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METHOD OF PRESSURE SENSOR DYNAMICS DETERMINATION USING REDUNDANT MEASUREMENTS

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Abstract. *The method of determining the dynamic characteristics of linear inertial pressure sensors based on one known sensor with redundant measurements usage is proposed. A method based on the approximate system of solving measurement inverse problems is offered. The proposed method ensures a lower relative measurement error as compared with any other existing method.*

Key words: *in-place control, dynamic characteristics, measuring information system, linear pressure sensors, multi-channel receiving, redundant measurements, measurement inverse problem, hazardous industrial facilities, measuring information system.*

МЕТОД ОПРЕДЕЛЕНИЯ ДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК ДАТЧИКОВ ДАВЛЕНИЯ ПРИ ИЗБЫТОЧНОМ ИЗМЕРЕНИИ

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Аннотация. *Предложен метод определения динамичных характеристик линейных инерциальных датчиков давления на основе известного датчика при избыточном измерении. Метод основывается на приближённом аппарате решения обратных измерительных задач. Относительная погрешность измерений ниже, чем в ранее существующих методах.*

Ключевые слова: *бездемонтажный контроль, динамические характеристики, измерительная информационная система, линейные датчики давления, многоканальный приём.*

МЕТОД ВИЗНАЧЕННЯ ДИНАМІЧНИХ ХАРАКТЕРИСТИК ДАТЧИКІВ ТИСКУ ПІД ЧАС НАДЛИШКОВОГО ВИМІРЮВАННЯ

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Анотація. *Запропоновано метод визначення динамічних характеристик лінійних інерційних датчиків тиску на основі відомого датчика під час надлишкового вимірювання. Метод ґрунтується на наближеному апараті розв'язання обернених вимірювальних задач. Відносна похибка вимірювань нижча, ніж у наявних методах.*

Ключові слова: *бездемонтажний контроль, динамічні характеристики, вимірювальна інформаційна система, лінійні датчики тиску, багатоканальний прийом.*

Introduction

Diagnostics of hazardous industrial facilities (HIF) requires using pressure sensors as components of measuring information systems (MIS).

The requirements to the reliability of measurement data received at HIFs are very strict. For this reason, the number of sensors that measure the same parameter of a facility can be increased, thus redundant measurements are used.

The reliability of measurement data depends considerably on the quality of metrological assurance of the MIS. During the operation metrological characteristics (MC) of sensors change: they are exposed to external influences (vibration, noise, microclimate parameters, etc.), they depend on the state of measuring lines (pipelines) and can change significantly over time with the «aging» of sensors.

Continuous monitoring of sensor MCs is only possible when it is performed in-place. At HIFs it is not used at all or is used partly. Thus, measuring control of sensors, namely their dynamic characteristics (DC), without removing them from the facility is required.

Recent Papers Review

Noise analysis method is presented in [1]. It allows us to determine the dynamic characteristics of the sensor (time constant). The accuracy of this method, according to Hashemian, is not always high (relative measurement error values can be as high as 30 % and higher). Also, this method requires significant amount of prior systematic information.

Methods for determining dynamic characteristics of inertial sensors through in-place control are being developed. For example, in [2] a method of approximate solution of the inverse problem based upon incomplete prior data on impulse response of a linear inertial sensor is developed. In some cases, this method allows sensor identification. In [3] a method for determining the time constant of a pressure sensor through in-place control solving the inverse problem is proposed. The accuracy of these methods is about the same as of the noise analysis method.

Purpose and Problem Description

The purpose of this article is to describe the method of determination of dynamic characteristics of linear inertial pressure sensors using redundant measurements.

The determination of pressure sensor dynamic characteristics using of measurement inverse problem usually requires known output and input pressure sensor signals and transition or impulse characteristic. In real environment the determination of such huge volumes of priori information is quite complicated task. Consider another approach of determination of dynamic characteristics of linear inertial sensors.

Problem Solution

The method consists in measuring redundancy when one and the same process is measured by several sensors. To assess the accuracy of the method we must consider the case where DCs o all sensors are known. The next step is a case where DCs of one sensor are known.

The studied object in this case is a part of the MIS, which consists of m linear inertial pressure sensors (fig. 1). The studied process is the process of measuring one and the same input action $x(t)$ (fig. 1) of this part of the MIS.

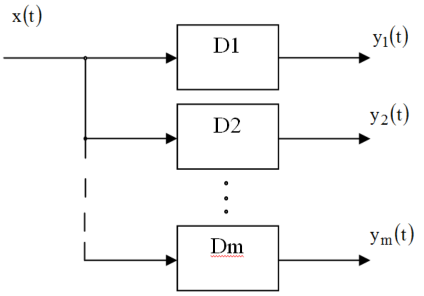

Fig. 1. Diagram of multichannel measurement of one and the same input action

Let us specify the type of impulse characteristics and values of time constants for all sensors.

The transfer characteristic of first-order diaphragm type sensors is most often expressed by Function [1]

$$H(t)=U_0\left(1-e^{-\frac{t}{\tau_0}}\right). \quad (1)$$

Using Function (1), we can identify the sensor impulse response taking into consideration the relation between impulse and transfer characteristics [4]

$$h(t)=\frac{dH(t)}{dt}=\frac{U_0}{\tau_0}e^{-\frac{t}{\tau_0}}. \quad (2)$$

In this case the pressure sensor impulse response is expressed by formula (2). The amplitude U_0 was defined by experiment [1]. However, in order to make calculations easier we will set the amplitude that equals 1. The unknown parameter τ_0 (time constant) is calculated using the technique described in [3]. The time constant values of all sensors included in the system are given in table 1.

Table 1 Setpoints of sensor time constants

Sensor	Time Constants
D1	0,30 s
D2	0,43 s
D3	0,35 s
D4	0,39 s

The input action model with noise (fig. 2) is close to a real one. At the output of the system (fig. 1) we will obtain m of implementations of output signals $y_i(t)$, $\left(i=\overline{1,m}\right)$. The measurement results are expressed in volts (1 V = 5 kPa). In general, at real facilities input action implementations of each of the sensors will be different due to the noises present in measuring lines. We will not consider these differences while solving this problem which implies using an ideal measuring line at the input of the MIS.

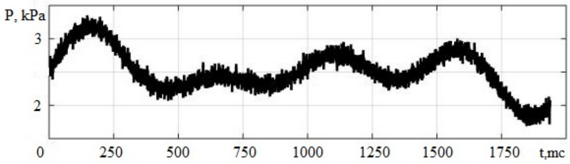

Fig. 2. Implementation of the input action in MatLab software package

Let us consider a case which is very important in practice when all dynamic characteristics of only one sensor, for example the first one, are specified. Let the first sensor be a new one, while others have been in operation for several years. In the process of measuring we obtain the output signals of all four sensors. Taking into account the similarity of these sensors, the mode of impulse response of the last $m-1$ sensors is partially known (fig. 3).

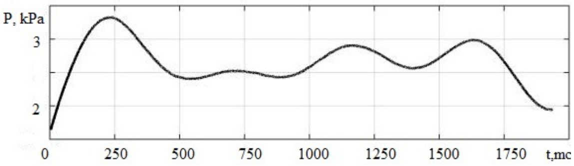

Fig. 3. Input of the first sensor available from experiments

Let us determine the input action at the input of the first sensor. The method of input action mapping is based upon the solution of an inverse problem which is described in [2].

The next step is to calculate the spectral density of the input signal $X(j\omega)$

$$X(j\omega)=\frac{Y_1(j\omega)}{H_1(j\omega)}, \tag{3}$$

where $Y_1(j\omega)$ is spectral density of the output signal power; $H_1(j\omega)$ is amplitude frequency response (AFR) of the first sensor which is expressed by means of its impulse response $h(t)$ [4].

AFRs of other sensors are calculated using the following formula

$$H_m(j\omega)=\frac{Y_m(j\omega)}{X(j\omega)}. \tag{4}$$

Impulse responses can be calculated using Formula (5). This will enable us to obtain time constants of all sensors (table 2).

$$h_i(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}H_i(j\omega)\cdot e^{j\omega t}d\omega. \tag{5}$$

If we know the time constant of the reference sensor, we will be able to determine this constant and estimate the error by solving the inverse problem. Let us determine the statistical characteristics of the time constant measurement error. We will use the average to correct the measurement result by means of the inverse problem solution for a sensor with unknown DCs, that is, we will add this value or subtract it from the obtained time constant.

With the help of mathematical modeling we have obtained the average which equals – 0,009 s, that means that the corrected value of the pressure sensor time constant equals 0,291 s.

Table 2 Calculated values of sensor time constants obtained using the proposed method

Sensor	Calculated values	Corrected values
D2	0,429 s	0,420 s
D3	0,346 s	0,337 s
D4	0,393 s	0,384 s

Let us verify the calculated values of the remaining sensors with the help of the same method of the inverse measurement problem solution (table 3).

Table 3 Accuracy of time constants measurements

Sensor	Verified values	Relative error
D2	0.424 s	0.94 %
D3	0.340 s	0.88 %
D4	0.389 s	1.29 %

Conclusion

Existing methods of determining the pressure sensor time constants for in-place control at hazardous industrial facilities have errors that reach 30 % or even higher. The proposed method is based on using the approximate apparatus for solving inverse measurement problems, its results are corrected when compared with a time constant of one of the sensors whose dynamic characteristics were identified earlier during the bench test. The time constant error in case of multi-channel systems does not exceed 5 %.

References

1. Хашемиан Х. М. Датчики технологических процессов: характеристики и методы повышения надёжности / Х.М. Хашемиан; пер. с англ. А. Н. Косилова. – М.: БИНОМ, 2008. – 336 с.
2. Полярус О. В. Метод відновлення сигналу на вході датчика / О. В. Полярус // Вестник НТУ «ХПИ». – 2011. – № 57. – С. 142–147.
3. Коваль А.А. Визначення постійної часу датчика при розв'язанні оберненої задачі вимірювань / А.А. Коваль, А.І. Котова, Є.О. Поляков, О.В. Полярус // Метрологія та прилади: науково-виробничий журнал (тематичний випуск). - 2014. – Вип. 1ІІ (45). – С. 111–114.
4. Басков С.И. Радиотехнические цепи и сигналы / С.И. Басков. – М. : Высшая школа, 1988. – 448 с.
5. Бендат Дж. Применение корреляционного и спектрального анализа / Дж. Бендат, А. Пирсол; пер. с англ. – М. : Мир, 1983. – 312 с.

References

1. Xashemian X.M. *Datchiki texnologicheskix proczessov : xarakteristiki i metody` povy`sheniya nad`ozhnosti* [Sensor Performance and Reliability ed.]. Moscow, Izdatel`stvo BINOM Publ., 2008. 336 p.
2. Polyarus O. V. *Metod vidnovlennya sy`gnalu na vxodi datchy`ka* [The Method of Sensor Recovery At The Sensor Iinput]. *Vestnik NTU «XPI»* - Gazette NTU «KhPI», 2011, no. 57, pp. 142–147.
3. Koval A.A., Kotova A.I., Polyakov Ye.O., Polyarus O.V. *Vyznachennya postijnoyi chasu datchyka pry rozvyazanni obernenoyi zadachi vymiryuvan* [The sensor time constant estimation by solving of inverse problem of measurements]. *Metrologiya ta prylady: naukovo-vyrobnychyj zhurnal (tematychnyj vypusk)* Metrology and Devices: Scientific and Production Journal (thematic issue), 2014, no. III (45), pp. 11-114.
4. Baskov S.I. *Radiotexnicheskiye czepi i signaly* [Radio Circuits and Signals]. Moscow, Vysshaya shkola Publ., 1988, 448 p.
5. Bendat Dzh. *Primeneniye korrelyacionnogo i spektral`nogo analiza* [The Use of Correlation and Spectral Analysis]. Moscow, Mir Publ., 1983, 312 p.

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