

Results of Experiments with Fiber Pressure Sensor Applied in the Polish Artificial Heart Prosthesis

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The following paper introduces the problem of noninvasive pressure measurements in Polish artificial heart prosthesis. The pressure sensor is proposed and introduced, and preliminary tests are shown. The paper deals with the proposed sensing elements, requirement noninvasive solution and preliminary tests of polyurethane membrane transmission. The paper includes also experimental results of a fiber pressure sensor introducing noninvasive pressure measurements with pressure transmission through a polyurethane tube wall.

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1. Introduction

A healthy heart is crucial for the proper functioning of the human body. In the case, when this organ does not function in the way it is supposed to, the usual treatment is based on drugs.

If the disease is more severe, drugs alone might be not enough to provide its proper recovery. In these cases modern medicine uses heart supporting devices.

The Polish heart supporting device (POLVAD) developed and manufactured by Foundation of Cardiac Surgery Development in Zabrze is used in patients with heart problems, allowing them to recover faster or provide a bridge to the heart transplant by releasing the heart of its burden, thus making drug-based treatment significantly more efficient. At this stage the POLVAD device is connected with the patients' circulatory system by skin connectors, with a prosthesis situated outside the body. The next step is to move the prosthesis inside the patient's body [1–3].

2. Subject of the study

Heart support is a difficult process. There are many variables that affect this process, therefore it is crucial to get as much information about the prosthesis itself and its surroundings in the human body as possible. Nowadays, when the device is situated outside the human body it is easy to evaluate the current state of POLVAD, both the state of the prosthesis and the effectiveness of the supporting process (by observing the movement of the inner membrane of the prosthesis), adjusting supporting parameters (pneumatic part pressures and heart rate speed). At this point POLVAD must be inserted into the human body, making it necessary to introduce sensors providing information about the current state of the

prosthesis. The sensors should provide information about the volume of blood being pumped by the device [4–8], the pressure in the pneumatic and blood part of the prosthesis and the pressure of blood at the entrance and exit of the prosthesis. The development of blood saturation sensors is also a part of the project. This enterprise is a part of the Program "Polskie Sztuczne Serce 2007–2012" [9–11]. The Department of Optoelectronics at the Silesian University of Technology is involved in the development of blood and air pressure sensors to be used in the Polish artificial heart prosthesis.

3. Fiber pressure sensors

The fiber pressure sensor is produced by the FISO company. The sensor that was used as a blood pressure sensor was FOP-M. The proposed sensor is intrinsically safe, immune to radio and electromagnetic interference and its measuring range (-100 mmHg ÷ 400 mmHg) meets the project requirements. Its operation is based on the Fabry–Perot optical resonator at the end of the fiber, where one of the resonator walls is built as a membrane deflecting under the pressure [9]. Pressure changes inflict different wavelengths being amplified in the reflected spectrum. The conditioner that introduces light into the measuring fiber sensor is also equipped with a CCD matrix for reflected light measurements, and because the relation between membrane deflection and pressure is linear, we can easily measure the pressure by measuring the membrane deflection.

The proposed measurement system consisted of a FOP-M fiber sensor, conditioner and computer for the presentation of results (Fig. 1).

A pressure sensor was chosen in preliminary tests and both air and water pressure measurements were conducted. The results of these tests were shown [6, 7].



Fig. 1. Fiber sensor measurement system.

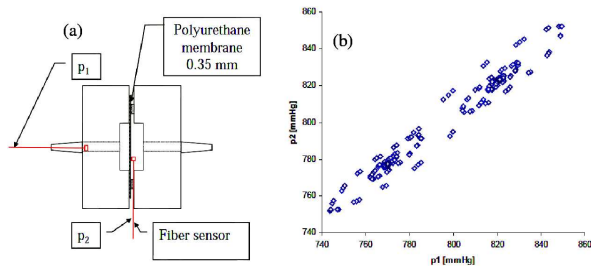


Fig. 2. Membrane transmission tests: testing chamber construction (a) and exemplary results (b).

The Polish artificial heart project requirements for blood pressure measurements required noninvasiveness of the sensor. The FOP-M sensor could not be, therefore, directly introduced to the blood environment. The idea of indirect measurements by blood pressure transmission through a thin polyurethane wall element was proposed. In order to test this idea, a testing chamber was constructed (Fig. 2a). The proposed element was split into halves by a polyurethane membrane made of the same material as the heart prosthesis. Both parts were filled with water. Pressure changes were being induced on the p_1 sensor side and measured with a p_2 sensor. Exemplary results of pressure transmission tests can be seen in Fig. 2b.

The analysis of pressure transmission through the membrane proved the idea to be valid. Despite pressure losses due to the properties of the membrane, the measured transmitted pressure was within the acceptable error range.

Results encouraged the research team to incorporate a sensing element into the actual polyurethane tube. Tests

The prosthesis that was used for water circulation, was driven by a POLPDU unit. Measurements were conducted under different heart support speeds and driving pressures. Exemplary results are shown in Fig. 5. The pressure was measured inside the polyurethane tube (induced pressure) and a second fiber probe was situated on the connector element, inside the chamber filled with oil (transmitted pressure).

The pressure drop caused by the polyurethane wall properties was observed, as had been expected after the preliminary tests shown in Fig. 2.

The relation between signals from both FOP-M sensors is linear. There are some measurement points that do not fit the linear relation. It may be due to the inertia of the membrane, the elastic properties and turbulent water flow. Despite these few points that do not follow the

were still made in water environment at the Foundation for Cardiac Surgery Development in Zabrze. The construction of the sensor is shown in Fig. 3.

To fulfill the noninvasiveness requirement, the proposed pressure sensor has no direct contact with the

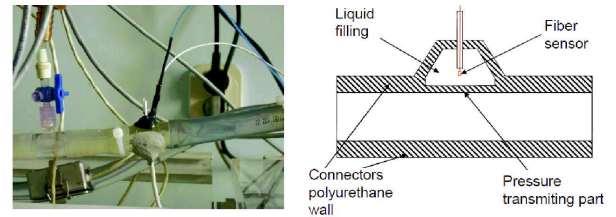


Fig. 3. Prototype blood pressure measurement construction.



Fig. 4. Physical model of the human circulatory system.

blood environment. A special small chamber for the sensing fiber was made in the tube wall. The polyurethane wall of the tested connectors tube was made thinner at the base of the sensor chamber, in order to allow pressure transmission. The cavity was filled with oil, and the fiber sensor was placed in the chamber. The constructed element was connected to the model of the physical human circulatory system (Fig. 4).

linear trend, most of the pressure is transmitted correctly.

The conducted research shows that pressure transmission proposed in this paper is promising. The results show that pressure transmission through a polyurethane membrane is possible, and small differences in the transmitted pressure do not influence the overall trend of the linear relation between both pressure signals.

It can be seen that the shape of the pressure wave is reproduced outside the blood track with an expected pressure drop due to the transmission process.

4. Conclusion

The main goal of the conducted research was to test the optical pressure sensor for its possible incorporating in the POLVAD prosthesis in future. The project

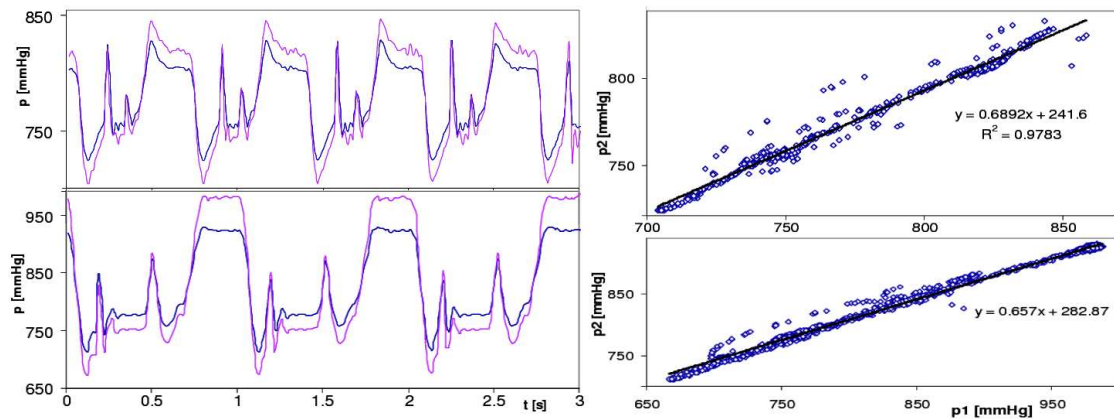


Fig. 5. Results of pressure transmission measurements with the use of the proposed pressure sensor and method. a) Real time pressure measurements results, b) measured pressure vs. induced pressure.

aims at the introduction of a fully functional, noninvasive blood pressure measurement system, with a measured pressure range of $-100 \div 400$ mmHg, with a dynamicity of 5 mmHg/ms. The sensor is to be used in the Polish artificial heart prosthesis. The conducted researches provide a new solid base for a future measurement system.

The fiber pressure sensor has been proven worth future investigations. It meets the requirements of the project. The noninvasiveness of blood pressure measurements was proved to be possible by pressure transmission through the wall of polyurethane elements. Future tests require the construction of measurement points with pressure transmission through the POLVAD prosthesis casing and tests on blood.

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