Research Into Pressure Measurement Methods For Using In POL-VAD

MSc. Grzegorz Konieczny, *Silesian University of Technlogy*
(**20.08.2009**, Tadeusz Pustelny, Zbigniew Opilski, Erwin Maciak, *Silesian University of Technology*)

Abstract

Presented material covers recent status of project concerning the development of blood pressure sensors for use in Polish Artificial Heart project. Work focuses on POLVAD, which is a pneumatic ventricular assist device - mechanical prothesis that is being used in patients with heart problems to allow faster recovery of the heart muscle. It is being produced by Foundation of Cardiac Surgery Development in Zabrze.

This presentation covers recent research into the possible pressure sensing methods for use in the noninvasive blood pressure measurement in required places around the prothesis.

Main requirement for developed methods is lack of contact with blood, to avoid the destruction of blood elements and minimize influence on blood flow.

Two sensing methods are being introduced: fiber pressure sensor and piezoelectric pressure measurement with piezofoils. Preliminary results are included, and choice of best method for the future development is being pointed out.

1. Introduction

Heart problems caused by diseases are very common among the human population. In serious cases it is crucial to release the hearth from part of its burden in order to accelerate its healing. One of the methods of doing it is using the mechanical hearth support by means of ventricular assist device (VAD) [1,2,3,4]. The main purpose of the VAD is to aid the human circulatory system by connecting an external blood pump to human vascular system. This kind of support relieves the heart from a large part of its load, thus allowing its faster recovery.

Fig. 1. Extracorporeal, pneumatic ventricular assist device POLVAD (FRK, Zabrze)[4]

The ventricular assist device (Fig 1) is controlled by a pneumatic driving unit (PDU) of the POLPDU-401 type and altogether form the Polish Cardiac Assist System (POLCAS) [5,6]. Presently by the means of POLCAS the medical staff is able to set both the volume and the rate of blood pumped during one cycle. There is no information about the current status of prosthesis provided by the assist system.

2. Research considerations

Conducted research considered introduction of the pressure measurement system for use in POL-VAD prosthesis. Pressure sensor parameters were predetermined by the project specifications and included: blood pressure measurements without direct contact with the blood environment, measured pressure range (-100 to +400 mmHg), dynamicity of measuring changes of 5 mmHg/ms.

The research includes the results of testing two possible pressure sensing methods: the fiber pressure sensor and the sensor based of piezoelectric foils.

2.1 Fiber sensor

The first of sensing devices investigated during the research was a fiber pressure sensor manufactured by FISO©. The results obtained by means of the fiber sensor are indifferent to radio and electromagnetic interference. The sensor gives the possibility of the remote measurement and the size of the sensing element (a total fiber diameter is ~1 mm) makes measurement points smaller, and thus easier to incorporate into prosthesis. A significant advantage to electrical sensors is the lack of additional wires (one fiber measurement system also doesn't need any electrical signal near sensing element). The fiber sensor is bio compatible due to teflon coating.

The measurement circuit consisted of a conditioner and a FOP-M fiber sensing element. For data acquisition and processing a special application, written with LabView 8.0, was created. Sensor operates as a Fabry-Perot interferometer, situated at the tip of the FOP-M fiber. Its dimensions change with applied pressure. For a given pressure, exact amplified wavelengths are detected in the reflected spectrum. The conditioner is responsible for driving of the fiber sensor and translating it into pressure changes expressed in required units [8].

The sensor was tested for compliancy with the project directives.

Reproducibility of pressure measurements was tested by simultaneous data acquisition from two FOP-M sensors put in the same cavity (Fig. 2).

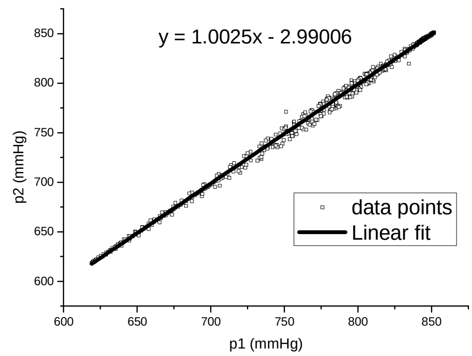


Fig. 2. Results of pressure measurements using two FOP-M sensors in the same environment.

Conducted experiment shows that data from both sensors is comparable, with minor differences less than 1%.

Also dynamic pressure measurement capabilities of the sensor were carried out for compliancy with project specifications.

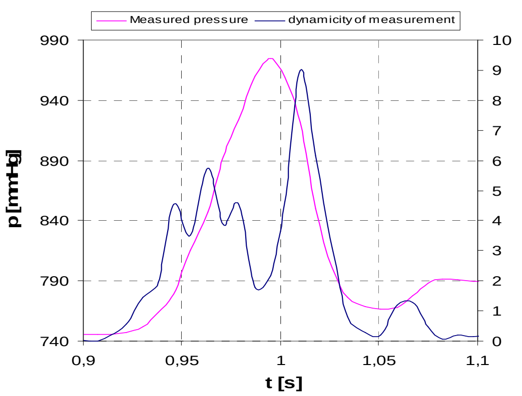


Fig. 3. Dynamic measurement tests of the fiber sensor.

The outcome of this investigation has been shown in Fig 3. The graph shows both the characteristics of the measured pressure and the dynamic pressure changes. The results indicate that the fiber sensor is capable of measuring dynamic pressure changes faster than 9 mmHg/ms. It is almost twice the dynamicity required by the project specifications (5 mmHg/ms).

The conducted research shows a wide potential application of fiber sensors in blood pressure measurements.

2.2 Pressure measurement with piezofoils

Piezoelectric foils manufactured by Measurement Specialties© were investigated as to their possible using in the pressure changes detection system. They require two wires (for the voltage changes detection), one extra wire compared with the fiber sensor.

Piezofoils behave like a very low-efficiency voltage source where pressure changes, among other factors (e.g. movement, temperature, light intensity changes and mechanical shock), cause charge generation on the piezofoil and, therefore, inflict voltage changes at the sensors output terminals. It is crucial to use a differential amplifier with a low input bias current in order to acquire voltage changes cause by pressure, and to prevent a discharge of the sensing element during measurements.

The introduced testing circuit (Fig. 4), is based on the INA116 instrumentation amplifier with input bias current of no more than 2 fA.

Fig. 4. Measurement equipment for piezoelectric foil tests.

During all tests a reference fiber sensor described in the (2.1) subchapter was used. For testing purposes both sensors were put in same cavity where pressure changes were being induced.

The tests covered three types of piezofoils : 28 μm thick laminated foil, 28 μm and 52 μm thick foils without laminate.

The pressure was being changed. Exemplary simultaneous readings from both sensors (fiber and piezofoil) are shown in Fig 5.

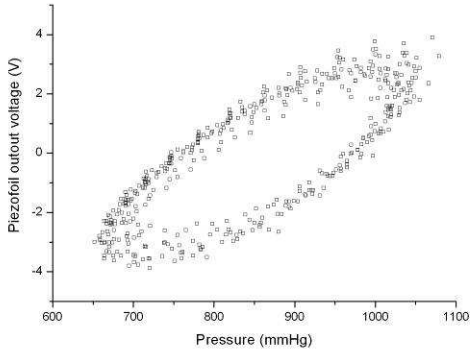
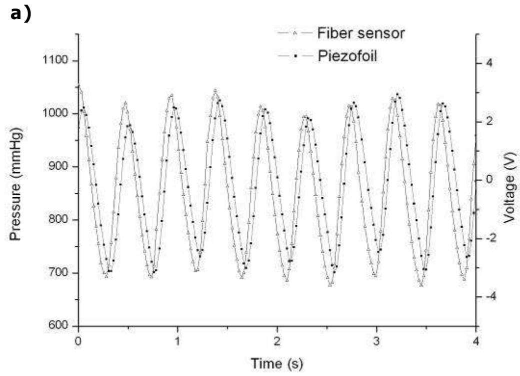


Fig 5. Measurement results of the piezofoil test.

A comparison of the results from both the piezofoil and the fiber sensor is shown (Fig. 6.). As can be seen in the picture there is a slight phase shift of unknown origin (Fig. 6a). After compensation of the phase difference, the almost linear relation can bee seen(Fig 6b). The first cause of this effect can be the time difference between data acquisition from both sensors, and the second one could be the piezofoil inertness. It is not certain what exactly causes this kind of piezofoil behavior on out testing circut. Even after compensation the reproducibility of results was very low. The foils of the same type gave different results.

a)



b)

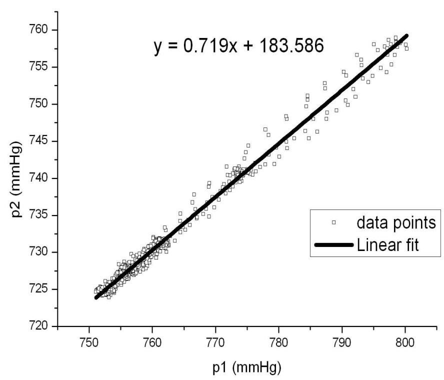


Fig. 6. Piezofoil output signal versus pressure i and compensated (b)

The results shown in Fig. 6. were ones of the best acquired of all carried out measurements. Studied sensors were very sensitive to other factors like temperature, and the movement of the sensing element. It was impossible to control their base voltage. Under the same initial conditions sensors readings varied significantly.

Since artificial heart project requires a high accuracy, stability and safety of measurements – this kind of requirements couldn't be met with the tested sensors and therefore piezofoils were proven inadequate for this kind of application.

4. Polyurethane membrane

An important project demand was separation of the pressure sensor from the blood environment. During tests the solution to this problem was introduced - blood pressure transmission through prosthesis wall. In the final project POLVAD its walls ought to be made in certain points thin enough, so that the inner pressure changes could be transmitted outside. In order to prove this possibility polyurethane foils, made of the same materials as prosthesis were examined. For these purposes a special testing element has been made (Fig. 7).

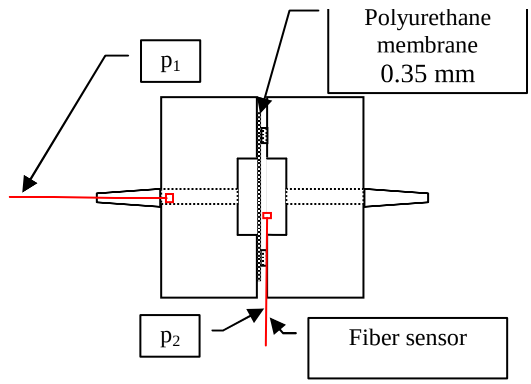


Fig. 7. Arrangement of sensors in testing chamber

The testing chamber was made as two cavities separated by thin polyurethane foils of different thicknesses. Both cavities were filled with water and the FOP-M sensors were situated on both sides of the membrane (Fig. 7). Pressure was induced and measured on "p_1" sensors side, and the transmitted pressure was measured on the other side of the membrane by a "p_2" fiber 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). This choice was also motivated

a) **b)**

by safety reasons – thicker wall provides better and firmer separation between sensor and blood environment. Linearity between the results acquired from both sensors can be observed (Fig. 8b). The properties of the foils have a significant influence on the result but in this case, the main cause spread of results is the presence of air bubbles inside the testing chamber, which was really difficult to be avoided. Nevertheless, the conducted research indicates that transmission of pressure through, a sufficiently thin, polyurethane membrane is possible and promising for use in the final sensor system design.

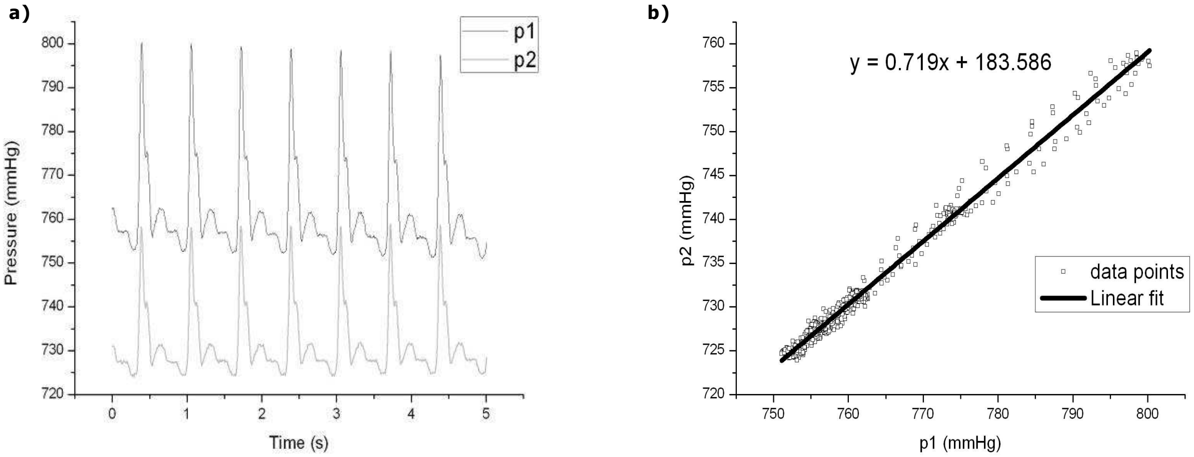


Fig. 8. Signal on both sides of the membrane (a) and relation between the sensors (b).

4. Conclusions

The main goal of the conducted research was to choose and test pressure sensors for future incorporating in POL-VAD prosthesis. It's the first part of a project aiming at the introduction of a fully functional, noninvasive blood pressure measurement system, for using in the Polish Artificial Heart.

The conducted researches bring a new solid base for a future measurement system development. During the studies the fiber pressure sensor has been chosen for future investigations. Piezoelectric foils have proved to be inappropriate for this project, and thus work on their future use in this project was suspended. The noninvasiveness of blood pressure measurements will be obtained by the VAD walls at certain points on the prosthesis, where polyurethane material will be made thin enough to transmit changes of the blood pressure to the external pressure sensors situated on the casing. Future development plans include designing of measurement points and tests on the VAD prosthesis model.

Bibliography

1. Religa Z., Kustosz R., *Mechanical heart supporting. Coronary vessels surgery*. PZWL, Warsaw 2002, 158-166 (in Polish).
2. Darlak M., Opilski Z., Gawlikowski M., Kustosz R., Pustelny T., *Acoustic method of noninvasive blood volume monitoring in POLVAD pump*, Artificial Organs, vol. 31, No 10, (A50) (2007).
3. Pustelny T., Struk P., Nawrat Z., Gawlikowski M., *Design and numerical analyses of the human greater circulatory system*, European Physical Journal-Special Topics, vol. 154, 165-170 (2008).
4. Gawlikowski M., Pustelny T., Przywara-Chowaniec B., Struk P., *The anatomic structure of pulmonary arterie as a source of unreliability in thermodilution cardiac output measurement*, Acta Physica Polonica, vol.114, No.6-A, 79-88 (2008).
5. Darlak M., Pustelny T., Gawlikowski M., Kustosz R., *Preliminary Investigations Regarding the Possibility of Acoustic Resonant Application for Blood Volume Measurement in Pneumatic Ventricular Assist Device,* Molecular and Quantum Acoustics, vol. 27, 89-96, (2006).
6. Pustelny T., Struk P., Nawrót Z., Gawlikowski M., *Numerical and experimental researches of mechanical heart prosthesis*, European Physical Journal- Special Topics, vol. 154, 161-164 (2008).
7. *http://www.frk.pl/frk/*
8. FISO – Fiber Optical Pressure Sensors – http://www.fiso.com/modules/

Authors:

MSc. Grzegorz Konieczny

Silesian University
of Technology
ul. Akademicka 10
44-100 Gliwice
tel. (032) 2371208
email: Grzegorz.Konieczny@polsl.pl