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Textronics System for Breathing Measurement

Abstract
This article will present a prototype of a textronics system for monitoring one of the most vital human signals, the frequency of breathing. Here, the authors present optical fibre techniques in textile engineering, as great methods to transmit measured signals inside fibrous structures. Good elastic properties and small dimensions of optical fibres are attributes which make these fibres particularl useful for the designed textronic applications. The authors focused on the design and description of a non-invasive system of health monitoring, which extends traditional clothing functions, and at the same creates a modern textronic product. The monitoring system is composed of two optical waveguides- the sender and receiver, a sensing head with textile spring and electronic system. The whole textronics system is an autonomic measuring device. The authors also present examples of a breathing rhythm recorded for different persons of different ages. The Breath Frequency Sensor (BFS) may be used in many applications, for example the uniformed services or medical personal monitoring clothing, which allows a normal life for patients as monitoring can take place without the need to stay in hospital all the time.

Key words: *textile sensor, optical fibers, breathing measurement.*

Introduction

The human organism needs oxygen for life. It is taken from air in the breathing process. This is rhythmical and people are unaware of this. A very important problem in breathing frequency measurement is knowledge of human physiology. During the respiratory cycle, the volume of the chest changes. This is the result of growing larger in three dimensions: anteroposterior, transverse and perpendicular. Exhalation is the passive phase in a correct breathing cycle. In a healthy human we can observe during the respiration process under rest conditions 14 - 18 breathing cycles per minute, which is equivalent to 8 litres of air. Every breath is equivalent to 350 - 500 ml of air, and it is called respiratory air, and this process is termed one-minute lung ventilation. The number of breaths changes during the workings of the organism, and could be several times greater than ventilation at rest [1, 2].

The most important function of the textronic BFS sensor presented is the increase in human safety, thanks to the possibility of early detection of threats and their proper counteraction. A lack of oxygen raises the level of adrenaline and noradrenaline, which causes pulse acceleration and an increase in blood arterial pressure. This means that a progress in/an increase in hypoxia may even put someone's life in danger. Dangerous situations connected with the professional activity of soldiers, policemen, fire-fighters, and lifeguards, as well as common people, who for example spend a period of convalescence in their own houses, provide an area of potential application of the textronic sensor described.

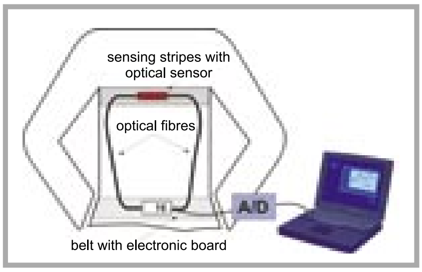

Figure 2. Scheme of the autonomic sensor's system for breathing frequency measurement, and its displacement in the textile structure, with a PC computer as an additional visualization device.

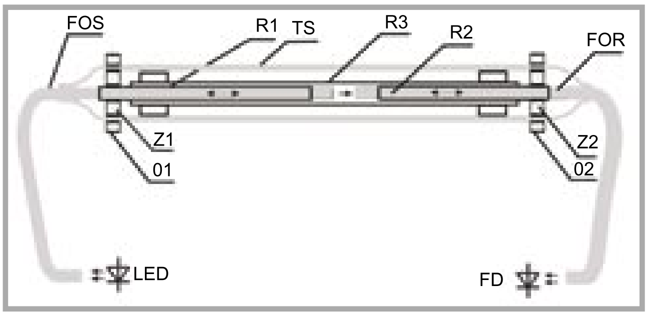

Figure 1. Scheme of the sensor's measuring head; FOS, FOR- optical fibers; R1, R2, R3 - sleeves; O1, O2 - clamps; Z1, Z2 - clips; LED - electroluminescence diode; FD - photodiode; TS - textile spring.

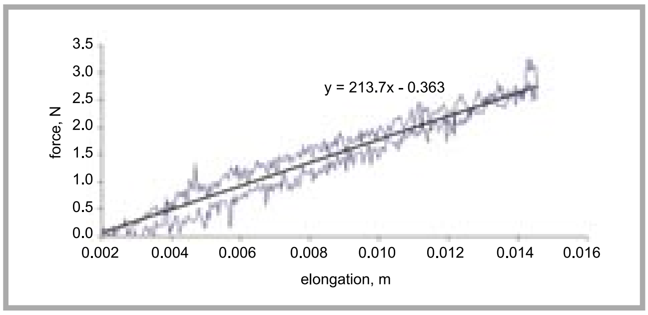

Figure 3. Dependence of force vs. elongation of the textile spring used in the sensor for breathing rythms measurement; y = 213.7 x - 0.363.

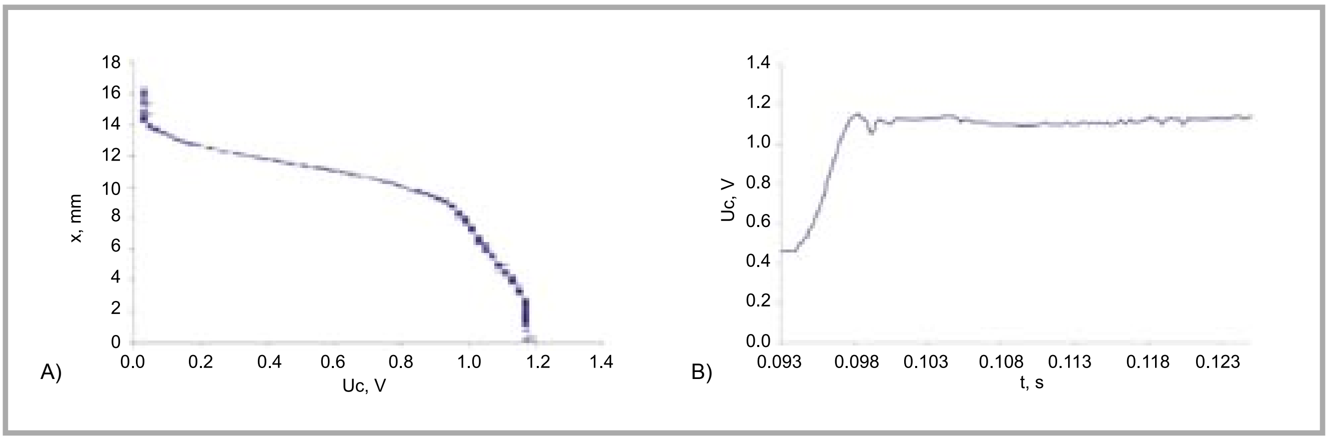

Figure 4. (A) Static characteristic of breathing frequency sensor; (B) Sensor's unit jump force response ΔF = 1.64 N, to optical fibres displacement Δx = 7.66 mm.

Design of the optoelectronic sensor for breathing rhythm measurement

A prototype of textile sensor BFS (Breaths Frequency Sensor), based on optical fibres, is presented in Figure 1. The measuring device is composed of a sensor head, sender and receiver light waveguides and an electronic system.

The sensorial head includes two optical fibres, the sender (FOS) and the receiver light waveguides (FOR). They are positioned horizontally in one line, and each of them is surrounded by a sleeve (R1, R2), which are slidable. Then the sleeves (R1, R2) are placed in a common sleeve (R3). The sleeves in turn are fastened by clamps (O1 and O2) manufactured of a material of good adhesion for clothing. The end of each sleeve (R1 and R2) is jammed by clips (Z1, Z2) which are mutually connected by a textile spring. One end of the optical fibre, that of the sender light waveguide (FOR), is placed directly opposite the electroluminescence diode (LED) of the electronic circuit, whereas the other end of the optical fibre, that of the receiver light waveguide (FOR) is placed opposite the photodiode (FD), connected to the circuit, which in turn is connected to an amplifier, whose output (Out) is connected to an electric current frequency recorder. The sensor's working principle consists in recording changes in the distance between the light waveguide ends the sensor's head, which is caused by the chest's movements. The sensorial head was stretched on a human thorax at a 2 cm maximum distance. The sensor's prototype, designed by us, has the shape of a band wrapped tightly around the chest, which is seen in Figure 2. This figure shows also the position of the optical waveguides together with the electronic system set up for counting the number of breaths per minute. The design presented is characterised by its easy assembly without disturbing the comfort of use.

Within the scope of our investigation, we determined the static and dynamic characteristics of the sensor and its component elements.

The elastic properties of the spring and the complete sensor were determined experimentally with use of an Instron tensile tester, and are presented in Figure 3. The spring constant was assessed experimentally on the basis of a series of recorded hysteresis of the force vs. elongation runs. Further tests were devoted to the determination of the static characteristic of the complete sensor.

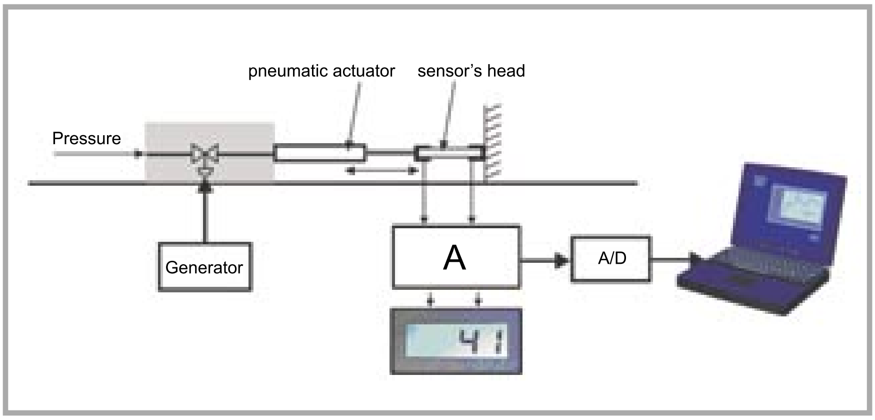

Figure 5. Scheme of measuring system.

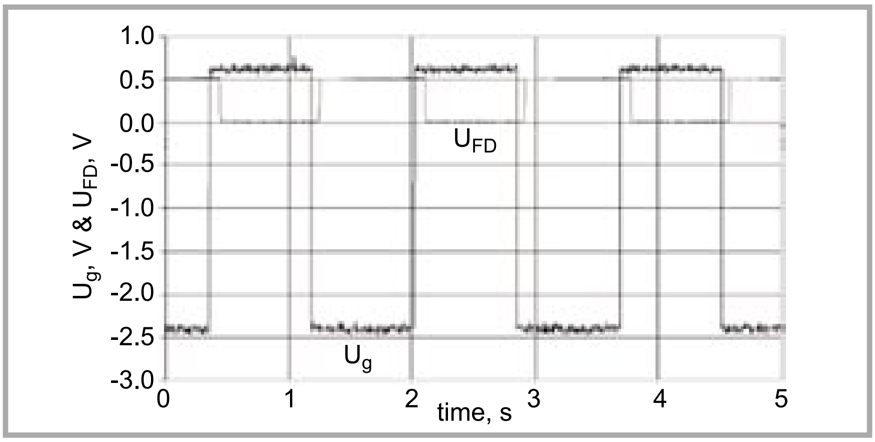

Figure 6. Voltage course from pilot oscillator Ug and breathing rhytm U_{FD} for 0,6 Hz generator frequency.

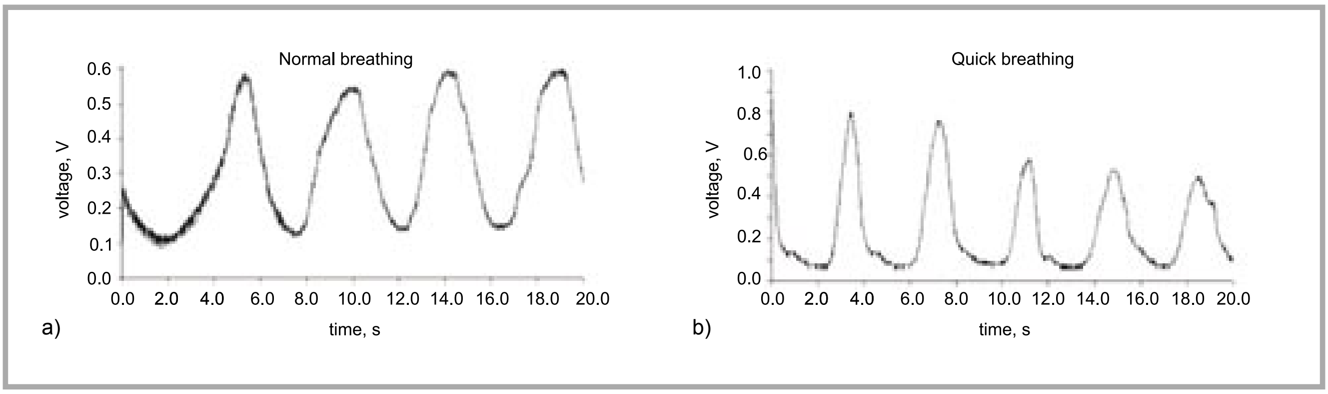

Figure 7. Results received for breathing rhythm for the output of the sensor: a) for normal breathing rhythm, b) after effort breathing rhythm.

Based on the presented characteristic, described by formula 1, the spring constant k can be evaluated:

$$F = 213.7x - 0.363 \quad (1)$$

Thus, spring constant:

$$k = \frac{\Delta F}{\Delta x} = 213.7\frac{N}{m}$$

The static characteristic of the breathing frequency sensor $Uc = f(x)$ is presented in Figure 4. It was also determined using an Instron tensile tester. This characteristic curve is nonlinear, because it results from thesensor's optoelectronic part. The dynamic characteristic of the sensor was also determined by changes in the unit jump force. The sensor's unit jump force $\Delta F = 1.64$ N andin response to optical fibre displacement $\Delta x = 7.66$ mm was recoreded.

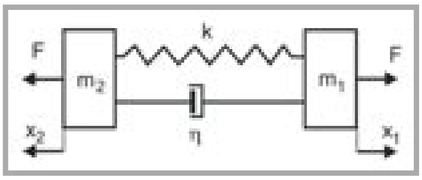

Figure 8. Mechanical model of the breathing sensor as a two-parameter Kelvin-Voight model.

During the research test a laboratory stand was built to two side input forced the end of optical fibres. The research performed for different frequency.

The sensor's sending light waveguide is motionless, whereas the receiving waveguide slides are forced by the pneumatic actuator movements. The actuator was controlled by a rectangular wave from a generator. The Piston rod of pneumatic actuators performs a reciprocating motion on a determined distance of 10 mm. The frequency of controlling the signal from the generator changed within the range of the physiological value.

A sample of tested signals and variable components from the optical sensor during a testing model input function of 0.6 Hz is shown in Figure 6.

A breathing rhythm recording checked the working correctness of the sensor. Examples of breathing rhythms recorded during some breaths for different persons of different age, while resting and during their normal state and medium activity, are presented in Figures 7.A and 7.B by runs of the photodiode voltage (FD in Figure 1).

Model of the mechanical part of the bfs sensor

A mathematical model of the mechanical part of the sensor is described, together with a scheme of the model calculation by a Matlab Simulink program. The mechanical model was analysed for the variant, where both the waveguides (the sending and the receiving) slide coaxially. This variant is presented in Figure 8.

The whole sensor's displacement consists of component dislocation $x_1 + x_2 = x$. The dynamic properties of the sensor depend mainly on its mechanical part, as the optoelectronic phenomenon proceeds very rapidly. The mechanical part of the sensor for the variant described may be specified by the following equation (2):

$$m_1\frac{d^2x_1}{dt^2} - \mu\left(\frac{dx_1}{dt} + \frac{dx_2}{dt}\right) - k(x_1 + x_2) = F$$
$$m_2\frac{d^2x_2}{dt^2} - \mu\left(\frac{dx_1}{dt} + \frac{dx_2}{dt}\right) - k(x_1 + x_2) = F \quad (2)$$

where:
m_1, m_2 – masses of the light waveguides,
μ – friction of the sleeve coefficient,
k – constant of the textile spring,
F – component force.

A mathematical model created using Matlab Simulink blocks is shown in Figure 9. The real forces recorded by a strain

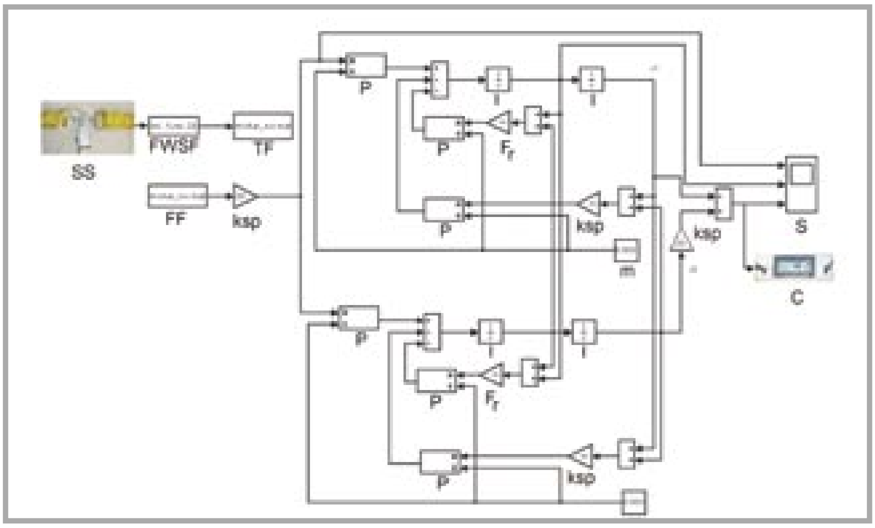

Figure 9. Block scheme of the textronic sensor and it's mechanical part created by a Matlab Simulink program for the second variant of real measurements of the Kelvin-Voight variant; SS - strain sensor, S - monitor, C - counter.

gauge during the breathing cycle were used as the input function.

The results obtained in the form of model runs are presented in Figure 10. The results for breathing frequency comply with the speed and movements of the the ends of the optical fibres.

The results of simulation tests are close to the experimental results. During laboratory tests the measuring system described was working correctly.

An example of an implemented sensor is presented in Figure 11, where optoelectronic BFS are connected to a fireman's uniform. The uniform presented is a example of the prototype measuring system. Figure 11 also shows the electronic system. It is necessary to count breathing. A wide and readable screen is very useful to control the respiratory physiological parameter.

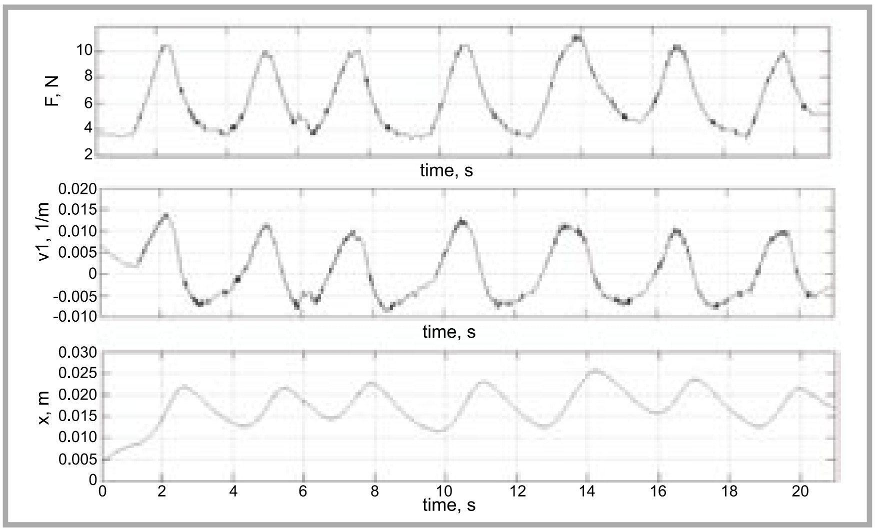

Figure 10. *(A) Force component course of breathing F, (B) Speed changes of breathing v, (C) Chest movement x.*

Figure 11. *The prototype of the implemented breathing frequency system (BFS).*

Conclusions

- The BFS sensor is a real textile device, considering its textile structure, and ultimately its minimum basic parts – the optimal wave guides of the sender and receiver and the textile.
- The sensor characterises simplicity of construction, and as a result of its fibrous structure allows easy implementation into clothing products, for example: uniforms of the rescue services.
- The innovative electronic system is cheep and suitable for applying in practice.
- The BFS sensor has got a fibrous structure because it is composed of two optical waveguides the sender and the receiver, and the textile spring, which splices the ends of optical fibres.
- The electronic system is innovative and cheap.
- The Sensor is located in a elastic bandage, which could easily be put on the thorax.
- It also characterizes simplicity of service, small device dimensions and low price.

Acknowledgment

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Editorial note

The textronic system presented won third place at the International Science Show IWIS, Warsaw 2007. It was also awarded first prize (gold medal) at EUREKA 2007, Brussels Science Show.

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