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A micromechanical device that monitors arterial pressure during general anesthesia and in intensive care units

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Abstract: A vibroacoustic fiber optic system that consists of micromechanical components designated for use in medicine and biology is reviewed. A theoretical analysis of a fiber optic microphone is done and its optimal construction parameters are determined. Указана The possibility of using the developed system with magnetic resonance tomography to noninvasively measure man's arterial pressure is specified.

1. Introduction

Circulation is foremost among all vital signs in importance. Arterial pressure is one of the basic parameters of the human body's circulatory system. Arterial pressure level is a key determinant of patient treatment and affects an infection's duration and outcome. Precisely measuring systolic and diastolic arterial pressure presupposes the use of hemodynamic monitoring during general anesthesia and of magnetic resonance imaging (MRI) in intensive care units. Creating and using new biomedical devices to ensure more precise diagnostics and determine arterial pressure therefore constitute a pressing issue. Presented in this plan is a compelling design for fiber optic sensors (FOS) and systems meant for various medical applications. An optical fiber's very small diameter (smaller than 250 μm), high flexibility and low loss upon exposure to light render possible the production of subminiature biomedical FOS and their direct installation at the location of measurement. A principal advantage of FOS is their insusceptibility to electromagnetic and radio frequency signals. This property makes FOS ideal for uninterruptedly diagnosing patients undergoing MRI examinations or computerized tomography, situations in which applying other types of sensors is problematic. This article considers the creation of acoustic micromechanical FOS, which will help ensure two-way acoustic connections with patients and the remote monitoring of arterial pressure through the use of auscultation during MRI examinations.

2. A micromechanical fiber optic instrumentation system

Micromechanical fiber optic instrumentation systems based on monitoring the micro-displacements of sensors under the influence of measurable physical phenomena have made prevalent the production of FOS [1]. This monitoring can be done through the use of interferometers with external primary transducers.

The optical fiber end-face interferometer (OFEI) is regarded as one of the simplest such devices [2]. Highly sensitive, this interferometer is remarkable in its simple construction, compactness, tolerance to external influences and low cost. An OFEI construction schematic is shown in figure 1. The operating principle of an OFEI lies in the introduction of an emission from laser diode 1 to optical fiber 2 and its consequent transmission through bifurcation 3 to optical fiber 4. An emission fragment reflects from the end of optical fiber 4 while another emission fragment flashes into the air, reflects from mirror 5 and returns back to optical fiber 4. The emission fragment reflected from the end of optical fiber 4 interferes with the emission fragment reflected from mirror 5 and photoelectric receiver

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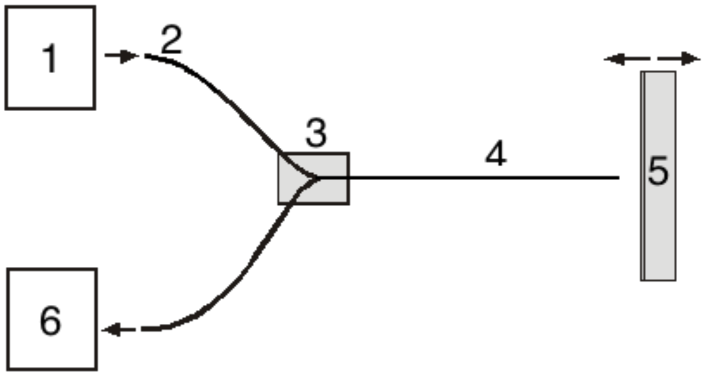

Figure 1. OFEI Construction Schematic

6 registers the emission power. Interference generally results in the superposition of not two, but several waves that emerge due to the repeated transformations of the light beam between the end of the optical fiber and the mirror.

3. A micromechanical fiber optic microphone

Using a micromechanical fiber optic microphone as a pressure measurement sensor necessitates a highly-sensitive membranous component to ensure the membrane's linear displacement even upon small changes in external pressure.

Membranous components are made from silicon wafers through the application of integrated-group methods and micromechanical technologies [3]. First, grooves of predetermined width and depth are etched on the front of the silicon water in the form of several concentric rings. A layer of Si_3N_4 0.2-0.3 μm thick then forms on the grooved side of the silicon wafer, after which a layer of metal settles in the central part of each component. Silicon finally peels off the back of the wafer, as a result of which is obtained a thin corrugated Si_3N_4 membrane with a reflecting center region fixed on a silicon base. Figure 2 is a photograph of a membranous component made specifically for fiber optic microphones at Saint Petersburg State Electrotechnical University's Microtechnology and Diagnostics Center.

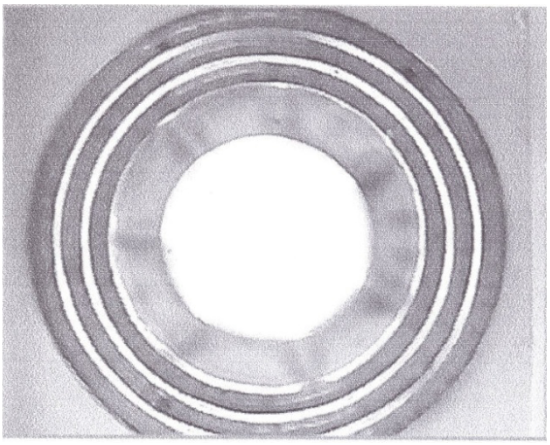

Figure 2. Membranous Component

Figure 3 is a construction schematic of the fiber optic microphone's primary transducer. A commercially-produced ceramic capillary can function as the base (1). A cement bonding connects the capillary to a standard single-mode optical fiber 9/125 μm in length (2), after which the end of the optical fiber is glazed so as to create a reflecting mirror surface for optical emission. The membranous component (4) is then connected to a commercially-produced ceramic centralizer (3). The membranous component and the centralizer on which it is anchored are fixed on the ceramic capillary, after which the primary transducer is finely tuned.

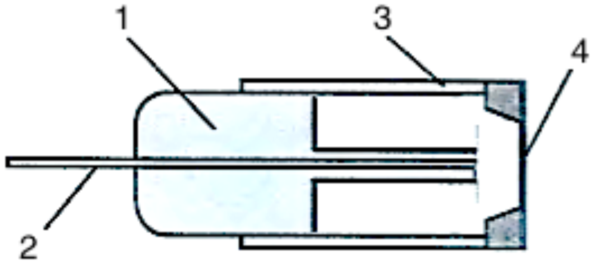

Figure 3. Construction schematic of a fiber optic microphone's primary transducer

Figure 4 is a photograph of a primary acoustic transducer with a membranous component 4x4 mm in size.

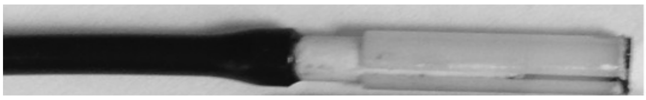

Figure 4. Primary acoustic transducer with membranous component 4x4 mm in size

Values calculated for the integral level of equivalent sound pressure determined by microphones' internal noises at the working frequency range evidence the sensor's high sensitivity (about 20-24 dB). The microphones' measured dynamic range amounts to 60-65 dB.

4. Measuring arterial pressure in different situations

Most noninvasive methods currently used to measure arterial pressure in clinical practice are classified according to the way in which this parameter is determined. Most commonly-employed measurement methods are auscultatory, as proposed Russian internist N. S. Korotkov, and oscillometric. Every method has its own advantages and limitations. Using Korotkov's method, for example, requires that the microphone be properly situated and encounter no disturbances during the course of observation. Considering subjective factors such as choosing locations for the seal and microphone is of particular concern. Despite the difficulty of standardizing its measurement conditions, Korotkov's method is routinely recommended (WHO, 1935). The oscillometric method does not require microphone placement, but it is not standard due to its low precision of measurement.

The standard device for measuring arterial pressure using Korotkov's method consists of an occlusal seal and something to blast air inside of the seal and measure its inside pressure [4]. Using this device requires skill and is inconvenient when it is necessary to obtain a precise result quickly. Strong electromagnetic emissions that cause measurement errors render impossible the use of electronic tonometers in life-saving situations, such as during an MRI examination done under general anesthesia.

Keeping this in mind, an idea for creating an automatic device that noninvasively measured arterial pressure by using the aforementioned micromechanical fiber optic microphone was put forth. This would ensure the complete and safe monitoring of arterial pressure for patients in need of an MRI examination or of surgery done during an MRI examination.

Figure 5 is a typical oscillogram of Korotkov tones taken from a healthy patient exposed to a strong electromagnetic force (up to 3 T).

Figure 5. Signal taken by a fiber optic microphone from a human exposed to a strong electromagnetic force

A fiber optic microphone rather than a conventional microphone was used for the auscultatory diagnostics. This result shows the potential for using fiber optic microphones to gauge arterial pressure through a specially-designated acoustic method.

5. Conclusion

It is at present possible to name the following characteristics as those by which the scientific practicality of future measuring instruments will be ensured:

- no acoustic or electrical disturbances upon exposure to strong electromagnetic forces;
- the possibility of being used as a distributed topographic system to validate results;
- the use of a wireless system for transmitting information through a communication channel;
- the possibility of obtaining additional information (a diagnostic of various anomalies in the heart and blood vessels);
- the application of optical sampling to decrease both the affect of the human factor on pressure monitoring and the number of measurement errors;

This work's results can be used for the further technical realization of vibroacoustic fiber optic systems (microphones) that measure arterial pressure in special situations, as well as for the development of a complete medical system that answers all contemporary concerns.

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