

# COMPUTERISED SYSTEM FOR SPINNING PROCESS MONITORING

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*Abstract: The paper presents a computerised multichannel system for monitoring of spinning processes in textile industry. The system operates 'on-line', directly on the rotor spinning machine without interrupting its work. Continuous measurements of three important spinning process parameters are taken, i.e., coefficient of mass variation of sliver, coefficient of mass variation of yarn, and yarn tension. Measurement data is stored in the computer so making further 'off-line' analysis and conversion possible. The modelled feed stream of fibres is used to generate the Multifrequency Binary Signal (MBS) as the input interrogating signal for the spinning process. The presented system offers a novel approach to dynamic measurements of yarn and sliver properties that can be useful in developing new spinning machines and technologies. System configuration and experimental results of the proposed process monitoring scheme are also presented in the paper.*

*Keywords: Rotor spinning process, computerised measuring systems, yarn and sliver properties.*

## 1 INTRODUCTION

Rotor spinning ensures much higher efficiency of yarn production as the classical spinning methods. Technical limits for spinning speed are set by the yarn tensions, which have an important influence on yarn tenacity and spinnability [1]. Therefore much theoretical research work is concerned with the analysis of forces present in yarns [2]. Yarn quality is the next important problem concerned with the spinning process. A satisfactory compromise between yarn quality and spinning productivity must be achieved. Considering a high complexity of the rotor spinning process there is very difficult to build its satisfactory model. *A priori* knowledge based on the laws of mechanics is completed by experiments. The aim of the work is to determine the relations between the parameters at the start of the process and their effect on the yarn quality and structure. Traditional measuring methods, used in textile industry and research are based on USTER apparatus [3], which allows for 'off-line' measurement of mass irregularity, separately for the yarn and for the sliver. Such the equipment gives the information about the corresponding coefficients of mass variation, and allows building a partial static model of the process, which evaluates average values of the process parameters [4]. The system presented in the paper may be applied for 'on-line' dynamic measurements of yarn and sliver properties directly on the machine. All the measurements are taken at the same time and the measured data are saved in the electronic form, what enables their analysis and conversion.

## 2 SPINNING PROCESS PARAMETERS

Yarn tension is an important process parameter depending on the machine construction and the method of spinning. For the rotor spinning the value of yarn tension outside the rotor can be defined from the formula (1) [1]:

$$F_v = \left( F_A + \frac{m\omega^2 r^2}{2} \right) \exp \frac{\mu P}{2} \quad (1)$$

where:  $F_A$  - yarn tension inside the rotor at the rotor wall,  $r$  - radius of the rotor,  $\mu$  - the coefficient of friction of the yarn against the steel trumpet,  $m$  - yarn linear density,  $\omega = \pi n/30$  - angular speed of the rotor,  $n$  - rotational speed of the rotor.

Rotor diameter remains constant for a given spinning machine; coefficient of friction of the yarn against the steel trumpet depends on the type of fibres. Angular speed of the rotor and linear density of yarn are important process parameters, which are set up by the spinning specialist. The angular speed of the rotor has the biggest influence on yarn tension, for it is proportional to its square value. Coefficients in equation (1) are usually determined experimentally.

Quality of yarn is determined by many parameters, from which the main are: linear density, irregularity of yarn mass distribution, tenacity, elongation, twist, faults in yarn, elasticity, hairiness, and dispersion index of the above parameters. Irregularity of yarn mass distribution is the most important quality parameter, which is determined by the coefficient of mass variation, CV. This parameter decides about yarn usefulness in the textile processes following on the spinning process and also determines costs and productivity of yarn production. Coefficient of mass variation depend on the kind of the spinning process and its parameters, on the fibres type and properties and finally on the preparation of a feeding sliver. Theoretical value of this coefficient is calculated from the Martindale's equation (2) [3]:

$$CV_T = \frac{100}{\sqrt{\bar{n}}} \sqrt{1 + 0,0004 CV_d^2} \quad (2)$$

where:  $CV_d$  – coefficient of fibres diameter variation,  $\bar{n} = m/m_f$  - number of fibres in the yarn cross-section,  $m$  - yarn linear density,  $m_f$  - fibre linear density.

For cotton fibres it is assumed that  $100 \cdot \sqrt{1 + 0,0004 CV_d^2} = 106$  and Martindale's formula has a form:

$$CV_T = 106 / \sqrt{m/m_f} \quad (3)$$

Martindale's equation takes into account only the dependence of CV coefficient on the number of fibres in the yarn cross-section. Other parameters effecting on the extra irregularities, such as kind of the spinning process and its parameters are neglected. According to this fact a real coefficient of mass variation, measured experimentally is higher than the theoretical value calculated from the Martindale's equation. In the presented approach the *a priori* knowledge must be completed with the *a posteriori* knowledge and the real value of yarn CV coefficient is calculated from the equation (4) [4]:

$$CV_m = C_0 + C_1 \left( 106 / \sqrt{m/m_f} \right) \quad (4)$$

where:  $C_0, C_1$  - coefficient estimated from the measured data.

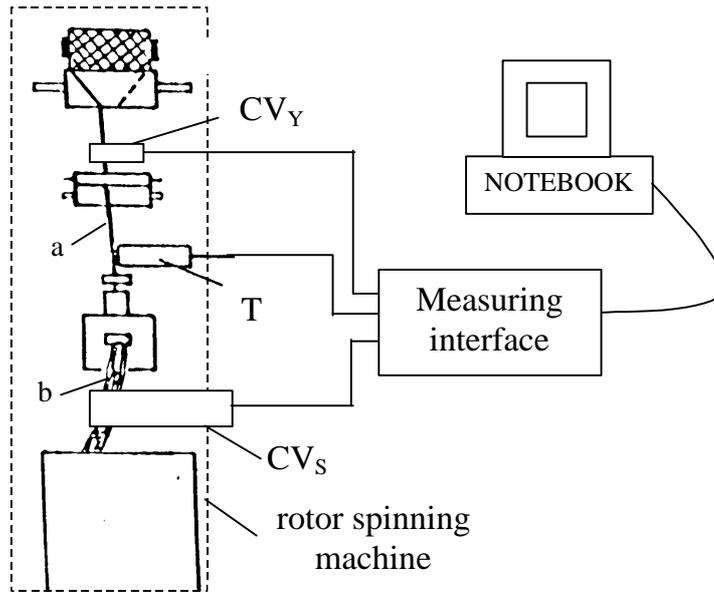
Because of the high complexity of the rotor spinning process, the models of the process are based on considerable simplifications and only some aspects of the process are taken into consideration. New modelling approach offering a powerful tool to modelling without complex analytical description of the process is application of Artificial Neural Networks (ANN) [4]. The model of the process is built on the base of experimental data. Another solution is hybrid analytical and neural modelling. In this approach, neural network part models these aspects of the process, which are not determined from a *priori* knowledge [5]. An example of Hybrid Neural Model is partial static model of spinning process, which has two inputs: rotor speed  $n$  and yarn linear density  $m$ . Average yarn tension  $F_v$  is calculated from the eq. (1) and theoretical value of the coefficient of yarn mass variation  $CV_T$  is computed from the Martindale's equation (3). Rotor speed and  $CV_T$  are introduced to the inputs of small artificial neural network (ANN), which determines the real value of the coefficient of yarn mass variation  $CV_m$ . Yarn tension  $F_v$  and yarn  $CV_m$  coefficient are the model outputs [5]. The presented model doesn't take into consideration all the important process parameters, as for example feeding sliver quality. Therefore a new measuring system for spinning process dynamical monitoring has been designed.

### 3 GENERAL INFORMATION ABOUT THE MEASURING SYSTEM

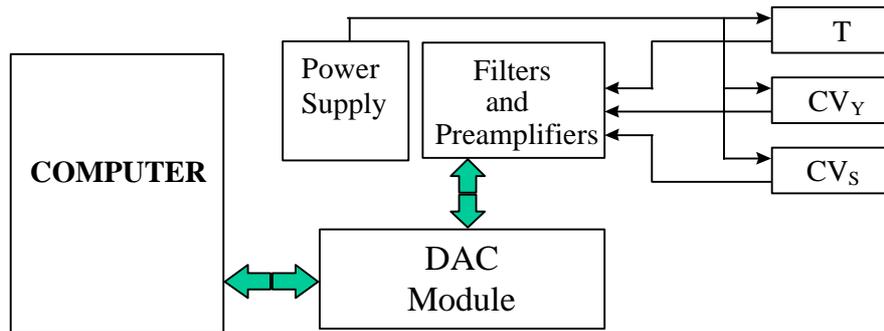
The presented multichannel system allows for 'on-line' monitoring of three important spinning process parameters:

- coefficient of mass variation of sliver –  $CV_s$ ,
- coefficient of mass variation of yarn –  $CV_y$ ,
- dynamic yarn tension  $T$ .

Beside the computer main components of the system are three sensors and measuring interface. The system setup and the sensors positions at the rotor-spinning machine are presented in Fig.1. Tensometric sensor  $T$  is used for yarn tension measuring [2]. Two electrocapacitance sensors of Zellweger Uster were applied for mass irregularity measurement, which is a base for calculation of the corresponding coefficients of mass variation of sliver –  $CV_s$  and of yarn –  $CV_y$  [6].



**Figure 1.** Computerised measuring system setup: T- sensor of yarn tension, CV<sub>Y</sub> – sensor of yarn mass irregularity, CV<sub>S</sub> – sensor of sliver mass irregularity, a- yarn path, b- sliver;



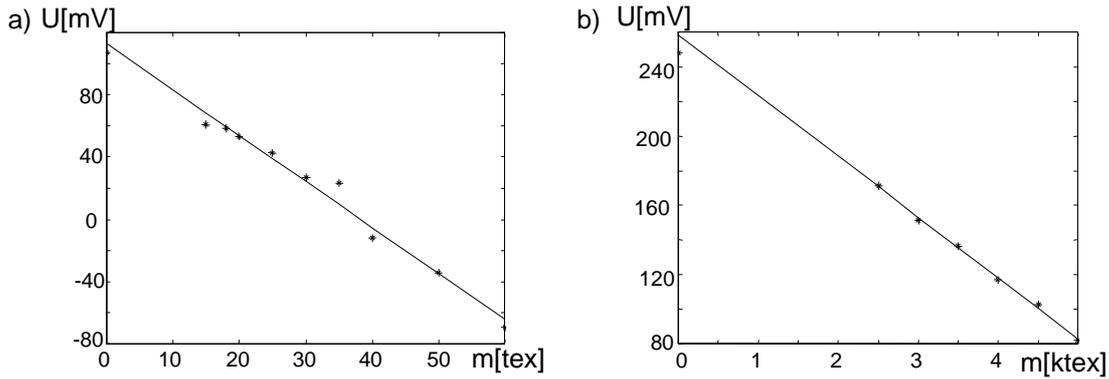
**Figure 2.** Configuration of a computerised measuring system: T- sensor of yarn tension, CV<sub>Y</sub> – sensor of yarn mass irregularity, CV<sub>S</sub> – sensor of sliver mass irregularity, DAC – Digital to Analog Converter;

Main configuration of the system is shown in Fig. 2. Measuring interface consists of Digital to Analog Converter Module - DAQPad - 1200, filters and preamplifiers and power supply. DAQPad - 1200 is a portable data acquisition system produced by National Instruments. It belongs to the new generation of sensor interfaces, which greatly simplify the design of advanced multi-sensor industrial systems. It ensures 12-bit digital to analog conversion and communicates with the computer through a standard parallel port CENTRONICS. Because of this the system is flexible and may be connected to notebook or any other PC computer.

Instrumentation software controls the measuring process, data visualisation and saving. Statistical and frequency analysis of the data is performed. Future research work will be concerned with the software for spinning process identification and user interface extension by the use of LabVIEW Graphical Programming.

#### 4 SYSTEM TESTING

New designed system was scaled and checked by the use of the existing classical measuring instruments. Tensometric sensor was scaled statically with tension tester produced by Zwick. Its static characteristic is linear in the measuring range. Static characteristics of electrocapacitance sensors were also tested experimentally with the set of cotton yarns and slivers, which had different linear densities -m. Both the characteristics are linear and they are shown in Fig. 3.



**Figure 3.** Static characteristics of the electrocapacitance sensors for mass irregularity measuring; a) - for cotton yarn; b) – for cotton sliver.

Then the system was tested using Uster Tester 3 apparatus. Successively one after the other electrocapacitance sensors were situated near by the apparatus. Mass irregularity of yarn and of sliver were measured by the system and by Uster Tester 3 at the same time and for the same parts of yarn and of sliver respectively. The corresponding coefficients of mass variation of yarn –  $CV_Y$ , and of sliver –  $CV_S$ , calculated by the system and by Uster Tester 3, are given in the tables 1 and 2.

Table 1. Coefficients of yarn mass variation calculated by the system and by Uster Tester 3

m [tex]	$CV_{Y(Uster)}$ [%]	$CV_Y$ [%]	$\Delta$ [%]	$\delta$ [%]
25	14,4	12,8	-1,6	11
30	13,6	16,4	2,8	21
35	13,6	13,8	0,2	1,5
40	13	11,6	-1,4	11

Table 2. Coefficients of sliver mass variation calculated by the system and by Uster Tester 3

m [ktex]	$CV_{S(Uster)}$ [%]	$CV_S$ [%]	$\Delta$ [%]	$\delta$ [%]
2,5	3,54	3,68	0,14	4
3,0	2,58	3,39	0,81	24
3,5	3,25	2,99	-0,26	8
4,0	3,42	3,16	-0,26	8
4,5	2,95	2,58	-0,37	13
5,0	3,00	2,92	-0,08	3

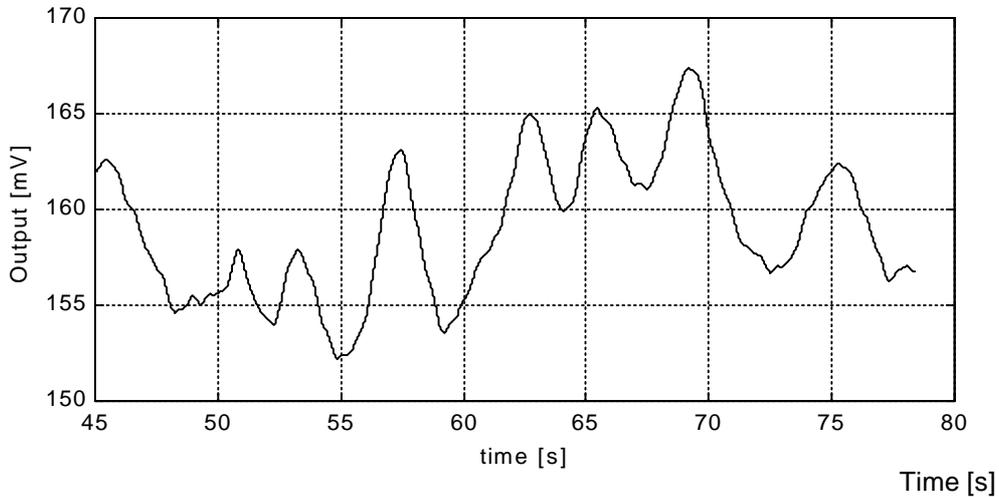
Because of the output signal of the system was contaminated by digital noise, CV coefficients calculated by the system had always a little bigger values as the same coefficients calculated by Uster tester 3. Therefore a correcting factor was introduced for the system scaling. The values of corrected CV coefficients, absolute errors  $\Delta$  and relative errors  $\delta$  are given in the tables. Future research work will be concerned with the improving of the system accuracy.

## 5 SPINNING PROCESS MONITORING

The presented computerised system was applied for ‘on-line’ dynamic measurements of yarn and sliver properties directly on the machine. The aim of the work was monitoring of the dynamic properties of the process. The feed stream of fibres, which is the input signal for the process, was modelled by superposing lengths of a 500 tex roving on a 2.5 ktex sliver [7]. In this way the input interrogating Multifrequency Binary Signal (MBS) was generated. Sections of the sliver with the roving correspond to positive values of MBS signal and the sections without the roving correspond to the negative values. The inverted Strathclyde MBS short odd octave signal with the base code  $3^1+1^3+$  was applied [8]. The main part of this signal power is concentrated in three dominant harmonics: 1, 2, and 4. The feeding sliver was modelled in this way, that four periods of MBS signal were generated. The corresponding sliver and yarn mass variations, and yarn tension were measured

and registered by the system at the rotor-spinning machine BD200S. The first bursts of the signals containing the switch-on transient were removed. All the signals were very noisy, so the specially designed lowpass Butterworth IIR digital filter of 6 order was applied for the data analysis. Filtered signals are shown in Fig. 4 - 6.

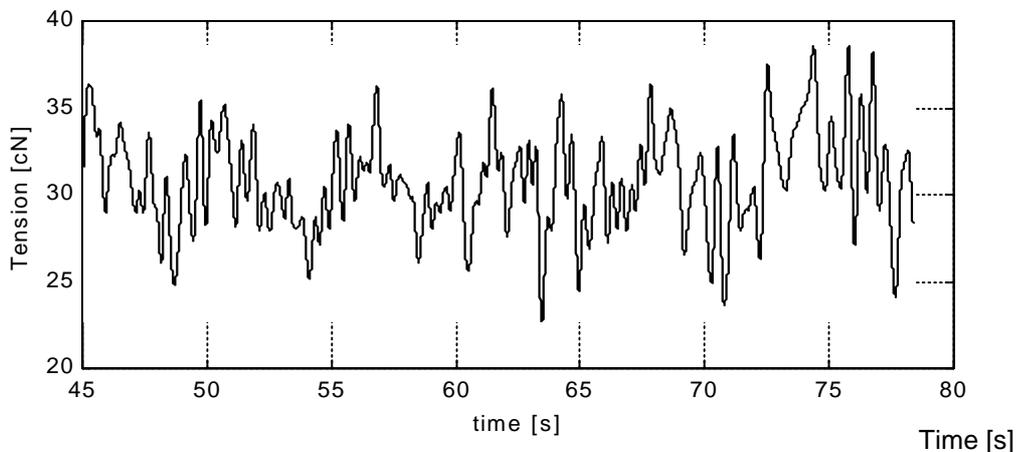
Fig. 4 shows a signal of the sliver mass variations, measured by the system.



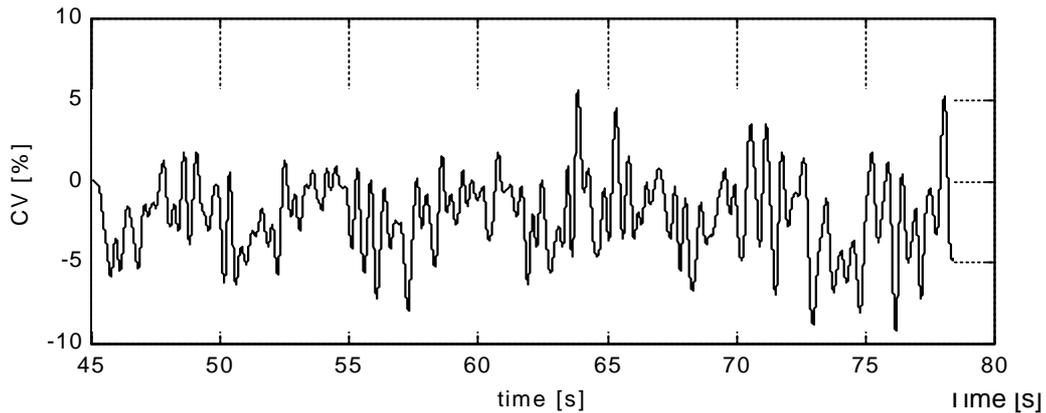
**Figure 4.** Sliver mass variations, measured by the system for the modelled sliver.

The feeding sliver was modelled with MBS signal and the signal presented in the figure is the response of an industrial electrocapacitance sensor for an inverted Strathclyde MBS short odd octave. The shape of this signal differs from the binary signal because of the measuring method and dynamical error introduced by the sensor. Sensor capacitance depends on the average capacitance of the sliver section inside the sensor. Therefore, step changes in the sliver mass are not detected exactly by the sensor. Additionally, the dynamic properties of this type of sensors depend strongly on their working environment. This indicates that sensors scaling and identification procedures should be performed before the measurements. The signal of the sensor MBS response presented in Fig. 4 is a non-parametric dynamic model of the sensor. More exactly, parametric identification of the sensor dynamics may be performed by the use of MBS method.

Fig. 5 and 6 show correspondingly signals of yarn tension and yarn mass irregularity measured by the system at rotor-spinning machine BD200S supplied with the modelled sliver. These two signals are output signals of the spinning process. They represent the process response for the input interrogating MBS signal, generated by the sliver mass modelling. They are partial non-parametric dynamical models of the process and contain the information about dynamic properties of the process.



**Figure 5.** Yarn tension changes measured at the rotor-spinning machine for the feeding sliver modelled with MBS signal.



**Figure 6.** Yarn mass changes measured at the rotor-spinning machine for the feeding sliver modelled with MBS signal.

## 6 CONCLUSIONS

Computerised system presented in the paper is the new technical solution, which allows for 'on-line' and 'in-situ' spinning process monitoring. Measuring sensors are mounted directly at the rotor spinning machine and the spinning process is unaffected. The measured data are saved in the electronic form, what enables their analysis and conversion. The system will be applied in the future research work for the dynamic measurements, which will be the basis for the modelling of the dynamic properties of the process. The presented system may be used to determination of the important yarn quality parameters and also to identification of spinning points and to new spinning machines and technologies testing.

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