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MAGNETIC SENSOR FOR MONITORING OF PHYSIOLOGICAL FUNCTIONS

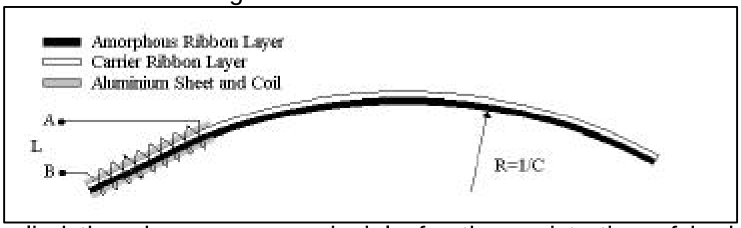
L. Mehnen, E. Kaniusas and H. Pfützner
Institute of Fundamentals and Theory of Electrical Engineering
Bioelectricity & Magnetism Lab., University of Technology, Vienna, Austria

Abstract: The present work investigates the application of magnetostrictive amorphous ribbons (AR, thickness d_{AR} »30 µm) for the detection of mechanical bending. Such ribbons exhibit high bending sensitivity if used as a bimetal where the second component is a nonmagnetic carrier ribbon (CR) of thickness d_{CR}. The aim of this study was to develop a bimetal ribbon which is fixed to the skin of the human body and should adjust itself to dynamic changes of the skin curvature. A main problem results from the demand of good flexibility - favoured by low d_{CR} - as well as high sensitivity - favoured by high d_{CR}. As a second problem, the agglutination layer showes a tendency to act as a third component. However, reducing the thickness of this layer to a minimum, sensitivity values sufficiently high to detect physiological functions during sleep or anaesthesia were attained. For this application, the bimetal was fixed on the neck skin in the region of the carotid artery. This position proves to offer a signal of "mixed" character. Through mathematical separation, it yields physiological data like heart rate and respiration rate, and further diagnostically relevant events like motions, swallowing actions or snoring.

1 INTRODUCTION

A bimetal ribbon consisting of two interconnected layers is the basis for a new sensor which enables to detect force, strain, displacement, temperature and others. According to Fig.1, the sensor is composed of a soft magnetic amorphous ribbon (AR, thichness 20-30µm) of strong positive saturation magnetostriction and a non-magnetostrictive carrier ribbon (CR, 100µm). As closer discussed in [1], slight bending of the sandwich yields strong axial compression of the AR. The corresponding decrease of its permeability is used to establish a sensor signal *s*.

Figure 1. Schematic outline of the bimetal sensor.



In earlier studies [2,3], we have applied the above sensor principle for the registration of body movements, sandwiches being fixed for example at the knee joints or in the region of the spinal column. In an other application it was inserted in a thorax belt in order to detect the rate and intensity of respiratory activity.

The present paper gives a first report about a novel sensor version fixed on the neck skin in the region of the carotid artery. This positions proves to offer a signal *s* of "mixed" character, including information on both the cardiac activity and the respiratory activity. Thus it promises to offer simple monitoring of physiological functions during sleep or anesthesia.

2 SENSOR DESIGN AND PREPARATION

In the above mentioned earlier studies, we attained an increased bending sensitivity by sticking the AR of thickness $d_{AR} \approx 30$ µm on a CR which is given by a plastic ribbon of low Young´s modulus *E* but considerably high thickness d_{CR} (typical thickness ratio: $d_{CR} / d_{AR} \approx 30$). For a further increase of sensitivity, stability and compactness, in the present project the plastic ribbon was replaced by a non-magnetic metal ribbon with $d_{CR} \approx 100$µm corresponding to $d_{CR} / d_{AR} \approx 3$. The resulting bimetal shows a typical geometry of 150 µm thickness, 50 mm length and 6 mm width. As a consequence of bending this sandwich structure, the neutral bending plane remains in the CR. Thus the AR is subject to almost pure compression.

As illustrated in Fig.1, one end of the bimetal was kept flat by means of two 1mm thick aluminium sheets. In this region, a 1.5 cm long slender coil was wound round the AR/CR sandwich, the number of turns being of the order 300 ($R_x \approx 20\ \Omega$, $L_s \approx 1$ mH). According to Fig.2, a HF generator is used to establish a 15 kHz signal of sinusoidal wave-form. An additional power source is used to feed a constant current into the sensor coil. Dynamic changes of L_s as a result of bending are transferred into a signal with the help of a difference amplifier, a rectifier and a low pass filter for demodulation. The resulting analog sensor signal s is digitized for computational use in the evaluation unit. Finally it can be stored and monitored.

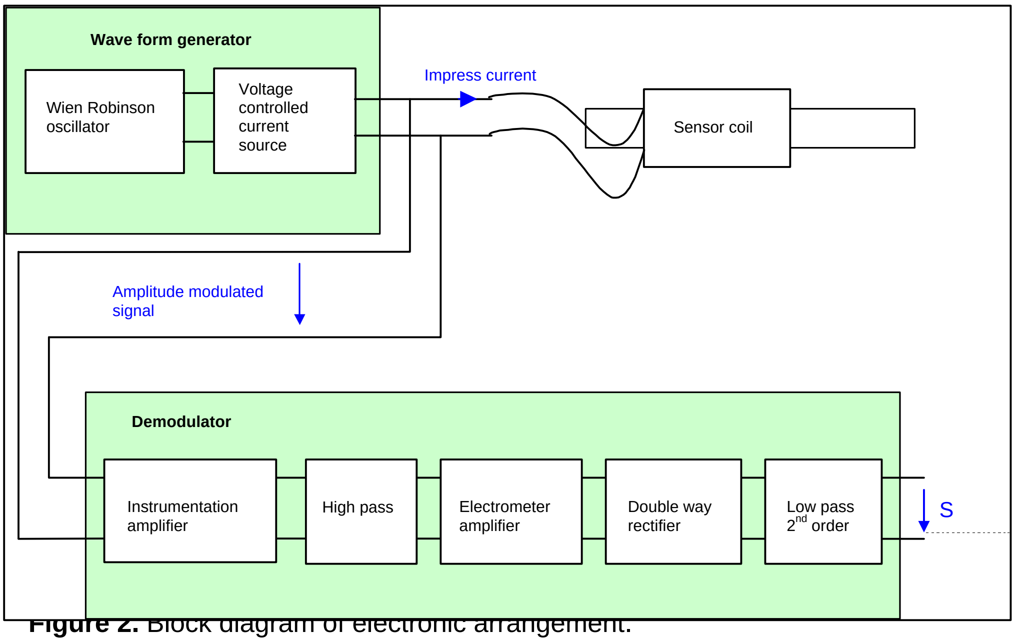


Figure 2. Block diagram of electronic arrangement.

The main goal for this sensor design is to sense the heart and respiration rates in order to detect sleep apnea. According to this demands, the optimum place for its application is the neck in the area of the carotid artery, normal to the vertebral column (spine), but every other place on the skin is suitable, too. When sticking the sensor-strip on to the skin, no further preparation is needed. The sensor automatically fits to the skin-surface in a comfortable way without loosing sensitivity, which is essential for a peaceful sleep.

3 RESULTS

The following shows results for a sensor application as sketched in Fig.3. By means of double-side adhesive plasters, the sandwich was arranged about 1 cm beside the larynx, normal to the vertebral column in order to collect a maximum of physiological information. As a specific demand, the sandwich should adapt itself to dynamic changes of the neck surface which suggests the use of low d_{CR}. The above mentioned value of $d_{CR} \approx 100$µm proves to be the upper limit. On the other hand it is the lower limit with respect to sensor sensitivity. The latter proved to be sufficient provided that the thickness d_{IAL} of the interlaminar adhesive layer (IAL) is kept very small. The following signals were established with $d_{IAL} \approx 30$µm which however does not represent the optimum corresponding to advanced technology.

Figure 3. Application of the sensor.

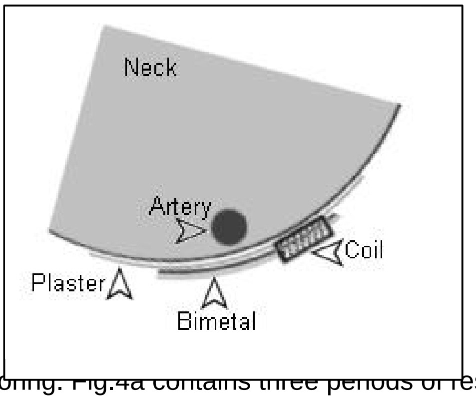


Fig.4 shows typical results of monitoring. Fig.4a contains three periods of respiration which arises in a predominant way. This breathing signal proves to be produced by the neck (and/or breast) muscles which contract for inhaling and release for exhaling. A further mechanism is given by neck swelling as a result of increased air pressure.

The respiratory signal of low frequency f_R is superimposed by a cardiac signal of higher frequency f_C but much lower amplitude (about 2dB distance according to Fig. 5). It is generated by the blood pressure pulsation of the carotid artery. Fig.4b shows in detail five periods of a cardiac signal as detected during breath holding. The here used high resolution visualises the main heart phases as assumed in this area.

As to be expected, the sensor signals are strongly affected by head motions. The corresponding amplitudes exceed those of the respiratory signal by an order of typically 10 dB. Such artifacts restrict the sensor application to monitoring during rest, anaesthesia or sleep. However, in the latter case, the head motion artifact may represent a diagnostically relevant information in itself. As a further information with similar signal strength, the sensor tends to yield specific signal patterns for swallowing as depicted by Fig.4c.

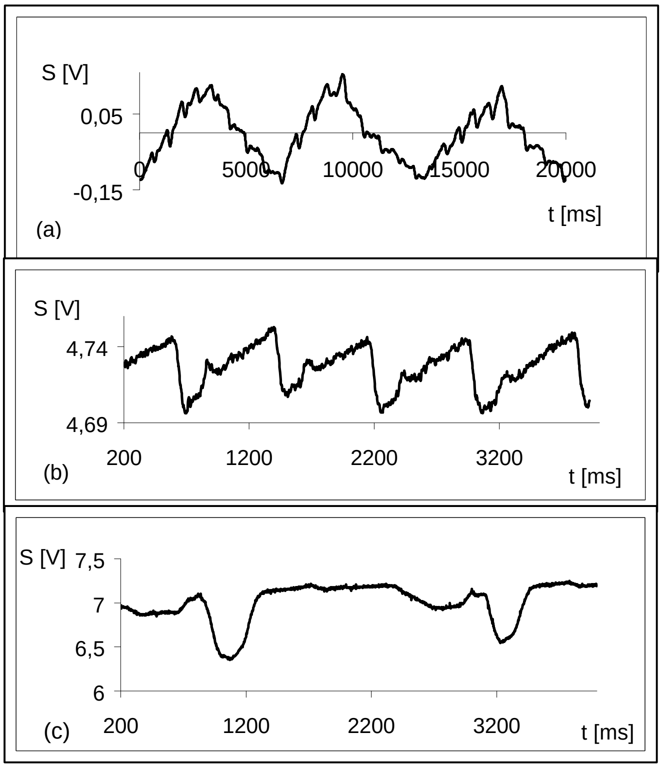


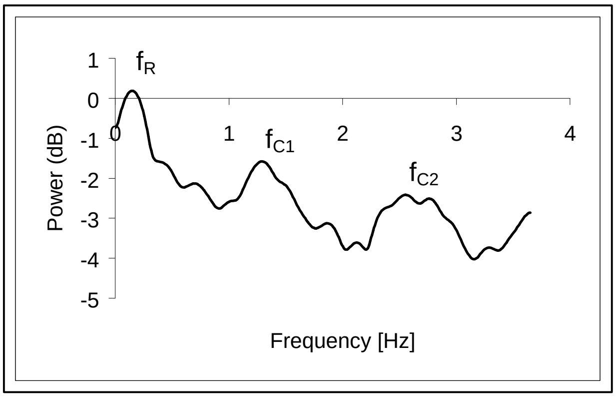
Figure 4. Typical examples of signal *s* as a function of time *t*.

(a) Monitoring during normal breathing yielding a low-frequency respiratory signal superimposed by a cardiac activity of higher frequency.

(b) Pure cardiac signal detected during breath holding.

(c) Artifacts as being typical for swallowing and offering additional information.

Figure 5. Short time power spectrum showing the typical orders of signal frequency and signal intensity.



4 CONCLUSIONS

The above described neck sensor yields a "mixed signal" which promises to offer the following physiologically relevant informations:

- respiration rate
- relative time changes of respiratory flow
- cardiac rate
- events as arising during sleep (head motions, swallowing)

First attempts of signal separation indicate that FFT yields respiratory data in an effective way. At present, attempts are made to establish cardiac data also by means of FFT applied on the time derivative d*s*/d*t*.

According to first experience, the robust and cheap sensor shows the main advantage of detecting respiratory and cardiac activities in a very simple and synchronous way. The low sensor mass promises that application during sleep should be possible without affecting the quality of sleep in a distinct way.

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AUTHORS: DI Lars MEHNEN, DI Eugen KANIUSAS , Prof. Dr. Helmut PFÜTZNER
University of Technology, Gusshausstr. 27-351, 1040 Vienna, Austria, Institute of Fundamentals and Theory of Electrotechnical Engineering, Bioelectricity and Magnetism Laboratory,
Phone Int: +43 / 1 / 58801 / 35122, Fax Int: +43 / 1 / 58801 / 35199, E-mail:mehnen@gte.tuwien.ac.at