarns will produce a higher variability and thus higher amplitudes.

One however should not forget that although this disadvantages, this approach still presents a single number per rotation, there is no risk of considering a faulty waveform as a without any fault, and during production, the raw material will not be exchanged.

Monitoring through the entire waveform

This approach seems to be the strongest candidate for successful detection of faults. The pre-processing stage absorbs the intrinsic and random variability of the raw material and knitting process, and allows standing out the abnormality produced on *YIT*. The location of the cause of the fault can be directly read from the resulting waveform, although there is an evident delay produced by the digital filtering stage. Nevertheless, this delay can be compensated since it is known. The precision is not affected if this approach is used.

Another advantage is that the waveform does not alter significantly if the raw material is different. The experiments made also showed that the different simulated faults produce different patterns, thus allowing to be used for automatic identification by means of pattern recognition.

The innovative aspects that should be noted are the pre-processing stage implemented before the *Average Magnitude Cross-Difference* measure, and the way this measure is used. The pre-processing stage can involve a digital filter and a synchronous average module, one followed by the other, in reversed order, or even one without the other. The pre-processing stage was adopted due to the inherent random variability of the knitting process, which in its turn is mainly due to the irregularity of the raw material and the knitting process itself. The examples show (Fig. from 7 to 10) two kinds of yarn (polyester continuous filament and 100% cotton) and how different the *YIT* in variation magnitude can be. In order to obtain a measure comparable for both kinds of yarns, the filtering and averaging are crucial. The figures presented show that there is not a significant difference after the two processing stages (pre-processing and specific processing in figure 4). At the same time, the *Average Magnitude Cross-Difference* uses a specific template which allows the pinpoint of the faults. Its size is also crucial for this task.

V. FURTHER DEVELOPMENTS

The approach involving the representation of a course by means of a single number requires further refinement in order to try to increase the observed differences between the faults.

The other approach proved to be very efficient. Further development, namely experiments with a significant number of raw material, knitted structures and knitting machines will be made in order to confirm the efficiency of this approach. Other approaches involving similar techniques are under research and a pattern recognition system is being developed.

At the same time a more cost effective measuring device is under refinement, which can allow the implementation of this technology on each yarn used on the knitting machine at an affordable price. This measuring system will be a stand-alone device [10].

VI. CONCLUSIONS

The yarn input tension can be a valuable instrument for inspecting the production of knitwear and for monitoring of faults, as it was shown during this paper. For the purpose of acquiring and monitoring the *YIT*, one measuring system prototype was presented and two different approaches for monitoring the *YIT* during production were discussed: one approach involves the representation of one entire course produced in each cylinder complete rotation; and the other approach transforms the waveform after specific signal processing and application of *Average Magnitude Cross-Difference* for further analysis and decision. Although with different philosophies behind them, both approaches can be valuable tools for detecting faults during production and thus contribute for products with higher quality and at the same time improved productivity.

VII. ACKNOWLEDGEMENTS

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