Development of computer-aided design system of elastic sensitive elements of automatic metering devices

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Abstract. The object of research is the element base of devices of control and automation systems, including in its composition annular elastic sensitive elements, methods of their modeling, calculation algorithms and software complexes for automation of their design processes. The article is devoted to the development of the computer-aided design system of elastic sensitive elements used in weight- and force-measuring automation devices. Based on the mathematical modeling of deformation processes in a solid, as well as the results of static and dynamic analysis, the calculation of elastic elements is given using the capabilities of modern software systems based on numerical simulation. In the course of the simulation, the model was a divided hexagonal grid of finite elements with a maximum size not exceeding 2.5 mm. The results of modal and dynamic analysis are presented in this article.

1. Introduction
Modern production of automation devices with a wide range of converters and various types of sensors is characterized by an ever increasing growth of automation processes, which in turn ensures an increase in productivity. The development of automation leads to an increase in the efficiency of technical systems, which include computing and control devices. An example of such systems can serve as automated control systems for production processes in the shipbuilding, automotive, metallurgical, chemical and other industries, which include cargo weighing, sorting and transportation of products [1]. Therefore, the main direction in the design and manufacture of weighing and dosing equipment is the development of modern weighing technology that will provide not only measurements of the mass of the object (weighing with the necessary accuracy and speed), but also automatic control, control and regulation of technological processes [2]. For this, in the design of weight- and force-measuring devices, it is necessary to realize two-way communication with the computer, which allows performing remote control and correction of the control process. Modern automatic weight- and force-measuring devices control systems are an important element in the complex automation in various branches of precision instrumentation and engineering.

Let us consider the most typical constructions of various weight- and force-measuring devices at the present time. Piezoelectric converters are used to measure force (weight). Despite the narrow range of measurements, they have high accuracy. Figure 1 shows the construction of this device.
Existing developments in electrical measurement technology make it possible to perform transformations of the measured quantity with the required degree of accuracy. However, it is impossible to achieve high accuracy of the measuring device with a low quality of the elastic sensing elements (ESE) included in the measuring devices [3]. Although ESE are fairly simple details, and many of them known and widely used for many centuries, their performance today does not meet the requirements for accuracy, sensitivity and other metrological characteristics.

The modern growth of requirements for primary converters and measuring devices makes the solution of the problem of improving the quality of ESE not only in the process of their manufacture, but also in their modeling and calculation, topical. This has resulted in new computational and experimental methods that led to a change in the overall methodology for the design of ESE.

There are currently a variety different methods for calculating ESE, but there is not a single simple and, at the same time, universal and effective method. In this connection, the proposed project most attention is paid to the creation of alternative methods for calculating ESE, which could simultaneously be based on analytical methods of classical mechanics, the theory of elasticity and resistance of materials, and on numerical methods with the aim of using their advantages and compensating for the weaknesses.

2. Discussion and results
To date, the development of modern non-contact computerized methods for researching the elemental base of measuring equipment for determining stress-strain states [4] is actual. This is necessary to ensure reliable forecasting of the quality of the element base of measuring equipment in the process of performing functional control. The procedure should also be applicable to the operational output control of the element base of measuring equipment.

The development of computer-aided design (CAD) systems, design and technological preparation of the production of ESE is, undoubtedly, an actual task, for the solution of which it is necessary to use both numerical methods and software complexes on their basis.

When solving the problems of creating CAD for the elastic element base of ESE, it is necessary to implement mathematical modeling of deformation processes in a solid, as well as to analyze the static and dynamic characteristics of their sensitive elements, using the capabilities of modern software systems, for example, the ANSYS software.

For this purpose, the finite element method (FEM) is most applicable, which makes it possible to automate the design process elastic element base. The choice of the software complex ANSYS is due to a wide range of capabilities of FEM, which allows both simple linear stationary analysis and realize a nonlinear analysis of transients processes.

The typical calculation of ESE in the program complex includes three stages:

- creating a finite element model;
• definition of boundary conditions;
• carrying out static and dynamic analysis.

As a result, a mathematical model of a physical prototype of WIS was created, which includes all nodes, elements, material properties, geometric characteristics, boundary conditions and other objects. For this purpose the ANSYS software complex was used, which allows one to determine the geometry of the location of nodes and elements of a mathematical model. The created theoretical model of the annular ESE satisfies the following requirements:
• high degree of adequacy, characterizing its static and dynamic parameters with satisfactory accuracy;
• low labor intensity and high productivity;
• small time costs.

The PC is based on the following methods:
• generation of the most geometric model;
• creating nodes and elements

The control-flow chart of the universal calculation algorithm of annular ESE is presented below (figure 2):
Due to the limited resources, the work was done in a simplified GUI interface, based on the use of the COMPAS 3-D V15 software product.

During the simulation, the model was divided by a finite element grid. The basic end element is the SOLID95 element with 20 nodes and 6 faces. This make it possible to use irregular shape grid of the splitting without losing accuracy. Partitioning was carried out on elements of hexagonal shape with a maximum size not exceeding 2.5 mm.

When describing the contact pairs of surfaces with nonlinearity, priority was given to the final elements of CONTA174 and TARGE170. Element CONTA174 is applicable for modeling the contact interaction (a three-dimensional contact element with 8 nodes), whereas element TARGE170 is used to model the slip between a three-dimensional mating surface and a deformable surface. To represent the contact pairs, the partition was automatically generated.

In the analysis of transients, as well as in the conduct of harmonic and modal analysis, finite elements used the type MASS21, used to simulate the loading processes of ESE. In this element, each direction of the coordinate system can be assigned its own masses and moments of inertia.

To represent the contact pairs, the partition was performed automatically.

Restrictions on the movement of the annular ESE, the load and the properties of the materials are selected as boundary conditions in the FEM.

As the boundary conditions in the FEM, constraints on the movement of the annular ESE, the load, and the properties of the materials are chosen. The discrete equations of motion:

\[
[M]\{\ddot{u}\} + \{\dot{C}\{\ddot{u}\} + K\{u\} = \{F\},
\]

where \{u\} – vector of nodal displacements for the whole body; \{\ddot{u}\} – vectors of acceleration and velocities of body points, \[M\], \[C\], \[K\] – "Global" matrixes mass, damping and rigidity for the whole body, respectively; \{F\} – vector of equivalent nodal forces for the whole body.

In reality, annular ESE are attached to the FMD through holes in the base, which imposes certain restrictions in moving of its surface on three axes, so the complex of bases consists of only two guiding bases and one thrust. The loads in the static analysis were applied in the form of a total force vector applied in the opposite direction the stubborn axle. Whereas while in dynamic analysis they were applied in the form of concentrated masses.

When calculating the statics, the result is the determination of the shaping of the limit formation of annular ESE, its optimal transmission scheme, the stress distribution fields and the most dangerous sections [5]. Taking into account these factors allows us to optimize the structure of annular ESE.

In the course of modeling, taking into account the constraints, variable loads were applied to the model, given by a tabular array that takes into account the dependence of the load on time.

When calculating the frequencies and forms of natural oscillations, the project uses a modal analysis that assumes that the system is linear. The nonlinearity was not taken into account. Zeroing out external forces and damping.

As the boundary conditions in the FEM, constraints on the movement of the annular ESE, the load, and the properties of the materials are chosen. The discrete equations of motion:

\[
[M]\{\ddot{u}\} + K\{u\} = \{0\},
\]

where \{u\} – vector of nodal displacements for the whole body; \{\ddot{u}\} – vectors of velocities of body points, \[M\], \[K\] – "Global" matrixes mass and rigidity for the whole body, respectively.

Taking into account the geometric complexity of the model and the high frequency of the finite element grid, the Lanczos decomposition method is used for calculations.

As the boundary conditions in the FEM, constraints on the movement of the annular ESE, the load, and the properties of the materials are chosen. The discrete equations of motion:

\[
[K]_g = [K] + [K]_e,
\]

where \([K]_g\) – geometric stiffness matrix.

The solutions obtained in the modal analysis were refined with the help of harmonic analysis and analysis of transient processes, which are applicable only to linear models.
In the modal analysis of a prestressed model, the attached load mass is replaced by the load applied to the ESE, which corresponds to the weight of the cargo. This approach does not contradict the classical theory of oscillations.

Modal analysis allows saving time for harmonic analysis and make contraction down the search range of natural frequencies.

Dynamic analysis requires immeasurably more time resources. As a result of the dynamic analysis, it is possible to obtain an amplitude frequency response and phase-frequency characteristic, which allow us to estimate the stability. The results of the dynamic calculation were compared with the experimental data. For this purpose, it used the stressing cyclogram of the ESE.

3. Conclusion
Thus, the analysis of the static and dynamic characteristics of annular ESE and the simulation with the use of an FEM and a specialized software package allow us to successfully implement and use the CAD of measuring instruments.

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