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DETECTING CHANGES IN THE CONDITION OF A PRESSURE TRANSDUCER BY ANALYSING ITS OUTPUT SIGNAL

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Abstract: A technique of detecting changes in the condition of a pressure transducer is described. The method is based on a spectral analysis of transducer output signal and estimating its frequency response. The study of the transducer finite-element model and experimental results show that it is possible to detect faults by this way so this technique can be used to develop a self-validating pressure sensor.

Keywords: pressure transducer, fault detection and diagnosis, finite-element model, self-validation

1. INTRODUCTION

Current scientific research in the field of intelligent sensors is closely related to their fault detection and diagnosis techniques as well as ways to improve the quality of measurements and to make them self-validating. The approach (called self-validation [1] or metrological self-check [2]) was presented in 1993 and now is well-known. Many principles and prototypes of self-validating sensors were proposed: dissolved oxygen, temperature sensors, flow-meters. A self-validating pressure sensor prototype was described by Z. Feng, Q. Wang, and K. Shida in [3]. Still there is a need of methods and techniques of detecting changes in the condition of sensor structure that may be caused by a diaphragm, weld joint or rod damage, change in other technical parameters.

To develop a self-validating sensor one should propose a method to diagnose its possible faults affecting the results of a measurement. The attractive way is to use additional information contained in its output signal. Methods of fault detection and diagnosis based on the signal model are described in [4]

In this paper a technique based on analyzing an output signal and estimating the transducer frequency response is examined and then applied to detect changes in the condition of a strain-gage pressure transducer. Investigations of such a method have been made in 1990-s by J.E. Amadi-Echendu and H. Zhu [5]. Their task was to detect changes in the condition of a flow-meter by analyzing the sensor signal. Dynamic response is used to control the damage of Trinity River Relief Bridge in [6].

We use the similar methodology that is consecutive excitation, recording a response, spectral analysis and estimation of the condition. As an excitation mean we use ultrasonic pulse. The spectrum considered is up to 100 kHz. Before we started an experiment we created a finite-element model of the transducer to analyze the possibility of detection of the change in its condition theoretically. Using of a finite-element model for the purpose of a pressure sensor fault diagnosis is also described in [7].

2. THE DESIGN OF A PRESSURE TRANSDUCER AND ITS NATURAL VIBRATIONS

2.1. Finite-element model of a pressure transducer

A pressure transducer (see Fig. 1) is an elastic body consisting of several mechanical components.

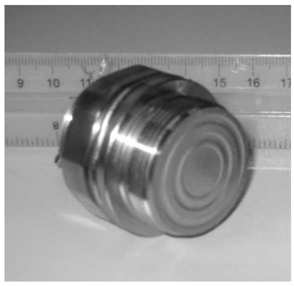

Fig. 1. A tensometric pressure transducer.

The finite-element model of the transducer can be developed by means of ANSYS (see Fig. 2).

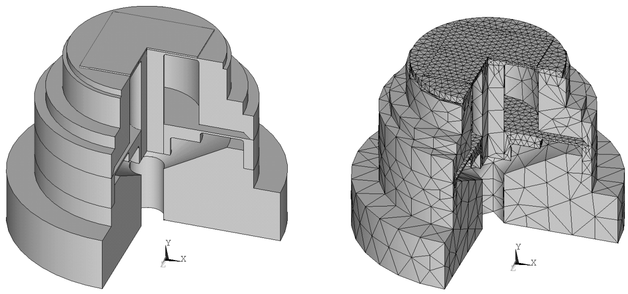

Fig. 2. Structure of a transducer and its finite-element model.

As the model is developed, the analysis of natural vibrations of the transducer components can be provided. The frequencies of the natural vibrations (Fig. 3) of these components depend primarily on the transducer structure rather than on ambient conditions. If these frequencies are estimated and isolated from those frequencies caused by the process, it will be possible to detect the condition of the transducer itself.

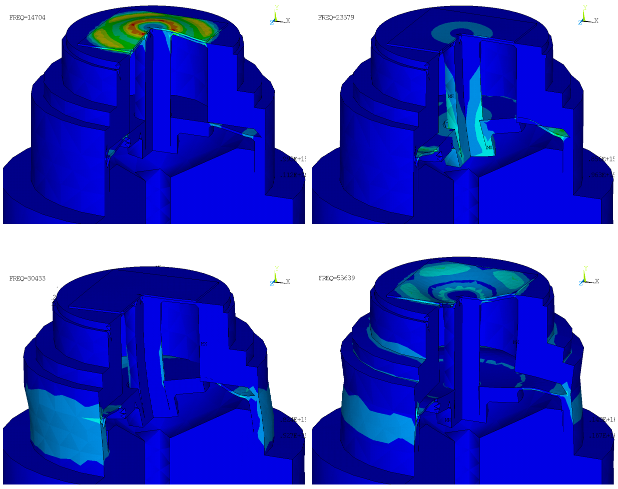

Fig. 3. The natural vibrations of the transducer components

2.2. Modeling changes in the condition of the transducer

The common approach to the development of a sensor with metrological self-check is to determine faults that influence the sensor accuracy. In case of pressure sensor possible faults can be damage of the diaphragm, disturbances in threaded connection and violation in weld joint.

The model of the transducer was changed to imitate possible defects in its structure. The simplest malfunction is sticking of an additional body to the sensor diaphragm. To analyze how change in the condition of the transducer influences its frequency response, the situation of sticking a mass to the diaphragm was modeled. The analysis showed that in the case there is a mass sticked to the diaphragm frequency response changes. As shown in Figure 4 presence of the mass influence the frequency response more significantly than its weight.

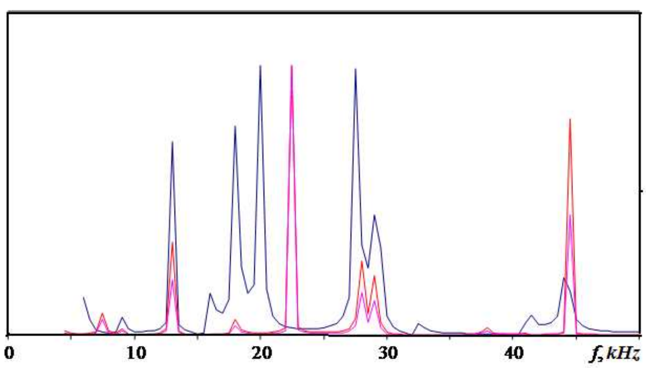

Fig. 4. Frequency responses corresponding to the three model conditions of the pressure transducer (blue – reference condition, red and pink – with additional mass of 0,5 and 0,25 g)

3. EXPERIMENTAL RESULTS

3.1. Estimating of a frequency response

A special rig was developed to check in practice the results of modeling. An ultrasonic pulse with known duration was used to excite the transducer. Then its output signal was recorded and analyzed. As a result of spectral analysis and taking into account input signal spectrum the frequency responses of different transducers were estimated. As it is shown in Figure 5 the frequency response characterizes (or in other words corresponds to) the certain transducer.

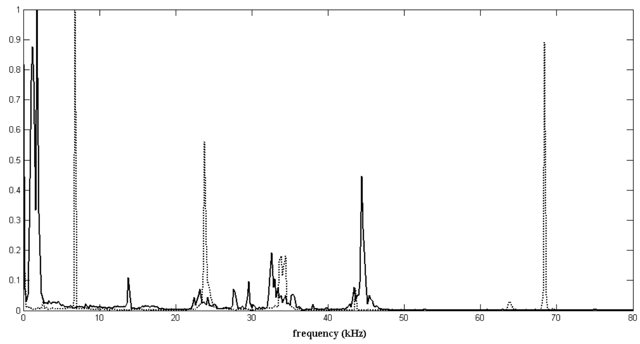

Fig. 5. The estimated frequency responses of the pressure transducers with different structures.

3.2. Simulation of change in the condition of the transducer

The additional mass was placed on the diaphragm and the experiment was repeated. Figure 6 shows that the frequency response changes when we add the mass. This change may be used for diagnosis of the sensor condition. The next step is to propose an algorithm that can estimate this change quantitatively and make the diagnosis actual.

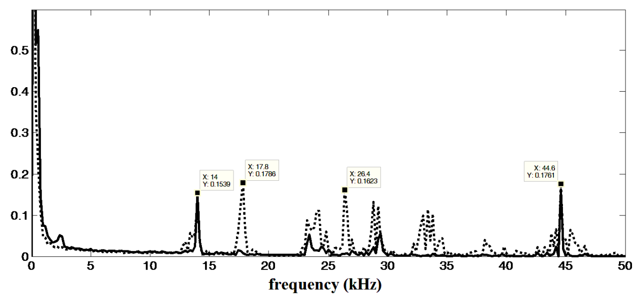

Fig. 6. Frequency responses of the transducer. Dotted line corresponds to the reference condition and the solid one corresponds to the case when there is a mass placed on the diaphragm.

4. DETECTING CHANGES IN THE CONDITION OF A PRESSURE TRANSDUCER BY ANALYSING ITS OUTPUT SIGNAL

4.1. A model of the transducer output signal

The key technical challenge of the task is to estimate the parameters of a pressure transducer output signal (such as frequencies or damping factors) with very high accuracy in order to be able to detect small shifts. The conventional method of spectral analysis is the Fourier transform, which suffers from various shortcomings, including the resolution limit depending on the response duration. That is why Fourier transform can be used for the purpose of pre-processing of the signal but alternative methods should be proposed to get a reliable fault detection scheme.

In order to study the efficiency of different methods of analysing the output signal and estimation of frequency response we developed a signal model that is a sum of damped sinusoids with certain frequencies and damping factors. Figure 7 shows spectra of the model and real output signal that are very similar.

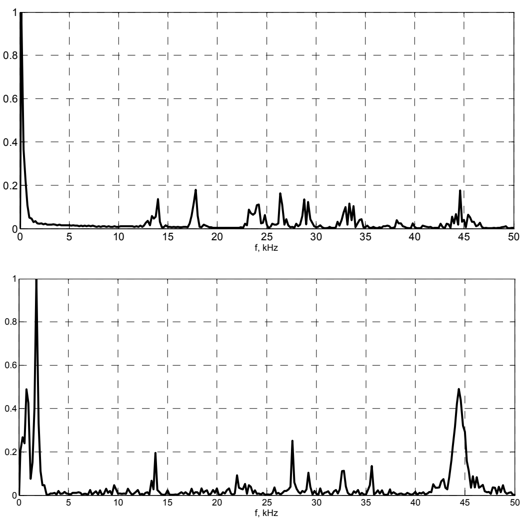

Fig. 7. The spectra of a real output signal (up) and its model (bottom).

4.2. A technique of detecting change in frequency response based on Fast Fourier Transform

A possible way to detect change in frequency response caused by a fault is to use a technique based on FFT and computation of correlation coefficient between two spectra corresponding to different signals – one is the reference signal and the other one is the signal under consideration. First we estimate spectrum of a signal and then compute the correlation coefficient between reference spectrum and estimated one. Correlation coefficient R between reference and considered spectra is computed within certain frequency range and difference $dR = (1 - R)$ can be used as a symptom to detect change in frequency response spectrum.

The proposed technique is sensitive not only to the change in the frequencies but also to the change in the amplitude of a certain frequency. Figures 8 and 9 show that the technique is sensitive to these changes and can be used for detection purpose.

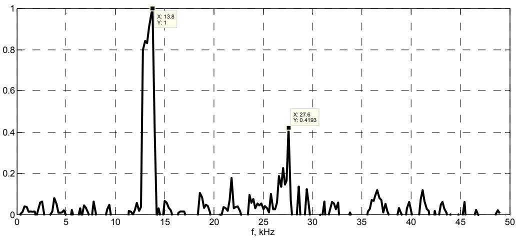

Fig. 8. Parameter dR for the signal model that is the sum of 9 damped sinusoids with two frequencies changed with respect to the reference condition.

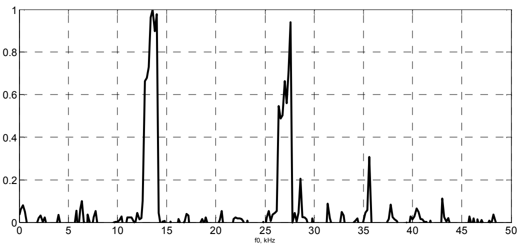

Fig. 9. Parameter dR for the signal model that is the sum of 9 damped sinusoids where one frequency and amplitude of second frequency have been changed.

4.3. The use of Prony's method

Prony's method is an alternative to the Fourier transform widely applied to spectral analysis. It provides high-accuracy estimation for amplitudes, damping factors, frequencies and phases of signals. Unfortunately, in practice there are some disadvantages with Prony's method because it is very sensitive to noise. Therefore special techniques are needed to analyze real signals with Prony's method. Moreover, the accuracy of the method depends on parameters choices, such as the model order, the sampling rate of the signal and the number of samples to be processed. It can be shown that by pre-processing the signal data, roughly estimating the frequencies using a Fourier transform, choosing the optimal sampling rate and then analyzing the signal by Prony's method may give very accurate estimate of signal parameters. The use of Prony's method for the purpose of fault detection is now being under investigations.

5. CONCLUSION

In this paper, a technique of detecting changes in the condition of a pressure transducer is described. The study of the transducer finite-element model and experimental results show that it is possible to detect faults by analyzing the output signal of the transducer. This technique involving excitation and analyzing the response can be used to develop a self-validating pressure sensor design.

5. REFERENCES

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