Analysis of ways and methods of deformation measuring of rigid mounted axially symmetrical device elements.

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Abstract. In this article some technologies of modern devices manufacturing are reviewed which are intended to achieve the needed device accuracy. The imprecision of sensing element (SE) manufacturing and different factors influencing on it are observed too. Functioning of axially symmetric non-ideal gear under high-frequency load leads to deflection of SE axis from vertical direction which is result of unbalanced mass and moments influence. Many researches were devoted to develop some methods of this disbalance evaluation. Some of them are based on theoretical approaches to disbalance elimination, but it is impossible to make it real even on contemporary technology achievements. In other researches the procedure is sufficiently simplified but it could not reach the needed accuracy of balancing. The solutions are known which allow to evaluate the deflection of SE axis under load throughout the shift of the bar free end but such processing is made not for the final stage of manufacturing. Thus the additional structural element is in the SE design. After removing this additional element the balancing of the SE could be ruined. In this article the other method of deformations evaluation in dynamics is offered when the shift caused by non-ideal SE condition needs appropriate balancing. The rigid mounting of the SE is offered, when the base end of the bar is fixed and the other end becomes free after last technological operation. The procedure of measuring of the shifts caused by unbalancing masses and moments is made through the bar mounting place. The questions of unbalancing mass and moments influence on shifts values in the sensors balance area are studied. According to the given geometry and physical and mechanical properties of sensors the best combinations of geometry and device sizes are offered with mounting area restrictions and shifts measuring kept in mind.

1. Introduction
Modern development of machinery is based on enlarging speed, range, mobility of operated and non-operated aircrafts and also higher difficulties of solving tasks. The most important role in the process of movement operation (determination of movement itself, orientation and self-contained navigation) belongs to gyroscope devices. Requirements for modern navigation devices accuracy are evaluated according to drift rate of gyroscope (about several thousandth of degree per hour) which is in its turn in results in disturbing moments. Strict requirements for navigation systems lead to permanent development of gyroscopes stats such as accuracy, reliability, operational life, warm-up time, dimensions, value etc. In this regard, in domestic and foreign instrument making, along with improving the design and manufacturing technology of existing gyroscopes, research is being conducted to improve the accuracy characteristics of existing navigation instruments.
Manufacturing techniques of modern devices, sensors and their elements are constantly being improved and already at the present time they allow us to obtain products with high manufacturing accuracy to fractions of a micrometer. Of particular interest are axisymmetric sensors made of ceramic or high-quality quartz glass, since they are obtained by machining with rotation around its axis, which is mastered at a sufficiently high level. One of the requirements for sensors is reliability, accuracy, symmetry of deformation under external load, including high-frequency, reaching several kilohertz. The size of the controlled mass is extremely small, and the removed layer of material reaches only a few angstroms. Based on the foregoing, the balancing of the chooses of modern devices and the improvement of methods for removing excess mass is an actual process aimed at raising the accuracy of the devices[1-6].

Balancing is the process of reducing the mass imbalance to the required level. Imbalance of the masses is called the deviation of the mass from the ideal performance, in view of various kinds of errors (instrumental errors, etc.). The imbalance of the masses is known, in most cases, leads to the appearance of vibration. In modern technology there is a high increase in working speeds. Some of the components of machine parts can reach rotational speeds from 20 to 120 thousand rpm, and in some cases even higher. The presence of vibration will be disastrous for the nodes of machines operating at such speeds. A further increase in speeds leads to a tightening of requirements both to the design and to the quality of the operation - balancing. Therefore, the fight against vibrations remains relevant to the present day.

As it is known, balancing can be divided into two main stages:
1. Determination of unbalanced mass and moment;
2. Correction of unbalanced mass and moment;

The determination of the unbalanced mass consists in finding the angular position (location) of the excess / mass deficiency and the amount necessary for the correction.

Separately, attention is required by the process of balancing products that do not perform a rotational motion, but at the same time operating at sufficiently high frequencies at which the deformation of its elastic part working on the precession of a standing wave occurs[7-10]. The idea of such devices is based on the effect of Brain. During operation of such products, the unbalanced mass causes a deviation of its axis from the initial position. An example of such products is shown in Figure1.

The analysis showed [11,12] that the forms of sensitive elements of the vibration type can be divided according to the geometry, materials and methods of fixing the legs of sensitive elements:
1. Cylindrical adhesive bond;
2. Cylindrical connection with tension;
3. Conical connection with tension.

Materials of the product can be both metallic and non-metallic, for example, from quartz glass, since it refers to high-quality materials.
In view of the variety of forms, materials and methods of fixing used electrical devices in devices, it is necessary to evaluate the possibility of applying the methods of balancing developed earlier, taking into account the use of standard technical equipment.

2. Existing balancing methods.
There is a method of balancing a hemispherical resonator wave solid-state gyroscope and a device for its implementation (RU 2147117, publ. 03/27/2000), which includes attaching the resonator to the leg, installing excitation sensors and measuring and removing unbalanced mass. The piezoelectric sensor is installed at the free end of the resonator legs to measure its displacement, excite the resonator oscillations, measure the voltage of the piezoelectric sensor for different orientations of the standing wave in the resonator, calculate the unbalanced mass by mathematically processing the obtained experimental data and remove the unbalanced mass from the hemispherical shell of the resonator by the ion beam, The diagram is shown in Figure 2.

The disadvantage of this method is the lack of the ability to register the reaction in the mounting support and to determine the moment of forces, allowing balancing over the entire surface of the hemisphere. Also, due to the limited number of measurement sensors, measurement accuracy is limited. The use of the technological leg of the sensing element, which has high limits, roughness and subsequently removes negatively affects the accuracy of balancing.

There is a method that describes the balancing of a HRG resonator, based on the definition of a defect not only on the edge of the shell, but also over the entire hemisphere (in 2 and 6 planes). This method allows for more accurate balancing. The analysis showed that for real products it is impossible to put it into practice, due to the large number of errors, when measuring the required parameters, as well as the lack of technological ability to implement this technique.

3. Modeling
The analysis showed that the most promising is the installation of measuring sensors directly in the place of fixing the sensitive element in the instrument case. This method allows balancing not on one plane. Even in view of the complexity of the technological implementation of the balancing method on several planes, it is possible to develop technical solutions for the implementation of this method.

From the foregoing, it can be concluded that the most appropriate is the measurement of unbalanced mass and moment at the point of fixing and balancing along the two planes of the resonator since the actions in each plane are repeated.
For such tasks, piezoelectric vibration sensors are most often used, which allow to detect the slightest oscillations of a sensitive element.

The simulation using the finite element method, shown in Figure 3.

Figure 3. Stress calculation. A, B, C, D, F - stress zones.

The simulation showed that the sensors installed in the frame, according to the diagram below shown in Figure 4, are fixed using compounds with properties that are close to the property of the piezoelectric element, and therefore are not taken into account in the calculation.

Table 1. Modeling parameters.

| Name                  | Materials                |
|-----------------------|--------------------------|
|                       | Quartz | Ceramics | Piezo ceramics |
| Density, gr/cm³       | 2,56   | 2,2      | 2,1             |
| Young's modulus, N/m² | 7,35×10¹⁰ | 7,37×10¹⁰ | 6,5×10¹⁰       |
| Poisson's ratio       | 0,17   | 0,16     | 0,32            |
| Applied force, N      | 1      | 1        | 1               |
| Amount of elements    | 3120   | 2600     | 640             |

This scheme allows the calculation of stresses and deformations of all elements of the reaction measurement system at the place of seizure. This calculation allows you to ensure the correct location of the sensors, taking into account the internal properties of materials. This layout of the system shows that the maximum voltage caused by the oscillation of the legs of the sensing element, due to the unbalanced mass, falls on the piezoelectric sensor. What allows to receive the maximum response of system and provides accuracy of the measured parameters.
Figure 4. Scheme of the finite element modeling.

1) Direction of force, 2) Quartz sensitive element segment, 3) Ceramic base segment, 4) Piezoelectric sensor.

The experiment diagram (Figure 4) shows the arrangement of the components of the experiment. The simulation results are shown in Table 2. The contacts of the elements were set between the ceramic base and the sensor, simulating the installation of a piezoelectric sensor in the ceramic base. A quartz glass element that simulates the leg of a sensitive element came into contact with a piezoelectric sensor. Forces were applied to a sensitive element of quartz.

| Options   | Meaning (MPa) |
|-----------|---------------|
| Zona - A  (MPa) | 1.76e^-5     |
| Zona – B  (MPa) | 0.0254        |
| Zona – C  (MPa) | 0.0635        |
| Zona – D  (MPa) | 0.0508        |
| Zona – F  (MPa) | 0.1142        |

To implement this system, the technological capabilities available at most enterprises engaged in the production of sensors of this type are sufficient.

This type of vibration control of a sensitive element allows not only to use the information obtained for balancing and quality control, but also the possible use of this type in the device, to control and compensate for disturbing influences on the device during its operation, which will allow to obtain more information about the operation of the device.

Conclusions
In this paper, we considered the existing types of sensitive elements of measuring instruments of axisymmetric type that require precise quality control of manufacturing. The features of these devices and methods of fixing the sensitive element are studied. Existing methods of balancing sensitive elements of this type were studied, and their shortcomings were identified. Finite element modeling of the non-ideal measuring system of the sensitive element in the fixing device was carried out. A model
was created that simulates the application of force equivalent to that applied to the device if there is an imbalance of masses in the sensitive element. From the simulation, we determined the magnitude and location of the maximum voltage. This simulation showed that the proposed installation location of the piezoelectric sensors is most suitable for obtaining the most accurate information about the vibrations of the sensitive element of the device.

Further study of the methods of quality control of manufacturing sensitive elements of devices by measuring vibrations in the place of fixing, it is planned to carry out with other properties and geometric characteristics of the sensors. And it is also necessary to further study the number of installed sensors and methods of processing the results. This work is considered relevant because Methods of quality control of manufactured sensitive measuring instruments leads to an increase in the accuracy of navigation instruments

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