Amorphous Ferromagnetic Materials used as Sensor in Monitoring Respiratory Movements

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Respiratory movements monitoring is critical in ensuring optimal patient supervision, especially in critical cases and also in diagnosing sleep apnea syndrome.The aim of our paper is to assess the possible role of magnetic impedance (MI) effect in respiratory movements recording.The study was carried out on 6 volunteers using a special mat equipped with quasi-non-contact MI sensors. Evaluation consisted in monitoring and recording the amplitude and frequency of the respiratory movements during normal breathing and while performing Valsalva maneuver.The constancy of pattern and amplitude of waves recorded suggests that this kind of respiratory movement monitoring may have considerable clinical application in monitoring critical patients and also sleep disorders, especially for children suspected of sleep apnea.

Keywords: Amorphous Ferromagnetic Materials, Magneto impedance, Sensor, Breathing, Apnea

Normal respiratory activity provides an optimal concentration of oxygen and carbon dioxide in blood. One of the requirements for this optimal concentration is dependent on a normal respiration pattern.

Changes that occur in blood gas concentrations, as shown in sleep apnea (SA), have effect on executive and cognitive functions, causing structural deficits, behavioral disorders, altering the health balance.

Monitoring and recording vital signs of the patient are essential for the insurance of an optimal medical intervention, especially in critical ill cases. Respiratory rate is one of the vital signs that can give essential information. There are some standardized monitoring systems. For example, the UK – News system[1] incorporates 6 of the vital signs (respiratory rate, temperature, blood pressure, oxygen saturation, pulse rate and level of consciousness).

Some other monitoring charts used to detect as early as possible the deterioration of the patient's state of health include between 5 and 6 key parameters. In all these charts, the respiratory rate is recorded just on the admission in the medical service. One study published in 2014[2] shows that none of the 11 patients that died at the first 8 hours post-operatively had any recording of the respiratory rate. Many authors have recognized that the respiratory rate is one of the most sensitive parameters for critic patients[3,4]

In a study issued in 2006[5], there are mentioned 4 reasons why the respiratory rate is usually poorly monitored: lack of time, lack of knowledge on how important this parameter is, omission during clinical decision making and lack of equipment or medical tools to measure the rate of respiration.

Magneto impedance (MI) effect was discovered by Panina&Mohri and Beach & Berkowitz. It was the start point of the development of MIsensors[6, 7]. A very high impedance variation was observed when a piece of amorphous ferromagnetic material, excited by alternative electric current was placed in an external magnetic field. This observation has opened new research and development possibilities in using this property in medical practice and life saving health oriented devices.

The classical MI effect consists in a significant change of the impedance of a high permeability magnetic conductor passed by a high frequency current when it is subjected to variable external field. Another MI configuration (pulse MI), which was used for the development of the presented sensor, is using a current pulse applied through the magnetic wire to generate a signal response in a surrounding coil base on a special domain structure of magnetic material[8]. The sensor response and impedance change (in both cases) are determined by the permeability change which is very sensitive to mechanical stress (elongation, torsion, bending) and external longitudinal magnetic field. This high sensitivity to stress was used to develop the MI sensor for detection of the small movements produced by breathing.

The aim of our study is to present the medical application of a quasi-non-contact magneto impedance sensor used for monitoring of respiratory movements.

Experimental part

The study included 6 healthy volunteered subjects (4 women and 2 men), with the age ranging from 25-49 years. The study was approved by the Ethics Committee of the Clinical Rehabilitation Hospitalla'i. An informed consent was obtained from the participants.

We used a special mattress designed by the National Institute of Research and Development for Technical Physics, Iasi, Romania. On the surface of the mattress a sensor was placed consisting from a 1 meter long CoFeSiB amorphous magnetic wire, prepared by melt ejectionin-rotating-water spinning method, wrapped in a single layer coil using a 0.07 mm copper wire. The CoFeSiB amorphous wires have very high mechanical resistance and show very high relative magnetic permeability (>1x105), high MI response (up to 500%) and very high sensitivity of these properties to external stress. These characteristics make this type of wires excellent candidate for displacement and stress sensors. The sensor and the testing circuit were presented in a paper published in 2014[9].

The subjects were placed in supine position on the mattress with the sensor placed at the level of the

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5th intercostals space (fig. 1). The subjects were instructed to breathe normal avoiding any other movements. The rate and amplitude of the respiratory movements of the thorax were evaluated.

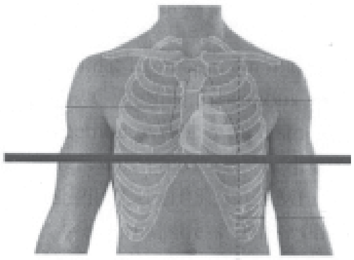

Fig. 1.Position of the sensor along the 5th Intercostal Space (black line)

The next step was to describe how the disturbances in the respiratory movement were reflected by the morphology of the waves recorded by our equipment. In this regard, each subject was asked to breathe normally several times, followed by a Valsalva maneuver (attempted exhalation against a closed airway - VM) that was standardized to last minimum 10 s after a deep inspiration.

Results and discussions

A distinct series of waves was recorded. The morphology of the waves recorded during normal breathing could be characterized by frequency and amplitude.

Frequency of the respiratory waves (the number of waves per unit of time) corresponds to respiratory rate. (fig. 2 and 3). The recording showed a mean frequency of 14 respirations per minute for all the 6 participants – accordingly to the normal respiratory rate.

The morphology of the waves during VM was dramatically different (fig. 4 and 5).During VM a wave complex was recorded: it was possible to describe sequentially a first wave labeled by us with letter "i" (inspiratory) followed by a plateau ("p") and ending with a negative wave ("e") expiratory.

The duration of this complex of waves, with an average of 13 seconds corresponded to the initial requirement of our test (the subjects were instructed to maintain VM for at least 10 s) knowing that the apnea during the sleep is considered pathologic if it is lasting for more than 10 seconds [10,11].

This complex of waves recorded during the VM was noted in all subjects.The constancy of pattern and amplitude of waves recorded on the normal breathing and during the VM suggests that this kind of respiratory movement monitoring may have considerable clinical application in the respiratory rate monitoring of the critical patient especially if it is coupled with an audible warning. On the other hand the shape and latency of the waves were changed significantly during the VM in comparison with the waves obtained during normal breathing, the pattern being the same for all the 6 participants in our study, during the VM.This last finding suggests that this sensor might be also useful in monitoring the respiratory movements and especially the duration of the absence of the respiratory activity during sleep, especially in those that are suspected of having sleep apnea.

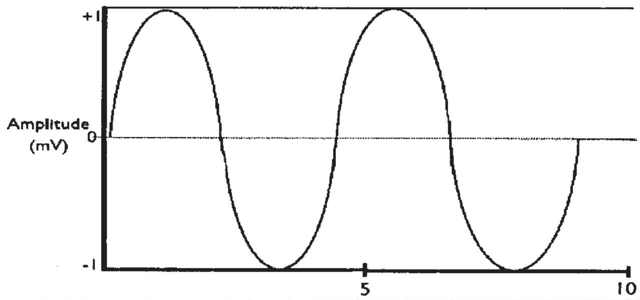

Fig. 2. The waves recorded during the normal breathing (schematic)

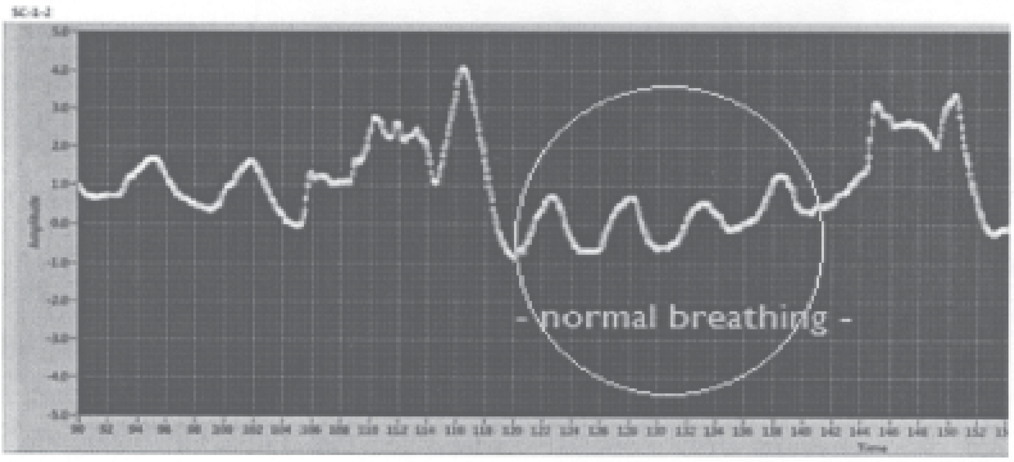

Fig. 3. The waves recorded during the normal breathing

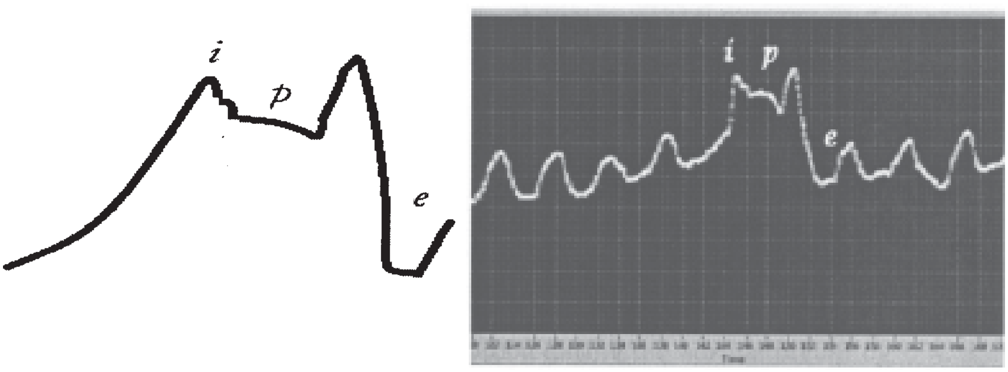

Fig. 4. The waves recorded during the Valsalva maneuver (schematic and real recording)

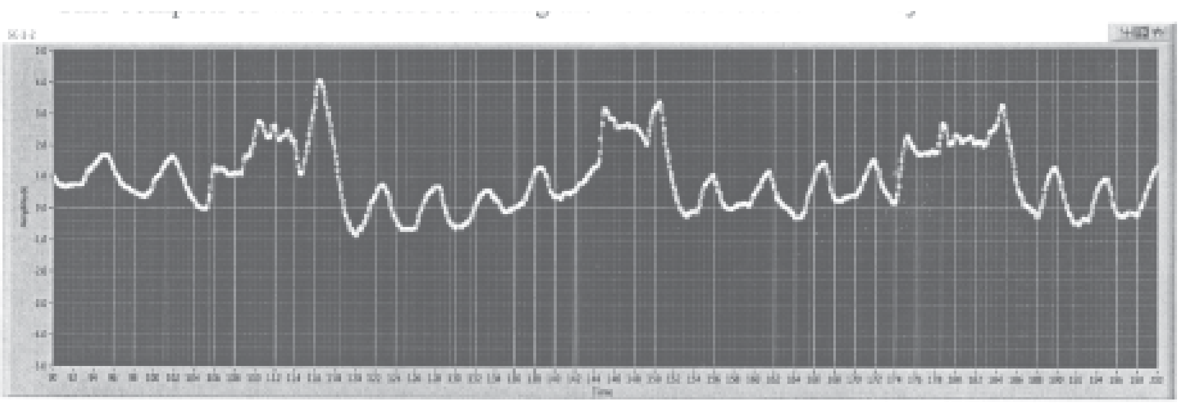

Fig. 5. Recording of succesive normal respiration followed by Valsalva maneuver (VM)

Conclusions

Monitoring and recording respiratory movements is a very important advantage in supporting critical patients. An easy, quasi-non-invasive and real-time respiration monitor is crucially useful in providing life saving medical services.The newly available technology of magneto impedance properties can have useful application in medical devices and help accurately monitor and record respiration movements. This opens new opportunities in diagnosing and follow-up in chronic sleep disorder. Magneto impedance based respiration rate monitoring proves to be reliable, with good recognition of various respiratory movement wave components: inhalation, exhalation and apnea intervals. Using this type of sensor placed in a mattress provides long time monitoring capabilities of the thoracic movements, without discomfort for the patient.

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11.*** The Report of an American Academy of Sleep Medicine Task Force". Sleep, August, **22** 5, 1999, p.667. On the other hand the shape and latency of the waves were changed significantly during the VM in comparison with the waves obtained during normal breathing, the pattern being the same for all the 6 participants in our study, during the VM.

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