REMOVAL OF TEMPERATURE DRIFT OF ZERO OF PIEZOELECTRIC ACCELEROMETER

The object of this research is to measure the dependence of the results of the vibration acceleration from the piezoelectric accelerometer feedback ambient temperature. The aim of this research is to reduce the error caused by the temperature influence of the environment when conducting measurements of vibration acceleration with a piezoelectric accelerometer.

2. Methods of research

When conducting research was used:
- The theory of research of vibration and shock signals, based on the use of piezoelectric acceleration sensors.
- The theory of solid state physics, which considers any substance, as well as its physical, mechanical, thermal and other properties from the point of view of its internal structure.

3. Research results and discussion

Piezoelectric accelerometers that operate on the principle of direct piezoelectric effect: when exposed to an external
force on the piezoelectric element, their geometric dimensions change, resulting in a charge, proportionally to the effective force, generated on specially applied electrodes. Thus, piezoelectric sensors do not require additional power supplies, and the lack of moving parts ensures the durability and stability of their operation.

However, piezoelectric accelerometers also exhibit negative manifestations not related to the piezoelectric parameter being measured, such as components of electrical induction, which occur under the influence of temperature changes and generate parasitic signals at the amplifier input. They create an additive or zero error of piezoelectric sensors. Especially this error manifests itself in the conditions of rapidly changing ambient temperature when measuring the parameters of low-frequency accelerations and vibrations.

The piezoelectric element, by changing its geometric dimensions under the action of temperature fluctuations, in the absence of influences from the side of the measured parameter, generates a charge on its electrodes [1, 2]. The more the coefficient of linear expansion of a piezoelectric element differs from the coefficients of linear expansion of other elements of the accelerometer structure (Fig. 1), the more its domain structure will be subjected to mechanical stress and generate additional charge [1, 3]. This charge is nothing more than an additive component of the measurement error of a piezo-accelerometer caused by fluctuations in ambient temperature.

The piezoelectric element in the design of the piezoelectric accelerometer (Fig. 1) is installed with a pre-tension (ten-

\[
F = F_p + F_n, \quad (1)
\]

where \(F_n = ma\) – force with which the inertial mass \(m\) acts on the piezoelectric element under the influence of acceleration \(a\); \(m\) – inertial mass; \(a\) – acceleration [3].

For alternating acceleration (vibration acceleration, etc.) expression (1) can be written in the form:

\[
F = F_p \pm F_n \sin(\omega t + \phi), \quad (2)
\]

where \(\omega\) – angular velocity; \(t\) – time; \(\phi\) – initial phase of measurement.

The force \(F\) which changes according to the described law (2) causes the generation of a piezoelectric charge, the value of which can be determined from the equation for the direct piezoelectric effect:

\[
Q = d_F F, \quad (3)
\]

where \(d_F\) – piezomodule of the piezoelectric element.

In this case, an accelerometer that acts on one axis – \(Z\) is considered, and the piezoelectric element is polarized in the direction of force \(F\), so the piezomodule is working \(d_{33}\) [4, 5].

Then, substituting (2) into (3), let’s obtain:

\[
Q = d_{33}(F_p + F_n \sin(\omega t + \phi)). \quad (4)
\]

In the electrical circuit of the piezoelectric element – the input stage of the amplifier will be the current \(I\), the value of which will be determined by the expression:

\[
Q = d_{33}(F_p + F_n \sin(\omega t + \phi)). \quad (5)
\]

Let’s give equation (4) to the form:

\[
Q = d_{33}F_p + d_{33}F_n \sin(\omega t + \phi). \quad (6)
\]

Obviously, as the temperature changes, the temperature effect on the domain structure of the piezoelectric element will be realized, which will change its geometric dimensions [4–6]. That is, as the temperature increases, the prestressing force will increase in proportion to the increase in linear dimensions \(h_0\), namely the height of the piezoelectric element \(\Delta F_p(h_0)\), by:

\[
F_p = (F_p + \Delta F_p(h_0)). \quad (7)
\]

Given (7) let’s write (6) in the following form:

\[
Q = d_{33}F_p + d_{33}\Delta F_p(h_0) + d_{33}F_n \sin(\omega t + \phi). \quad (8)
\]

Enter the following notation:

\[
Q_0 = d_{33}F_p; \quad Q_n = d_{33}\Delta F_p(h_0); \quad Q_\alpha = d_{33}F_n \sin(\omega t + \phi).
\]

Then (8) let’s have the form:

\[
Q = Q_0 + Q_n + Q_\alpha. \quad (9)
\]

where \(Q_0\) – charge from the pre-voltage of the package; \(Q_n\) – charge that depends on the temperature effect; \(Q_\alpha\) – charge from the action of forces caused by the action of acceleration.
To some degree, the effect of temperature on the occurrence of mechanical stress in the piezoelectric element can be offset by the use of the compensation element shown in Fig. 1. \( a \) in the accelerometer design. The compensation element, structurally in the form of a washer, is located between the piezoelectric element and the inertial mass, which are pulled into the general package by a bolt 5. In order to reduce the dependence of the change of the linear dimensions of the package on the temperature change, this element is made of a material which coefficient of linear temperature expansion is opposite to that of the material piezoelectric element. Thus, with temperature changes, the mechanical stress in the package remains constant. This solution has an apparent simplicity in implementation, but in practice it is very difficult to find or create a composite material with the required value of the linear temperature expansion to produce such an element of compensation under the required mark of piezoceramics.

In view of the foregoing, a solution is proposed to compensate for the effect of temperature on the piezoelectric element by applying a compensation element 3 in the accelerometer design (Fig. 1, b). The compensation element is a piezoelectric element operating on the inverse piezoelectric effect along the polarization axis (fashion \( d_{33} \)). The compensation element is controlled by the automatic control system shown in Fig. 2, which operates according to the principle of deviation control. In the initial state, at normal temperatures \( (T=18–22 ^\circ C) \), the geometric dimensions, namely the height of the piezoelectric element and the height of the compensation element, are equal to \( h \):

\[
h = h_0 + h_c.
\]  

(10)

Changing the temperature of the medium acting on the piezoelectric element of the accelerometer causes a change in its geometric dimensions by magnitude \( \Delta h_0(T) \). This is due to the force \( F(T) \) as a reaction of the accelerometer design, which leads to the appearance of additional charge and a constant component voltage at the output of the measuring path. The so-called zero deviation of the sensor is observed in the absence of influence from the measured parameter [7].

To eliminate this effect, the automatic control system, by analyzing the level of a constant component in the complex signal coming from the piezoelectric element, acts on the control compensation element \( U \) (Fig. 2), which changes the geometric size of the compensation element by a value \( \Delta h_c(U) \). Thus, the control system monitors the condition:

\[
\Delta h_0(T) - \Delta h_c(U) = 0,
\]  

then

\[
h = (h_0 + \Delta h_0(T)) + (h_c - \Delta h_c(U)).
\]  

(12)

and the condition is fulfilled: \( h = \text{const} \).

The scheme of the automatic control system is shown in Fig. 2 includes the following elements: 1 – phase filter; 2 – integrator; 3 – power amplifier; 4 – piezoelectric actuator; 5 – piezoelectric sensor.

The scheme under consideration regulates the deviation, the principle of which is as follows:

1. a signal of deviation of the regulated value from the set value is sent to the controller;
2. the regulator on the deviation signal changes the control voltage \( U \) so as to reduce the deviation \( \Delta h_0(T) \) [8–10].

It should be noted that the specified controller changes the control action regardless of the reason that caused the adjustment error and estimates the error by the level of the constant component in the complex signal. Therefore, the correction for the constant component in the form of \( U_c \) is additionally introduced. This is a constant component of the accelerometer signal at normal temperature values inherent in the reaction of the piezoelectric element to the action of force \( F_c \).

Completely the error of regulation in this system is not completely eliminated, since the regulatory influence is formed only by error. The error will be the closer to zero, the more accurate the comparison scheme will be.

The scheme works as follows: with increasing ambient temperature, the geometric dimensions of the piezoelectric sensor 5 change (Fig. 2), which leads to an increase in the value of the constant component in the output signal. The output signal is fed to one input of the adder on a straight line and to the other input of the adder through a phase filter that delays it by 180°. After the adder, the constituent enters the integrator with an integration time comparable to the rate of change of temperature. The power amplifier 3 controls the piezoelectric actuator 4 by applying a voltage \( U \) to its electrodes, the polarity of which is directed opposite to the polarization polarity. The piezoelectric actuator by working out the control influence reduces its size in height and seeks to fulfill the requirements of equation (1).

4. Conclusion

The study shows the dependence of the piezomodule of the sensitive element of the accelerometer on temperature. A method of correction of the generation of a parasitic charge of a sensitive accelerometer piezoelectric element is proposed. The results of the study allow to improve the accuracy of measurements performed with the help of piezoelectric accelerometers. This is achieved by reducing the parasitic charge. It occurs with changes in temperature and is an additive component of the error in the measurement of vibrational acceleration. The research results also extend the temperature range of application of these accelerometers in the measurement of vibrational accelerations.

References

FIRE SAFETY IMPROVEMENT OF PYROTECHNIC NITRATE-METAL MIXTURES UNDER EXTERNAL THERMAL CONDITIONS

1. Introduction

Nowadays, pyrotechnic mixtures of metallic fuels (aluminum, magnesium, titanium, zirconium, aluminum-magnesium alloys, etc.) are widely used in various fields. They are used in the national economy and military technology (mixtures for fireworks, lighting and signaling devices, elements of rocket and space technology, etc.) [1–3]. These mixtures...