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Methods and Ways of Piezoelectric Accelerometers Fastening on the Objects of Research

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Methods and ways of piezoelectric measuring converters fastening on the objects of research are considered in the article. Piezoelectric accelerometers are sensors of a contact type, they have a mechanical contact with the object of research. The peculiarity of such connection is the fact that the object immediately has an influence on the output signal of the accelerometer. Therefore, study of methods and ways of piezoelectric accelerometers fastening on the objects of research is, undoubtedly, topical. Their advantages and disadvantages are specified. Recommendations about the choice of the way of piezoelectric measuring converters fastening on the objects of research depending on the operating conditions are made.

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1. Introduction

The piezoelectric measuring converters (PMC) are most often used for measurement of dynamic processes [1], mechanical parameters (efforts, pressure, accelerations, deformations) [2–5], thermal devices (sensors of thermal streams) [6–8], devices to control the structure and concentration of gases [9–11]. In many cases, PMC surpass the sensors made on other physical principles in the accuracy and scopes of usage. PMC are used in mechanical engineering, medicine, industrial systems of measurement and management, inertial systems of navigation, aircraft, geological researches, telecommunication and in many other spheres of human life [12, 13]. The PMC sensitive element is single-crystal or polycrystalline materials with piezoelectric properties. The principle of operation is based on the physical phenomenon of a direct piezoeffect, i.e. the ability of piezoelectric materials to generate electric charge under the impact of mechanical forces [1].

PMC for measurement of mechanical oscillations and impacts are most widely used. The piezoelectric accelerometers (PA) differ from other types of sensors of acceleration and vibration by the wide operating frequency band and dynamic ranges, small sensitivity to the influence of magnetic fields, linear characteristics in these wide ranges, reliability of a design, and rather long-term stability of parameters [14]. As PA are active sensors which generate the electric signal proportional to mechanical oscillations, so at their operation the power supply is not required. Lack of mobile elements of the design excludes the possibility of wear-out and guarantees durability of PA. Besides, the signal which an accelerometer gives, can be integrated for the purpose of measurement and analysis of speed or shift of mechanical oscillations. The basic shortcoming of PA is the impossibility to measure the constant component of the dynamic process [15]. Piezoelectric accelerometers are sensors of a contact type, they have a mechanical contact with the object of research [16]. The peculiarity of such connection is the fact that the object immediately has an influence on the output signal of the accelerometer. Therefore, study of methods and ways of PA fastening on the objects of research is, undoubtedly, topical [17].

Types of PMC designs, widespread piezoelements, scopes of PMC application and their characteristics are given in the literature [1–17, etc.]. Today one of the most accurate gravimeters aviation gravimetric system is piezoelectric gravimeter [1, 5], which contributes to measuring the acceleration of gravity anomalies with a precision close to 0.1×10^{-5} m/s^2. Measurement results of the acceleration of gravity obtained with the help of the above mentioned gravimeters contain large measurement errors caused by the influence of various factors: cross-angular velocity of the base and angular velocity of the Earth (584×10^{-5} m/s^2), changes in temperature, atmospheric pressure, the emergence of noises of various origin, and vibrations at the installation site of the device. For the high-precision measurements of the Earth gravitational field the presence of the above indicated errors is unacceptable. Therefore, the problem of increase of the aviation gravimetric measurements accuracy is important.

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The modern stabilization systems, using the spring, string, quartz, magnetic, and gyroscopic accelerometers cannot provide the required speed of response and accuracy [4]. Therefore, the urgent scientific and technical challenge is to improve the accuracy and speed of response when measuring the acceleration values by increase precision of a piezoelectric sensor for the automatic weapons stabilization system. Though, there is no information on methods and ways of PMC fastening on the objects of research and influence of these methods and ways on the output signals of piezoelectric accelerometers.

2. The piezoelectric measuring converters fastening on the object of research

Objective of the article is the analysis of methods and ways of fastening of piezoelectric measuring converters on the objects of research and the assessment of their advantages and disadvantages. Schematic diagram of PMC for mechanical oscillations research is shown in Fig. 1.

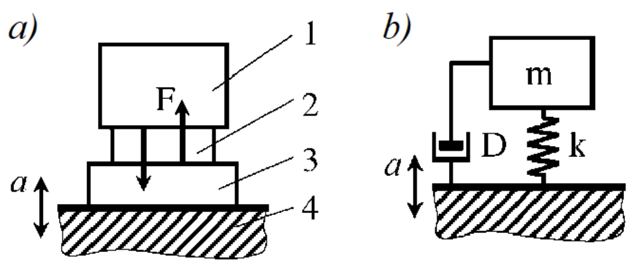

Fig. 1. PMC schematic diagram (a) and mechanical (b): 1 — inertial element, 2 — piezoelement, 3 — basis, 4 — object.

Let us consider at greater length the ways of sensors fastening to measure the vibration parameters (of piezoelectric accelerometers) on the objects of research. To measure the parameters of vibration with the minimal error, PA installation should not affect the dynamic characteristics of the test object, and the movements of the object and the accelerometer, in the place of its fastening, should be completely identical. Also, the constraint of dynamic and frequency ranges of the accelerometer should not take place. Appreciable variations of mechanical parameters of an oscillating body (total mass and local rigidity) are observed in the cases when the mechanical impedance of the accelerometer is commensurable with own impedance of this body. The arrangement of places of PA fastening is defined in terms of the objectives and tasks of the measurement and the design features of the test object, which influence the character of mechanical oscillations propagation. It is necessary to avoid accommodation of sensors in the places conterminous with central points of oscillations and characterized by maximal mechanical tensions, capable, owing to accelerometer sensitivity to deformation, to cause distortions of the output signal. Besides, the intermediate elements located between the object and the sensor lead to frequency decrease of its positioning resonance or can have their own resonance, situated in the frequency range of measured oscillations.

At installation it is necessary to focus PA body so that its axis of the maximal sensitivity (a working axis) coincided with the direction of measured vibration acceleration. While choosing the way of fastening, it is necessary to preliminary compare the required metrological characteristics of PA with achievable characteristics (parameters) for each specific application case, considering recommendations of the manufacturer. The ways of PA fastening with the use of threaded connection, adhesion and magnet are most widespread. Sometimes mechanical compression is used, and vacuum fastening is used very seldom. Using any of these ways, except adhesion, in order to increase the contact rigidity, it is recommended to cover all interfaced surfaces with grease lubricant. The basic versions of threaded fastening of accelerometers are shown in Fig. 2.

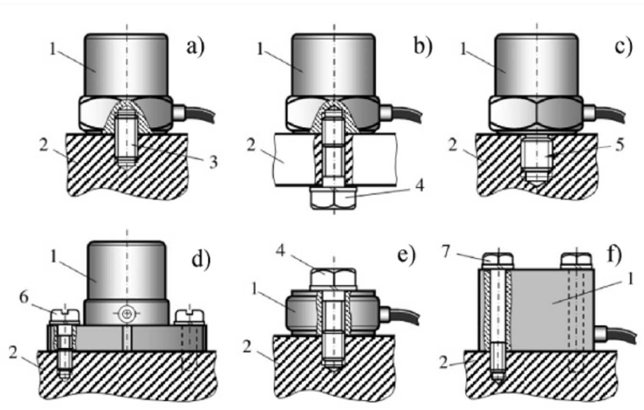

Fig. 2. Versions of accelerometers threaded fastening: 1 — PA, 2 — test object, 3 — thread stud, 4, 6, 7 — screw, 5 — threaded ledge.

Object surface patch in the place of accelerometer installation should be carefully prepared and have the size of one and a half or twice more than its bases. Requirements for the quality of the fastening surface processing increase with the growth of upper limit of the measured frequencies range. If there is no possibility to process the object fastening surface with necessary quality, it is possible to use a thin filler block under PA, made of plastic material (aluminum or copper), which, filling the microroughnesses at deformation, makes for increase of contact connection rigidity. Fastening studs and screws are usually made of steel, however, at work in strong variable magnetic fields, non-magnetic materials can be used.

Most preferential is PA fastening by thread stud (Fig. 2a), which allows to receive the maximal value of frequency of a positioning resonance at qualitatively processed positioning surface of the object. The depth of a threaded aperture of the object should be such that stud did not rest against the bottom of the threaded aperture of PA basis and thus the clearance between adjacent surfaces was not formed. Double threaded play and the possibility of a stud bend allow, in certain limits, to compensate misalignment to the positioning plane of the threaded aperture of the object. PA with a threaded aperture, owing to the flat surface of the basis, are most universal in fastening and, if necessary, can be fixed by means of the through screw (Fig. 2b) or adhesion.

PA with a cylindrical threaded fastening ledge are widespread (Fig. 2c). As well as at fastening by a stud, PA contact with the object is realized, mainly, due to compression of the flat part of the basis. On quality, fastening by a threaded ledge of PA basis comes maximum close to fastening by a thread stud.

Common faults of these ways of fastening are the complexity of PA orientation on the positioning plane if necessary, and probability of self-unscrewing without additional fixing at long-term operation. PA with flange fastening (Fig. 2d), being highly reliable and allowing their installation in the fixed position, are widely used. It is necessary to take into account that an increase of mass and overall dimensions of such PA due to flange, as well as the non-uniform compression effort on the contact surface makes for decrease in frequency of the positioning resonance.

Some types of PA can be fastened by one or several screws through axial or peripheral apertures in the body (Fig. 2e,f), that is sometimes convenient at installation. Such fastening leads to static deformation of the whole body and can negatively affect the work of the piezoelement if PA design is made without taking into account this factor. In cases of constant threaded fastening of PA, adhesives or compounds, suitable to conditions of operation and raising connections reliability, can be used instead of grease lubricant.

The adhesive way of fastening (Fig. 3) is used when it is impossible to make fastening apertures in PA installation place. It is necessary to apply solid adhesives with anaerobic polymerization, for example cyanoacrylic and epoxy. To increase the operating frequency of PA, it is necessary to seek the maximal rigidity of adhesive contact that is reached only at a thin layer of adhesive and its high hardness. Cyanoacrylic adhesives can be used only for flat and smooth surfaces since they do not fill hollows and clearances. The adhesives containing solvent, do not provide high rigidity of connection on all positioning surface. Before adhesion, the bearing faces of the object and the sensor are cleaned of dirt and degreased. After applying the adhesive and compression, a closed belt of extruded adhesive must appear around the base of PA (Fig. 3a), which indicates the absence of not-adhered parts. When temporary installing PA at normal temperature, sometimes, beeswax and thin double-sided adhesive plate or tape are used as adhesive materials (Fig. 3b). For multiple installations of PA, adhered transition threaded element can be used (Fig. 3c), which is a flat disk with a threaded ledge in the center. The use of adhesive, due to filling microvoids between the joined surfaces with a relatively stiff material, may help reduce requirements to the surface processing quality of the test object. Adhesive fastening of PA in compliance with the relevant requirements to the processing of the object surface, the choice of adhesive and technology provides a fairly high metrological characteristics when measuring. The main drawbacks of this fastening are lower reliability and strength of adhesive fastening in comparison with threaded fastening, limit of the operating temperature range (for most adhesives — up to 80 °C), and the complexity of sensor dismantling without damaging it.

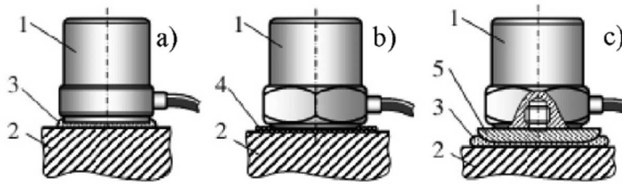

Fig. 3. Versions of PA adhesive fastening: 1 — PA, 2 — test object, 3 — adhesive, 4 — double-sided adhesive tape, 5 — adhered transitive threaded element.

When studying the mechanical oscillations associated with the need to move PA quickly on the surface of the test object, the magnet installation or the hand-held probe is used. Magnet installation is only possible on a well processed surface made of ferromagnetic material. For fastening, a special holder, which consists of a permanent magnet and steel magnetic core, is used. On the part of the holder facing PA, there is a threaded ledge for its fastening.

Characteristics of different ways of PA fastening. TABLE I

No.	Method of fastening		Resonance frequency [kHz]
1	threaded, on a steel stud with grease	with optimal tightening torque	23–25
		with low tightening torque	11–12
		through a thin mica separator	23–24
2	adhesive	stiff adhesive	24–25
		transition threaded element and stiff adhesive	20–22
		thin layer of wax	23–24
		thin double-sided adhesive tape	17–19
3	permanent magnet		7–10

In order to evaluate the possibilities of usage of different methods of fastening, Table I shows the experimental values of resonance frequencies obtained for the same PA. PA sets on the exciter calibration unit so that the oscillation direction coincides with the measurement axis PA. Then it connects the PA output to the input of the voltmeter and one of the inputs of a two-beam oscilloscope. On the second of the oscilloscope input signal is supplied to the oscillator. Varying the frequency of the oscillation exciter, at constant acceleration, fixed frequency value at which a maximum voltmeter reading, and the change is observed on the oscilloscope verified screen PA signal phase by 90° compared with a signal from a master oscillator. In addition to proper mechanical connection of the PA housing with the object of study, it is necessary to pay attention to the placement and fixation of the connection cable. Its effect on the PA operation can be significant due to transmission of mechanical stresses to the piezoelement through the structural elements.

These mechanical stresses are generated during the vibration of the cable in the vicinity of the sensor. In addition, the deformation of the cable caused by its vibration contribute to the emergence of additional electrical signals because of the triboelectric effect. During the important measurements in a wide bandwidth, to estimate an upper limit of the operating range, it is desirable to determine experimentally the value of the positioning resonance frequency of PA installed on the test object.

3. Conclusions

To measure the dynamic processes, to date, PMC is the most commonly used. PMC fastening on the object of research should be maximum hard, PMC mass and fastening design must be small compared to the mass of the object of research. The optimal way to fasten the PMC on the object of research is fastening with screws or studs.

The paper analyzes the prospects for further improvement of accuracy of a piezoelectric gravimeter and precision sensor for an automatic weapons stabilizer system by implementing the process of instrumental error compensation resulting from effects of changes of different ways of PA fastening, also obtained values of resonance frequencies for different ways of PA fastening.

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