FIBER PRESSURE SENSOR FOR THE POLVAD PROSTHESIS

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This paper covers research on possible pressure measurement methods for the "Polish Artificial Heart" Project. The investigations covered fiber pressure sensor. The final aim of the project is to introduce pressure sensors for noninvasive blood pressure measurements in selected points around the pneumatic ventricular assist device (POLVAD). The paper includes testing results and development plans for final sensor.

Keywords: *blood pressure sensor, optical fibre sensors*

1. INTRODUCTION

Heart problems are more and more common in human population. Living with diseased heart is difficult and sometimes impossible. In these cases the only way to cure heart muscle is mechanical support [1-4]. For this purpose POLVAD heart supporting devices are used. The main purpose of the ventricular assist device (VAD) is to aid the human circulatory system by external blood pump connected directly to the human vascular system. Artificial heart support relieves the human heart from a large part of its burden, what accelerates healing process. The POLVAD device (Fig 1) is driven by a pneumatic driving unit (PDU) of the POLPDU-401 type.

Fig. 1. Extracorporeal, pneumatic ventricular assist device POLVAD and connection with human vascular system(FRK, Zabrze)[4].

Both prosthesis and driver form the Polish Cardiac Assist System (POLCAS) [5,6]. Presently PDU gives possibility of setting both the volume and the rate of blood pumped during one cycle. The main problem to be solved is feedback, so the driving unit could provide information about the current status of prosthesis, which is impossible now.

The main purpose of this work is to research possible real time pressure measurement systems, and choose one method for future incorporation in prosthesis.
This paper includes recent researches on fiber pressure sensor.

2. OBJECT OF RESEARCH

Conducted research focused on the pressure measurement system for use in POL-VAD prosthesis. Project specifications required certain specifications for sensor to meet. Main requirement is pressure measurements without direct contact with the blood environment, what forces indirect blood pressure measurement. Measured pressure range should cover -100 to +400 mmHg, with 5 mmHg/ms dynamicity. The research includes the results of the fiber pressure sensor manufactured by FISO©.

2.1. FISO FIBER PRESSURE SENSOR RESULTS

Fiber sensor was the first pressure sensor to be tested. For our purposes a fiber pressure sensor manufactured by FISO© was used. Fiber sensor has many advantages compared to sensors based on electrical effects. The most important is resistance to radio and electromagnetic interference, so we can neglect measurement errors caused by remote sensing that would occur in electrical sensors. The size of the sensing element is ~1 mm in diameter which makes measurement points around prosthesis significantly smaller.

A significant advantage to electrical sensors is the lack of additional wires (one fiber measurement system). The bio compatibility of fiber is acquired by a teflon coating.

The operation of the sensor bases on a Fabry-Perot interferometer, situated at the tip of the FOP-M fiber, which changes its dimensions when pressure is applied. For a given pressure, concrete wavelengths are amplified in the reflected spectrum. The conditioner is responsible for introducing light into the sensing fiber, detecting reflected light, and translating it into pressure changes expressed in required units [8].

The measured pressure range, guaranteed by the manufacturer, meets the project requirements. The sensor was tested for compliancy with other project directives.

First of all we researched repeatability of measurements using two fiber sensors of the same type (Fig. 2).

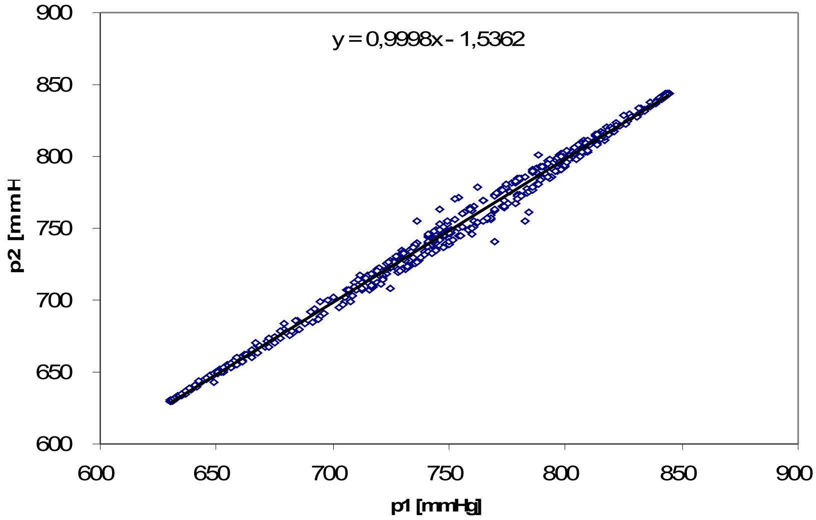

Fig. 2. Results of pressure measurements with using two FOP-M sensors in the same environment.

Two sensors were put in the same cavity and pressure changes were induced. Readings from both sensors are almost identical (Fig.2). Differences are below the required accuracy level and can be caused by uneven pressure changes inside the test cavity.

Since project required certain dynamic properties of the final sensor, such measurements were carried out.

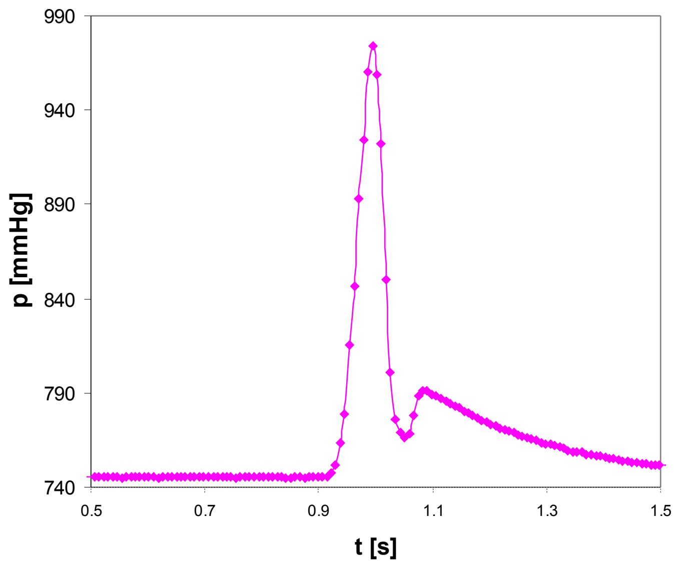

Fig. 3. Dynamic measurement tests of the fiber sensor.

The results indicate (Fig.3.) that the fiber sensor is capable of measuring dynamic pressure changes faster than 9 mmHg/ms, which is enough to comply with project specifications
(5 mmHg/ms).

After initial tests of FOPM sensor properties, tests of comparison with medically attested blood pressure sensor were conducted. The measurement circuit consisted of a conditioner and a FOP-M fiber sensing element. First tests of fiber sensor were conducted with PMSET medical blood pressure sensor from BD *(*Becton*,* Dickinson *and Company)* as a reference (Fig. 4.). For data acquisition and processing a special application, programmed with *LabView 8.0*, was used.

Fig. 4. Measurement system used for testing of fiber sensor.

Measurements were in air environment and pressure changes were being inducted with use of special syringe. Fiber sensor was introduces near sensing element inside PMSET sensor and both pressure from fiber sensor and voltage from PMSET sensor were acquired by LabView application. Results are shown in Fig. 5.

a) b)

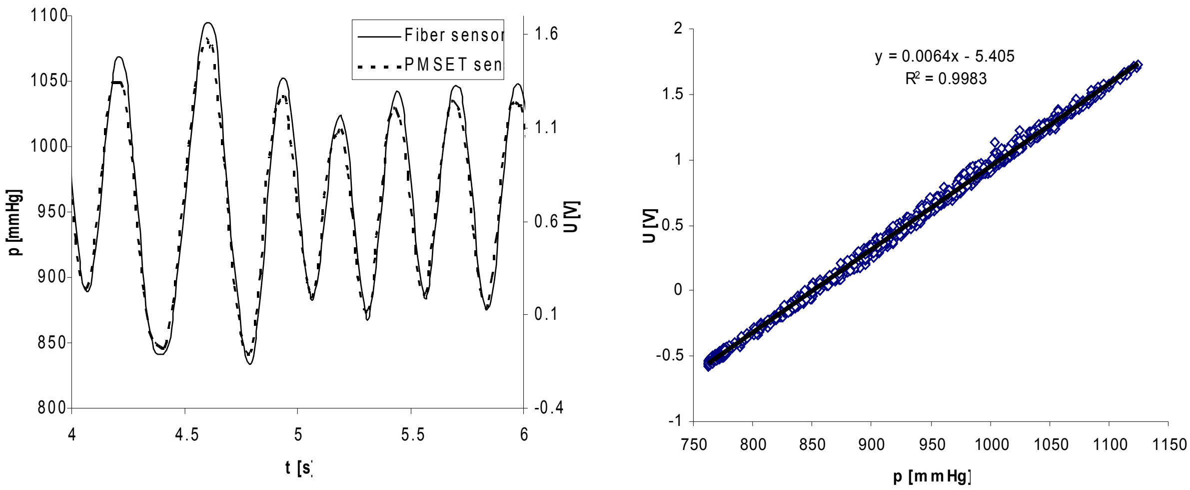

Fig. 5. Results acquired by measurement system form Fig. 2 (a) and direct comparison of readings from fiber sensor and PMSET sensor (b).

In Fig. 5. one can see that both sensors react to pressure changes in the same manner (a). Results from PMSET sensor are given in Volts, and they need further conversion to pressure units, while results from fiber sensor are directly translated by conditioner into desired units (in our case mmHg). In Fig. 5b direct comparison of results from both sensors is shown. There is very good correlation between readings from sensors .

Next step of testing was to measure correlation between readings from both sensors in water environment, to introduce conditions more similar to blood environment (Fig.6.)

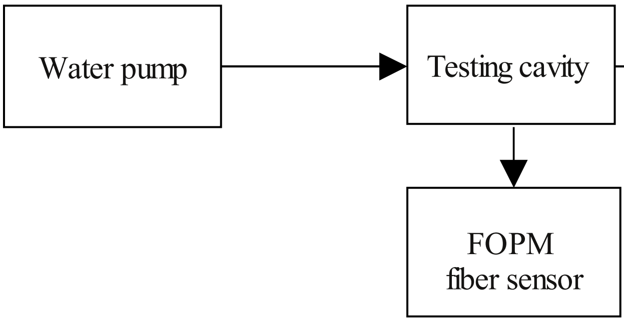

Fig. 6. Block diagram of water pressure measurement system.

As pressure inducer automatic water pump was used. It was able to generate pressure changes of different shapes and periods. Few different configurations were tested. In Fig.7. the exemplary results are shown, where generated pressure wave was trapezoid.

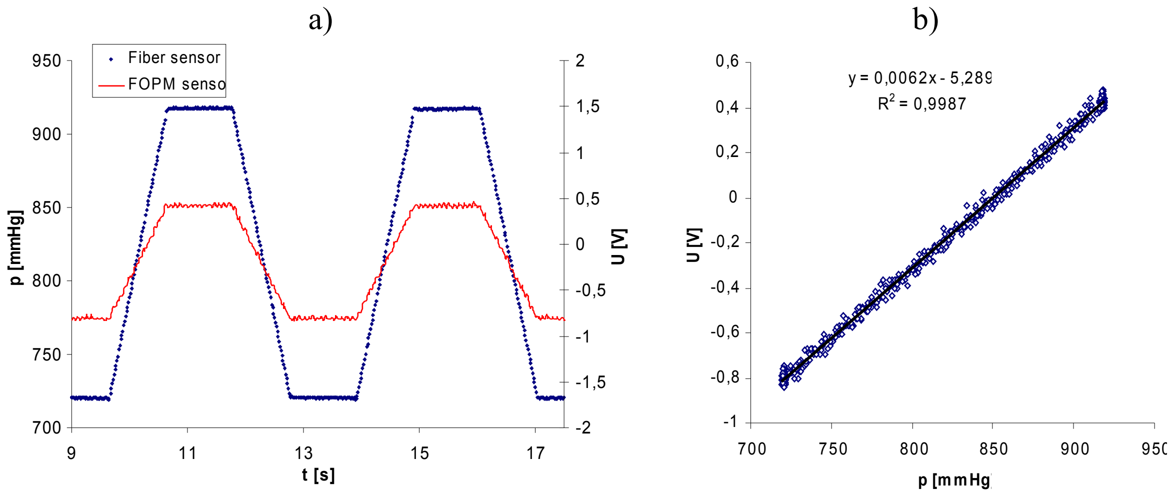

Fig. 7. Results acquired by measurement system form Fig. 4 (a) and direct comparison of readings from fiber sensor and PMSET sensor (b).

Also in this case relation between results from both sensors is almost linear (Fig.5b). Fiber sensor is measuring water pressure changes in the same manner as the PMSET sensor. Water in most cases behaves like blood, so we can claim that fiber sensor can be used in measuring blood pressure when given proper separation providing noninvasiveness.

4. POLYURETHANE MEMBRANE TESTS

As mentioned above blood pressure sensor must be separated from blood environment to avoid destruction and coagulation of blood elements. Finding the best way to separate sensor from blood without loosing possibility to measure pressure is difficult task. The proposed solution to this problem was measurement of blood pressure through prosthesis casing. To find out if this would be possible, polyurethane foils, made of the same materials as prosthesis, of different thickness were tested. For these purposes special a testing element has been made (Fig. 7).

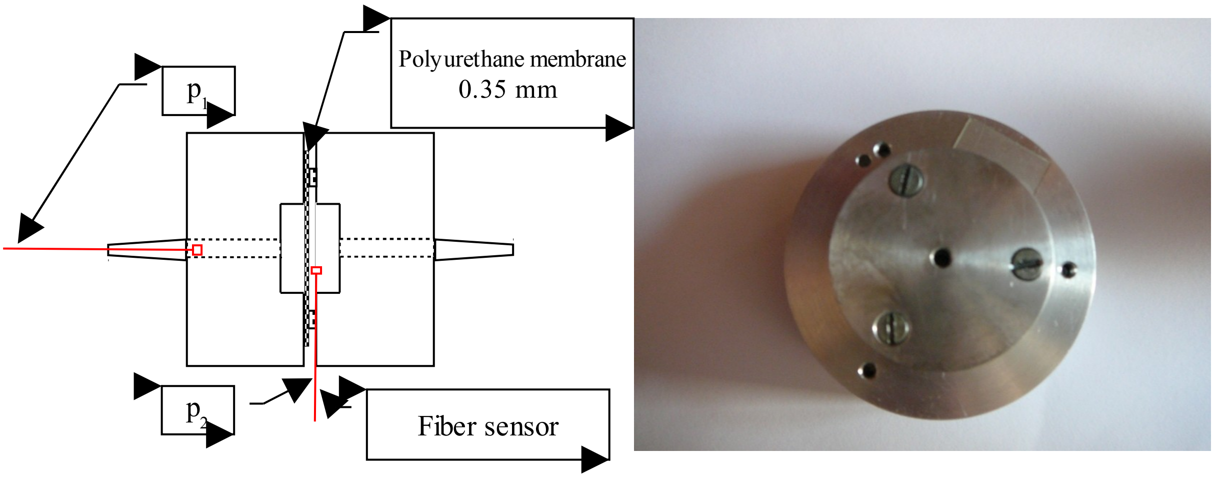

Fig. 7. Arrangement of the sensor in the testing chamber (a) and a top view of the testing chamber (b).

The testing chamber was divided into two cavities by thin polyurethane foils. The chamber volume was filled with water and the FOP-M sensors were situated on both sides of the membrane (Fig. 7).

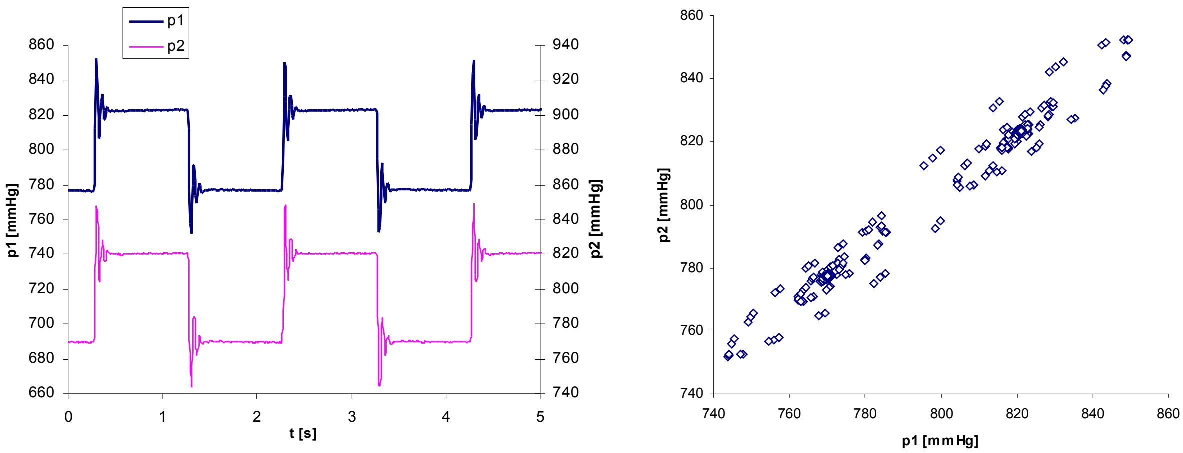

Fig. 8. Signal on both sides of the membrane (a) and relation between the sensors (b).

The induced pressure was measured on "p_1" sensor side, and the transmitted pressure was measured on the other side of the membrane by a "p_2" sensor.

Since the pressure transmission highly depends on the foil thickness, the test has been conducted on the thickest one (0.35 mm) supplied with Foundation of Cardiac Surgery Development, where the measurement was made simultaneously in both chambers (Fig. 8a). There is observable linearity between the results acquired from both sensors (Fig. 8b). The properties of the foils have a significant influence on the result but in this case – in this case it might be phase shift between results from both sides of foil. Another cause of testing problems is the presence of air bubbles inside the testing chamber, which was really difficult to be avoided. Testing proves that there is possibility of achieving pressure measurement noninvasiveness by pressure transmission through polyurethane foil.

In the final project POLVAD its walls ought to be made in certain points thin enough, to transmit the inner pressure changes outside.

5. CONCLUSIONS

The main goal of the conducted research was to test fiber pressure sensor for possible future incorporating in POL-VAD prosthesis. Project aims at the introduction of a fully functional, noninvasive blood pressure measurement system, with measured pressure range of -100 – 400 mmHg, with a dynamicity of 5 mmHg/ms. The sensor is to be used in the Polish Artificial Heart.

The conducted researches bring a new solid base for a future measurement system.

The fiber pressure sensor has been proven worth future investigation. Researches show that its properties meet those of attested medical sensor in this project. The noninvasiveness of blood pressure measurements will be obtained by the VAD casing, where polyurethane material will be made thin enough to transmit changes of the blood pressure to the external pressure sensor. Future test require construction of measurement points with pressure transmission through POLVAD casing and tests with blood.

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