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METHOD FOR INPUT SIGNAL RESTORATION DURING DYNAMIC PRESSURE MEASUREMENT AND ITS SENSOR

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Abstract: One of the methods for input signal restoration during dynamic pressure measurement in real time and its relevant piezoresistive sensor are proposed.

Keywords: restoration, input signal.

1. INTRODUCTION

Currently in the measurement technology of dynamic magnitudes the basic problem of the restoration of the input signal is especially pertinent. As known from the point of view of mathematics this is an incorrect problem. Currently there are a number of general methods for resolving such a problem [1-2]. In practice these methods do not produce the desired result because considerable computer resources and time are needed. Therefore, the measurement of dynamic magnitudes in real time, for example in the aerospace industry, nuclear industry, automobile manufacturing control systems, etc., is a complex problem.

This paper examines one of the methods for input signal restoration in real time and its relevant piezoresistive sensor.

2. THE ANALYSIS OF PIEZORESISTIVE SENSOR DYNAMICS

The typical structure scheme of a piezoresistive pressure sensor including body, round restrained diaphragm and piezoresistors located on the diaphragm is show in Fig. 1.

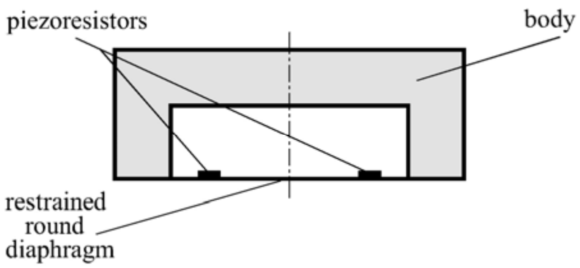

Fig. 1. Typical structure scheme of sensor

The oscillations of a round restrained diaphragm are known to be described by means of the equation

$$c^4 \Delta\Delta\ w + \frac{\partial^2 w}{\partial t^2} + 2\beta \frac{\partial w}{\partial t} = \frac{p(t)}{\gamma} \qquad (1)$$

where $c^4 = \dfrac{Eh^2}{12(1-\mu^2)\rho} = \dfrac{D}{\gamma}$, $\gamma = \rho h$, D – bending rigidity of diaphragm, E – Young's modulus, ρ - density of diaphragm material, h - diaphragm thickness, β - damping coefficient, μ - Poisson's ratio, $w(t,r)$ – vertical deflection of the diaphragm at the point with coordinate r and time t, $p(t)$ – measurable pressure.

Resolving (1) leads to [3]

$$w(t,r) = \frac{1}{\gamma}\sum_{n=0}^{\infty}\frac{\eta_n}{\omega_n \cdot \xi_n} F_n(\alpha_n, r)\int_0^t p(\tau)\times \cdot \times e^{-\beta(t-\tau)} \cdot \sin(\omega_n(t-\tau))\,d\tau \qquad (2)$$

where $\eta_n = \dfrac{I_0(\xi_n)\cdot J_1(\xi_n) - J_0(\xi_n)\cdot I_1(\xi_n)}{J_0^2(\xi_n)\cdot I_0^2(\xi_n)}$, ξ_n - proper values of the boundary problem, $I_0(\xi_n)$, $J_1(\xi_n)$, $J_0(\xi_n)$, $I_1(\xi_n)$ - Bass11el function, $F_n(\alpha_n, r) = I_0(\xi_n)\cdot J_0(\alpha_n r) - J_0(\xi_n) I_0(\alpha_n r)$; R - radius of the diafragm; $\omega_n = \sqrt{\omega_{0n}^2 - \beta^2}$; $\omega_{0n} = c^4 \dfrac{\xi_n^4}{R^4}$ - circular frequency of the diaphragm.

In practice, we may set $n = 0$ in (2), then

$$w(t,r) = \frac{1}{\gamma}\frac{\eta_0}{\omega_0 \cdot \xi_0} F_0(\alpha_0, r)\int_0^t p(\tau)\times \times e^{-\beta(t-\tau)} \cdot \sin(\omega_0(t-\tau))\,d\tau \qquad (3)$$

If we set $r = 0$ in (3), then

$$w_0(t) = \frac{1}{\gamma}\frac{\eta_0}{\omega_0 \cdot \xi_0} F_0(\alpha_0, 0)\int_0^t p(\tau)\times \times e^{-\beta(t-\tau)} \cdot \sin(\omega_0(t-\tau))\,d\tau \qquad (4)$$

By differentiating (4) we obtain

$$w'_0(t) = k \cdot \int_0^t -\beta\, p(\tau) \cdot e^{-\beta(t-\tau)} \cdot \sin(\omega_0 (t-\tau)) d\tau +$$

$$+ k \cdot \int_0^t \omega_0 p(\tau) \cdot e^{-\beta(t-\tau)} \cdot \cos(\omega_0 (t-\tau)) d\tau =$$

$$= -\beta w_0(t) + k \cdot \int_0^t \omega_0 p(\tau) \cdot e^{-\beta(t-\tau)} \cdot \cos(\omega_0 (t-\tau)) d\tau \quad (5)$$

where

$$k = \frac{1}{\gamma} \frac{\eta_0}{\omega_0 \cdot \xi_0} F_0(\alpha_0, 0)$$

By differentiating (5) we obtain

$$w''_0(t) = -\beta\, w'_0(t) + k\omega_0 p(t) -$$

$$- k \cdot \int_0^t \beta \cdot \omega_0 \cdot p(\tau) \cdot e^{-\beta(t-\tau)} \cdot \cos(\omega_0 (t-\tau)) d\tau -$$

$$- k \cdot \int_0^t \omega_0^2\; p(\tau) \cdot e^{-\beta(t-\tau)} \cdot \sin(\omega_0 (t-\tau)) d\tau =$$

$$= -2\beta\, w'_0(t) + k\omega_0 p(t) - (\omega_0^2 + \beta^2) w_0(t) \quad (6)$$

Resolving (6) leads to

$$p(t) = \frac{w''_0(t) + 2\beta\, w'_0(t) + (\omega_0^2 + \beta^2) w_0(t)}{k\omega_0} \quad (7)$$

Equation (7) is the key to restoring the input signal.

3. DESCRIPTION OF THE METHOD

The restoration method is as follows:

1. Measuring the deflection of the diaphragm- $w_0(t)$. This is accomplished by piezoresistors located on the diaphragm.
2. Measuring the acceleration of the diaphragm- $w_0''(t)$. This is accomplished using an accelerometer located on the center of the diaphragm.
3. Calculating the oscillation rate of the diaphragm- $w_0'(t)$ by the integration of the acceleration of the diaphragm- $w_0''(t)$.
4. Possessing the parameters of ω_0, β, k, and applying (7) we achieve the restoration of the input signal $p(t)$.

4. DESCRIPTION OF PIEZORESISTIVE PRESSURE SENSOR

The piezoresistive pressure sensor for realization proposed method including body, round restrained diaphragm, piezoresistors located on the diaphragm, accelerometer located on the center of the diaphragm. Sensors structure scheme is show in Fig. 2.

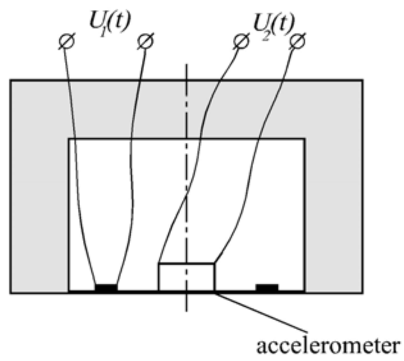

Fig. 2. Sensor structure scheme

The strain unit and all the construction elements of sensor were produced from Fe-Ni-Co (covar) alloy. Si strain gauge mounting was carried out by glass-to-metal fusion [4]. As a result the unit covar alloy - silicon - glass with TCLE of each component close to another was created. Main parameters of the developed sensors are presented in Table 1.

Table 1. Performance of silicon pressure sensors

Parameter	Value
Pressure ranges, Pa	$0\div10^5$; $-1\times10^5\div+2.5\times10^5$; $0\div10^7$; $(0\div4)\times10^7$
Full-scale output without amplification for 2 V d.c. excitation, mV	40÷60
Resonant frequency, Hz	10,000÷40,000
Mounting size: diameter, mm height. mm	10÷14 10-30
Mass, g	11÷20

Sensors output signal during measurement deflection of the diaphragm $w_0(t)$ is

$$U_1(t) = U_0 \zeta_1 \zeta_2 \cdot \varepsilon \quad (7)$$

where: U_0 -supply voltage of piezoresistors, ζ_1-transformations coefficient of electric bridge, ζ_2-gauge factor, ε-relative deformation of diaphragm at the point location of piezoresistors;

If piezoresistors are located along of radius, then

$$\varepsilon = \varepsilon_r ,$$

and

$$w_0(t) = \frac{\varepsilon_r}{\frac{2h}{R^2} \cdot (3\frac{r^2}{R^2} - 1)} = \frac{U(t)}{\frac{2h}{R^2} \cdot (3\frac{r^2}{R^2} - 1) \times U_0 \zeta_1 \zeta_2} \quad (9)$$

where: $w_0(t)$ -vertical deflection of the diaphragm at the point with coordinate $r = 0$; r- point location of piezoresistors.

Sensors output signal during measurement acceleration of the diaphragm $w_0''(t)$

$$U(t)_2 = \chi\, w_0''(t) \quad (10)$$

where χ-transformations coefficient of electric circuit accelerometer. Then

$$w_0''(t) = \frac{U(t)_2}{\chi} \quad (11)$$

Calculating the oscillation rate of the diaphragm- $w_0'(t)$ by the integration of the acceleration of the diaphragm- $w_0''(t)$ and applying (7) we achieve the restoration of the input signal $p(t)$.

4. CONCLUSIONS

The methods and its relevant sensor give a possibility restoration of input signal during dynamic pressure measurement in real time.

The develope sensors were applied in different branches of science and industry for special applications, for example: for aerospace investigations, aerodynamic tests, measurements of pressure pulses in gas media during the tests of aircraft engines, cryogenic techniques, during development of different vehicles.

The analysis of proposed method demonstrated that its error was not more then error measurement magnitudes $w_0(t)$ and $w_0''(t)$.

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