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ОБОСНОВАНИЕ ВАРИАНТА РАЗВИТИЯ ТРАНСПОРТНО-ЭКСПЕДИТОРСКОЙ КОМПАНИИ В УСЛОВИЯХ НЕОПРЕДЕЛЕННОСТИ

Идентифицированы факторы неопределенности в деятельности транспортно-экспедиторских компаний. Установлена поэтапная трансформация неопределенности в процессе реализации мероприятий по развитию. Существующий метод выбора в нечетких условиях адаптирован для обоснования варианта развития транспортно-экспедиторской компании. Установлено множество критериев выбора варианта развития. Представлены экспериментальные расчеты по выбору варианта развития комплекса услуг транспортно-экспедиторской компании.

Ключевые слова: теория нечетких множеств, факторы неопределенности, развитие комплекса услуг транспортно-экспедиторской компании.

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COMPENSATION OF THE SPATIAL DEVIATIONS OF MEASURING ELEMENTS IN CAD

Показано, що при вимірюваннях великогабаритних складних об'єктів іноді доводиться розташовувати частину елементів засобів вимірювання всередині об'єкта, а частину – зовні. В цьому випадку, особливо коли зовнішні елементи рухомі, можлива девіація останніх від запланованого розташування у просторі. Запропоновані методи, які здійснюють проектування засобів вимірювання таким чином, щоб вони адаптивно протидіяли таким явищам, що дозволяє знизити похибку вимірювання та підвищити його достовірність.

Ключові слова: *елементи метрологічних засобів, просторова девіація, автоматизоване проектування, похибка та достовірність вимірювань.*

1. Introduction

The automated design of measuring instruments has certain features, which consist in the need to create additional favorable conditions for the operation of their sensitive organs. The fact is that the accuracy of the measuring instruments (MI) depends essentially on the stability of the geometric arrangement of their elements (EMI). And, although in EMI, as a rule, there are no significant mechanical strains, even minor deviations can lead to significant losses in positioning accuracy, and hence the accuracy and reliability of the results of such measurement.

Under the EMI deviation, static deformations or displacements, as well as dynamic oscillations or any combination of them, which are not envisaged in the passport geometric or kinematic scheme of the corresponding means, are understood in the work.

To eliminate external influences that can lead to similar deviations in the design of pollutants, various design techniques are used: increasing the stiffness of the elements, optimizing their design, modern materials with improved resistance characteristics, and the like. Widely used are methods of active and passive vibration protection, thermostating, screening and many others.

Of course, any protection is not capable of completely eliminating unwanted EMI deviations. This is especially true for measurement objects that have large dimensions (tens of meters) and weight, opacity, high temperatures (hundreds of degrees), significant external influences of unpredictable nature, and the like. Models of behavior of such objects under load are extremely complex, and methods for their analysis and use in CAD are not available at all, which leads to the laying of significant future errors of the future measurement already at the design stage.

Therefore, current research is aimed at developing methods and models that are in the early stages of metrology tools (for example, at the stage of computer-aided design) ensure the required accuracy of the measurement parameters of the future of large-sized objects, regardless of the conditions of their use in practice.

2. The object of research and its technological audit

The object of research is the processes of automated design of the elements of complex measuring instruments intended to work under conditions of significant deviations of such elements in space caused by internal and external mechanical or thermal stresses.

Technological audit is a method of diagnostics of an innovative CAD subsystem in metrology, and allows to receive the characteristic of innovative potential at creation of new and reconstruction of existing measuring instruments. Conducting a technological audit gives the project company the opportunity to formulate a strategy for making a profit based on the results of innovation activities. It is assumed that the developer uses the results of innovation directly in the design process, releasing new projects in the field of instrumentation using the created design innovations.

The procedure for assessing the commercial potential of the innovation idea is carried out according to an algorithm consisting of 6 consecutive steps [1]:

1) conducting a preliminary analysis of existing tools for measuring the parameters of large-sized heterogeneous objects when they are created;

2) search for analogs of metrological means in adjacent objects and analysis of the effectiveness of their application for the investigated objects;

3) verification of the technical feasibility of the innovative idea of measuring the density of reinforced concrete in complex products in the conditions of deviation of elements of metrological means using the capacitive method;

4) product identification (design result) for comparison with analogues;

5) determination of market advantages of the created product;

6) practical feasibility of an innovative idea in real production.

The conducted studies confirmed the high commercial potential of the innovative idea: the use of new models of deviation of elements in the measurement of object parameters.

3. The aim and objectives of research

The aim of research is increasing the accuracy of measurements of technical parameters of large-sized objects of responsible designation by creating automatic systems for the design of new complex measuring instruments. Such means should be based on new models of undesirable movements of individual elements of the latter and methods for their compensation.

To achieve this aim, it is necessary to solve the following tasks:

1. To build models and analyze static, technological and dynamic movements (deformations) of the elements of the measuring instruments.

2. To develop methods of compensation for future undesirable static, dynamic and technological movements at the stage of computer-aided design of measuring instruments.

3. To carry out practical tests of the research results and evaluate their technical effect.

4. Research of existing solutions of the problem

In recent years, the automated design of special metrological support (MS) for investigating the internal parameters of the object [2–4] has become very widespread. This is due to the fact that in the first, the project phase of the MS life cycle it is possible to effectively choose the measurement method and the design of the corresponding MIs that have normalized metrological characteristics. The latter include measures of physical quantities, measuring devices, converters and equipment, information and measuring systems, computer systems and measuring instruments, in which only one of the components of the measurement procedure is performed, for example: conversion, scaling, comparison, or other operations with a signal.

Existing MS CAD are not able to function effectively, because they are not «equipped» with models and methods for measuring the critical facilities. Examples of such objects are large-sized building structures, the study of internal parameters of which (for example, density) is very problematic due to the considerable spatial deviation of MS elements, which lead to unacceptable losses in measurement accuracy.

Among the main directions of elimination of these problems, identified in the resources of the world scientific periodicals, the following can be singled out:

1) application of methods and tools external to the object of non-destructive testing [5–9];

2) use of non-destructive testing facilities built into the facility [10–14];

3) application of complex means of nondestructive testing, which are only partially integrated into the measured object [15–19].

Let's consider these directions in more detail.

1. Nondestructive testing is widely used in the production and operation of vital products, components and structures (buildings, railroads, aircraft, ships, oil and gas pipelines and other equipment) to detect internal defects of the object without destroying it [5, 6]. Common methods for nondestructive testing (measurement) also include those when the sensor is entirely outside the object of measurement (for example, a thermal imager [7] or an ultrasonic head [8] (Fig. 1, *a*).

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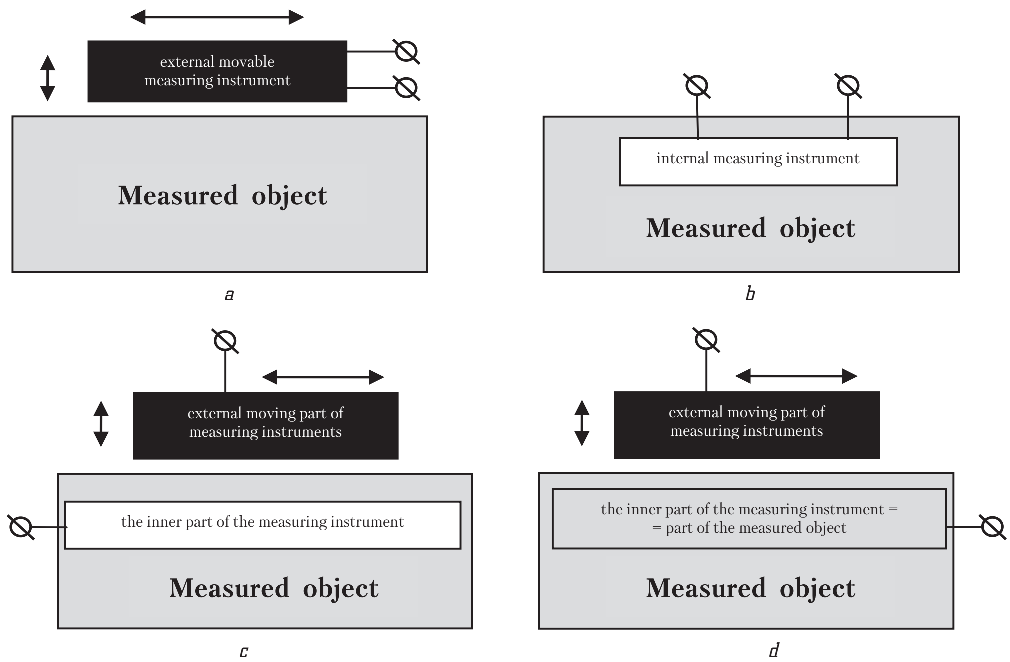

Fig. 1. Schemes of arrangement of the measuring instrument with respect to the measured object: *a* – outside; *b* – inside; *c* – partially inside, partly outside; *d* – internal elements of the measuring instrument is part of the object

External sensors require precise positioning relative to the object and creating additional conditions for interaction with the latter. For example, to create conditions for the penetration of ultrasonic waves from the measuring head to the object and back, it is necessary to ensure that the gap between them is filled with a special liquid [9].

2. According to DSTU 3400:2006, state tests of measuring equipment are conducted to ensure the uniformity of measurements in Ukraine. When it comes to reversible measurement of the internal parameters of a solid object, the unity of measurements can be ensured by the fact that the measuring instrument (for example, the thermocouple) is fully integrated into it already in the design (Fig. 1, *b*), that is, becomes an element construction, and therefore part of the technical specification for the object [10]. With reliable protection, such means are, as a rule, not amenable to the relative displacement of the individual parts relative to them and do not require compensation for the corresponding deviation, which affects the accuracy and reliability of their indices [11–13].

The main disadvantage of «built-in» sensors is their one-off, inability to use in other objects, makes them inapplicable in mass production. In addition, disposable elements of measuring instruments, remaining forever alien inside the measured object, can significantly complicate the technology of its manufacture. They are also able to change its properties (strength, presence of metallic inclusions, general porosity and thermal conductivity, etc.), which, in the end, makes such method «not completely non-destructive» [14].

It is also unclear why in the sources of literature are called «non-destructive» partially «immersed» in an object, so-called, mechanical methods. For example, when measuring the properties of concrete in a finished product, the latter is exposed to sufficiently destructive influences. These include: plastic deformation, elastic rebound, detachment (or detachment with shearing), chipping of the rib, as well as methods for exploding, driving and pulling out parts of fittings, grinding, etc. [15].

After all, even a slight violation of the structure or geometry of a heterogeneous product, to which concrete certainly belongs, may in the future significantly affect its reliability in general.

3. The structural separation of the sensors into two parts: the internal built-in and the external mobile (Fig. 1, *c*) in the design of both measured products and complex MIs, sometimes partially solves the problem of «metrological» reliability [16]. But this does not eliminate now the total shortcomings resulting from the disposability of internal and inaccurate positioning of external parts.

After all, in this case, there remains one-time (and, consequently, high costs) in relation to the internal parts of the measuring instrument, and all the problems of the external moving parts of the instrument are added to it, in particular, a certain coherence between the elements of the tool. For large objects, there is an additional significant drawback: the need to shift the sensor over a long distance, which creates the prerequisites for a significant dynamic deviation during the movement [18].

Additional opportunities appear when, during the design phase of the pollutant, the role of the internal element of the complex sensor is «entrusted» to the part of the object itself (Fig. 1, *d*) [19]. This eliminates all the problems of the «foreign body» in the design of the latter and greatly simplifies the technology of its manufacture. But there are problems of positioning the outer part and its movement

It is clear that in this case it is necessary to «intervene» in the future measurement process at the morning stages of designing both the object itself and metrological support to it, which, in the end, makes this problem the prerogative of CAD.

Thus, the results of the analysis of world experience lead to the conclusion that a significant contribution to the accuracy of measurements can be made only at the stage of designing methods and tools for the latter. However, for this it is necessary to develop new models of the origin and methods for compensating for the spatial deviation of the elements of the measuring instruments in CAD.

5. Methods of research

The basis for the creation of individual CAD subsystems is the theory of the analysis of technical systems, the theory of measurements, the theory of the resistance of materials and oscillations, and the theory of computer-aided design.

To develop a capacitive method for measuring the density of parts of large-sized objects made from heterogeneous materials (for example, reinforced concrete), methods of pattern recognition and a virtual object are used.

To test the adequacy of the methods, as well as the accuracy and reliability of the models, the laboratory and production facilities of JSC «Galenenergobudprom» (Lviv region, Ukraine) are used.

6. Research results

6.1. Construction of deviation models (deviation, displacement, deformation) of elements of complex measuring instruments. At the beginning of the creation of models of elements of complex MIs, let's perform a classification of the MI deviation by their location relative to the large-sized complex measurement object and the causes of their occurrence (Table 1).

Static deviations are the result of mechanical or thermal stress on the elements of metrological means, which led to deformation and displacement of elements.

Table 1

Classification of deviation of elements of complex measuring instruments by location and causes

Elements of complex MIs	Causes of deviation		
	Static	Dynamic	Technological
Internal (built into the object)	Displacement, rotation, bending of the measurement object together with the internal EMIs	3-D vibration of the measurement object together with the internal EMIs	Deviation from the drawing and displacement of the internal EMIs relative to the measurement object
External to the object	Displacement, rotation, bending of the external EMIs	3-D vibration of external movable EMIs from drive and guides	Deviation from the drawing and displacement of the external EMIs relative to the measurement object

Dynamic: deviations are the result of mechanical interaction with the drive and direction of movement of the external element of a metrological facility or object.

Technological: deviations are a consequence of a violation of the technology of manufacturing products, for example, the use of metal, which in size does not match the design of the product, inaccuracies in welding, metalworking, etc., inaccurate installations and fixing of metal reinforcement in the mold, etc.

Let's consider a plane capacitor with parallel plates with the plane S at a distance d from each other. The capacitance of such capacitor, as is known, is determined by the formula:

$$C = \varepsilon(\rho)\varepsilon_0 \frac{S}{d}, \qquad (1)$$

where C – the capacitance of the capacitor, F; $\varepsilon_0 = 8.854187817\cdot 10^{-12}$ F/m – the electrical constant; ε – the average permittivity; ρ – the average dielectric density, kg/m^3, located between the capacitor plates; S – the capacitor area of, m^2; d – the distance between the plates, m.

Obviously, in a real measuring device, all the listed parameters (except for the electric constant) can be determined only approximately, and hence the real capacitance is a deviation calculated according to (1). In this case, the general models of static deviations consist of their elementary displacements (Fig. 2, *a–c*).

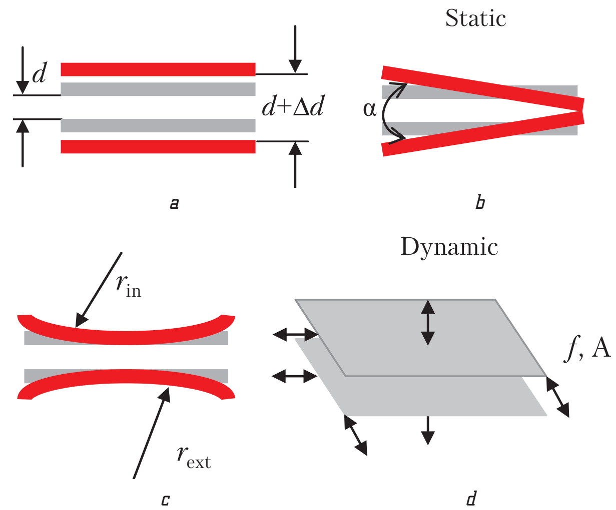

Fig. 2. Schemes of elementary movements of elements of measuring instruments: *a* – parallel shift; *b* – rotation; *c* – bend; *d* – 3D vibration

Accordingly, the mathematical form of such elementary displacements is the change in the distance between the plates Δd with parallel shift. The angle of the relative rotation of the plates α, the radii of the bending of the lining: inner r_{in} and external r_{ext}, and accordingly the parameters of the oscillations are the frequency f and the amplitude A. The dynamic deviation models are stipulated by the 3-D vibration of the technological equipment and EMIs when the latter move along the product along the guides (Fig. 2, *d*).

A real complex capacitor in a complex product, for example, a capacitor «product armature – outer plate» in a reinforced concrete cylinder, next to which is a MI, is, of course, not plane-parallel according to the drawing and exact in manufacturing technology. Thus, Fig. 3 shows the appearance of the fittings of the future cylindrical large-sized (20 m) product, which was also used as the internal embedded in the object of the already completely non-flat capacitor.

Imagine an ideal complex capacitor, the internal cover of which is the steel armature of the product, and the external one – some metal element located next to the product at a structurally defined distance from it (Fig. 4, *a*).

It is clear that even having precise drawings of the reinforcement of the external element and their mutual arrangement, it is theoretically difficult to calculate the

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first capacitance value of this capacitor because of the configuration complexity. From the same complexity, it is also impossible to produce the exact fixture and install it in the formwork before pouring. From this it becomes evident that the theoretical calculation of the actual capacitance of the capacitor with the indicated internal part only according to the drawing is also impossible.

Fig. 3. General view of the finished welded reinforcement for the reinforced-concrete product «Power transmission line support» 20 m long

In fact, there is a capacitor with an indeterminate and inaccessible for direct monitoring of the internal part (Fig. 4, *b*), does not allow to apply formula (1) when measuring the concrete density. And also it is adapted to measuring the density ρ reverse version:

$$\rho(\varepsilon)=C\varepsilon_0\frac{S}{d}. \quad (2)$$

To determine ρ as a measurement result, it is necessary not only to have the function ρ(ε) in an explicit (for example, tabular) form and measure the value of *C* and *S*, but also obtain an immeasurable value of *d*.

To solve the latter problem, the image recognition of a real capacitor in the form of an equal in capacitance using the virtual object method is used.

In the framework of this method, let's search for a virtual capacitor with a conventionally flat inner cover which capacity of C_{virt} is equal to the capacitance of the real measurable capacitor C_{real} with the air layer between the plates for the current object, that is, $C_{real\ with\ air}=C_{virt}$. Thus, obtain a virtual image of a real capacitor (Fig. 4, *c*).

Measurement $C_{real\ with\ air}$ is carried out on the working measuring stand [20] to fill the formwork with concrete reinforcement, that is, when the place of the future concrete is filled with air.

Next, fill the formwork with the concrete reinforcement installed (Fig. 4, *d*), perform the second measurement of the capacity of the same capacitor, but «with concrete» and calculate the dielectric constant of the latter according to the formula:

$$\varepsilon_{concr}=\frac{C_{real\ with\ concrete}}{C_{real\ with\ air}}. \quad (3)$$

To obtain the dependence ρ_{concr} (namely, this index is the aim of the metrological process), from the measured value ε_{concr} let's perform the experimental calibration of the measuring instrument using the virtual representation of the object (Fig. 4, *c*).

Since the permittivity of air ε_{air} is practically equal to 1, from (2):

$$d_{virt}=\varepsilon_0\frac{S}{C_{real\ with\ air}}. \quad (4)$$

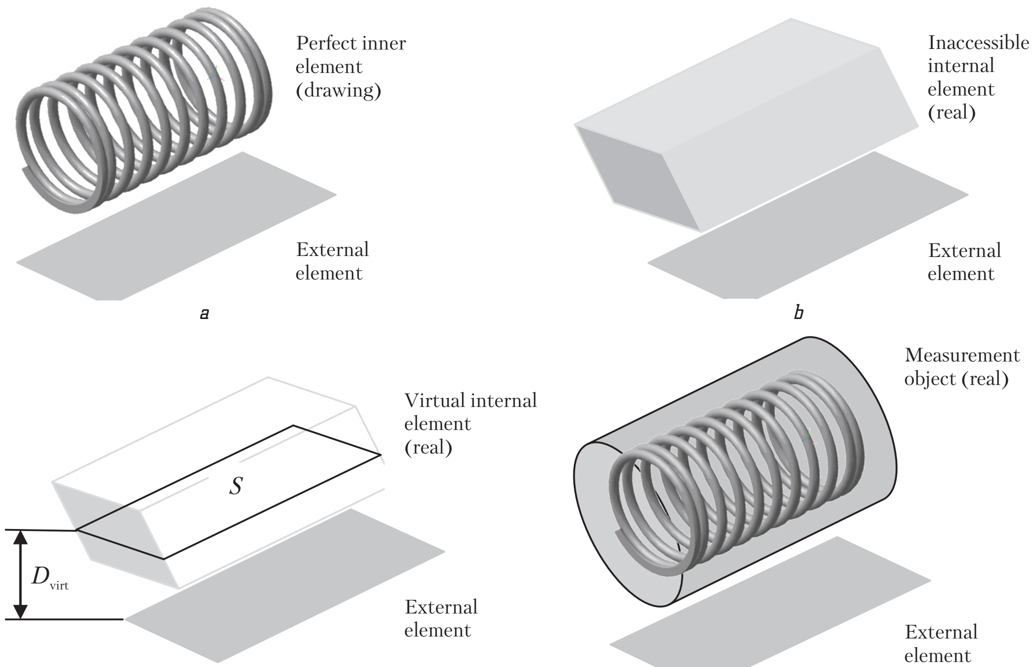

Fig. 4. Models of the construction of a complex capacitor with one unobservable panel:
a – model of the «ideal» complex capacitor (according to the drawings); *b* – real capacitor with an inaccessible «internal» coating for observation;
c – recognized virtual image of a real capacitor; *d* – real object during measurement

Calibration is carried out using a separate flat capacitor, in which the distance between the plates is d_{virt}. Its results are shown in Fig. 5.

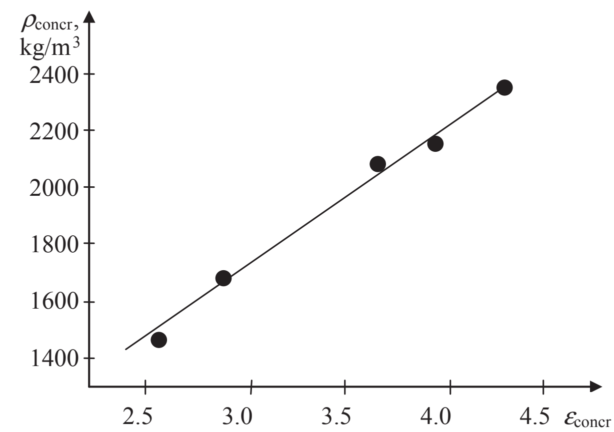

Fig. 5. Results of calibration of the virtual capacitor with d_{virt} = 5.73 cm

As a result, there are theoretically experimentally obtained models necessary for use in automated design systems for complex means for measuring the density of concrete required for managing the technological process of manufacturing reinforced concrete products of large dimensions with geometrically complex fittings.

6.2. Methods for compensation of undesirable static, technological and dynamic deviations at the stage of automated design of metrological means. Any spatial deviation of the measuring device elements from the calculated (design) position leads to a deterioration in the measurement accuracy [21].

Therefore, reliable compensation of deviations contributes to the increase of this accuracy, and hence the effectiveness of process control, in which the measurement results are used in closed cycles.

The following requirements are imposed on methods of compensation for unwanted deviations of any origin.

First, compensation must occur automatically as deviation occurs.

Secondly, compensation must occur in a short time.

Thirdly, the reason for such behavior of the elements of the metrological means, the deviation of which is compensated, should be the properties of the latter, laid down at the stage of its automated design.

Let's consider the methods for compensating for the deviations of the elements of complex measuring instruments by the example of the above-mentioned capacitive measurement method.

The mathematical method assumes that all compensation measures are performed only due to changes in computational models.

For example, under the known laws of changing the dimensions and/or configuration of the plates, when measuring the capacitor, mathematical compensation involves introducing an additional coefficient into formula (1), which is calculated by the formula:

$$K=\frac{C\Delta d}{\varepsilon_0\rho(\varepsilon)S}. \quad (5)$$

As a result:

$$C=K\varepsilon_0\rho(\varepsilon)\frac{S}{d}. \quad (6)$$

Expression (6) is practically applicable only if the designer knows the laws of variation of the distance d under the load and the true value of C for the «passport» capacitor. These laws follow from the methods of calculating deformations and displacements in the resistance of materials.

It follows from Fig. 4, the virtual surface of the inner lining is always flat. If, however, the outer lining loses its flatness when the form deviates, the formula for calculating the capacitance (1) becomes much more complicated. Let's suppose, for example, that in the general case, the surfaces $y_1(x_1^{k1}, x_2^{k2})$ and $y_2(x_1^{k3}, x_2^{k4})$, the capacity between which is calculated, is described by the expressions:

$$\begin{cases} y_1=x_1^2+x_2^2; \\ y_2=-x_1^2-x_2^2, \end{cases} \quad (7)$$

at restrictions:

$$x_{1\min}\le x_1\le x_{1\max}; \quad (8)$$

$$x_{2\min}\le x_2\le x_{2\max}. \quad (9)$$

Then the capacitance between these surfaces within (6) and (7) can be calculated as [20]:

$$C=\varepsilon\varepsilon_0\int\limits_{x_{1\min}}^{x_{1\max}}\int\limits_{x_{2\min}}^{x_{2\max}}\frac{\mathrm{d}x_1\mathrm{d}x_2}{\left|f_1(x_1x_2)-f_2(x_1x_2)\right|}=$$
$$=\varepsilon\varepsilon_0\int\limits_{x_{1\min}}^{x_{1\max}}\int\limits_{x_{2\min}}^{x_{2\max}}\frac{1}{(x_1^2+x_2^2)-(-x_1^2-x_2^2)}\mathrm{d}x_1\mathrm{d}x_2=$$
$$=\frac{1}{2}\varepsilon\varepsilon_0\int\limits_{x_{1\min}}^{x_{1\max}}\int\limits_{x_{2\min}}^{x_{2\max}}\frac{1}{(x_1^2+x_2^2)}\mathrm{d}x_1\mathrm{d}x_2. \quad (10)$$

The mechanical method assumes constant models of processing of the metrological information, but the condenser (more often external elements) are subjected to geometrical transformation, which compensates deviations. Let's consider the methods developed for static and dynamic deviations.

Mechanical compensation of static deviations. The suggested methods of compensation of EMI static deviations will be considered on the example of designing complex equipment for capacitive measurement of concrete density. In accordance with formula (1), as d changes to $d+\Delta d$, it is necessary that S automatically change to $S+\Delta S$, compensating for the «additions» to the distance Δd:

$$\Delta S=\frac{C\Delta d}{\varepsilon_0\rho(\varepsilon)}. \quad (11)$$

In fact, such addition can be carried out, for example, by displacing the parts of the electrode (Fig. 6, *a*) or by rotating it (Fig. 6, *b*). The displacement or rotation is carried out by a simple mechanism in which ΔS and Δd must be connected uniquely, for example, rail.

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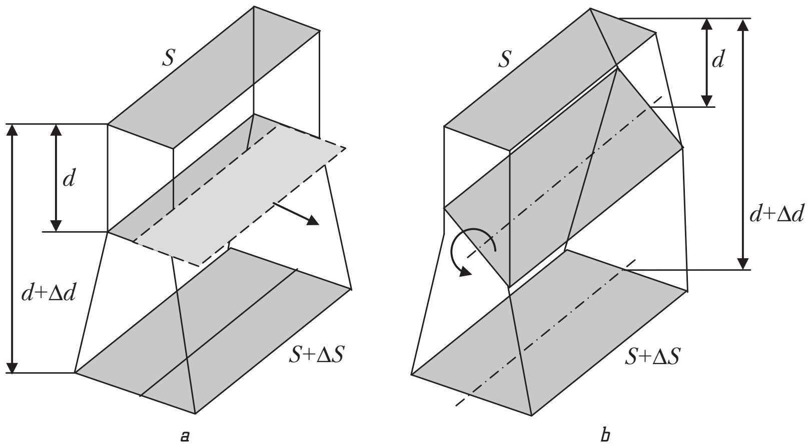

Fig. 6. The scheme of automatic geometric compensation of increasing the distance between the plates by increasing the projection area of one of the plates: *a* – offset compensation; *b* – compensation by rotation

Mechanical compensators for dynamic deviations are essentially shock absorbers.

In work, adaptive shock absorbers are used for the mechanical compensation of dynamic deviations.

Adaptive are such active damping systems which parameters can vary during operation in such way as to ensure minimum transmission of vibration from the motor and the guides to the external element of the measuring instrument.

Such systems operate according to two main schemes. The first scheme provides for preliminary monitoring of the frequency spectrum of mechanical deviations that propagate from the drive and guides (Fig. 7, *a*), and the introduction of future compensating actions at the previous stage of computer-aided design of the corresponding shock absorbers.

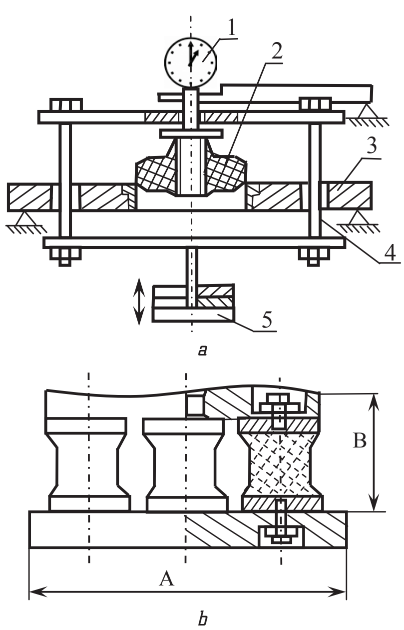

Fig. 7. Rubber-metal shock absorbers for devices according to GOST 11679.1-76: *a* – diagram of the device for preliminary monitoring of the frequency spectrum of mechanical deviations; *b* – project of 3-D rubber-metal shock absorber; 1 – measuring instrument; 2 – rubber part of the device; 3 – fixed platform; 4 – staple; 5 – cargo

The frequency spectrum of such oscillations is relatively wide [22], and they act in all directions (Fig. 2, *d*). Therefore, shock absorbers for their compensation are chosen from the class of 3-D rubber-metal multilayer (Fig. 7, *b*). Mathematical models in CAD for their calculation are models of electromechanical filters used in radio engineering [23, 24].

The second scheme involves obtaining a signal for adapting the depreciation systems directly during the movement of the moving EMI. Such systems are much more complicated, but they work better in conditions of unpredictable deviations of elements.

6.3. Practical use of research results. The scheme for setting and solving the problem of measuring the density of concrete in large-sized objects of increased complexity is shown in Fig. 8. The choice of this or that method of testing concrete depends on the purpose of the test (quality control of the products in the factory, selective or continuous strength testing, testing of structures of concrete with unknown properties).

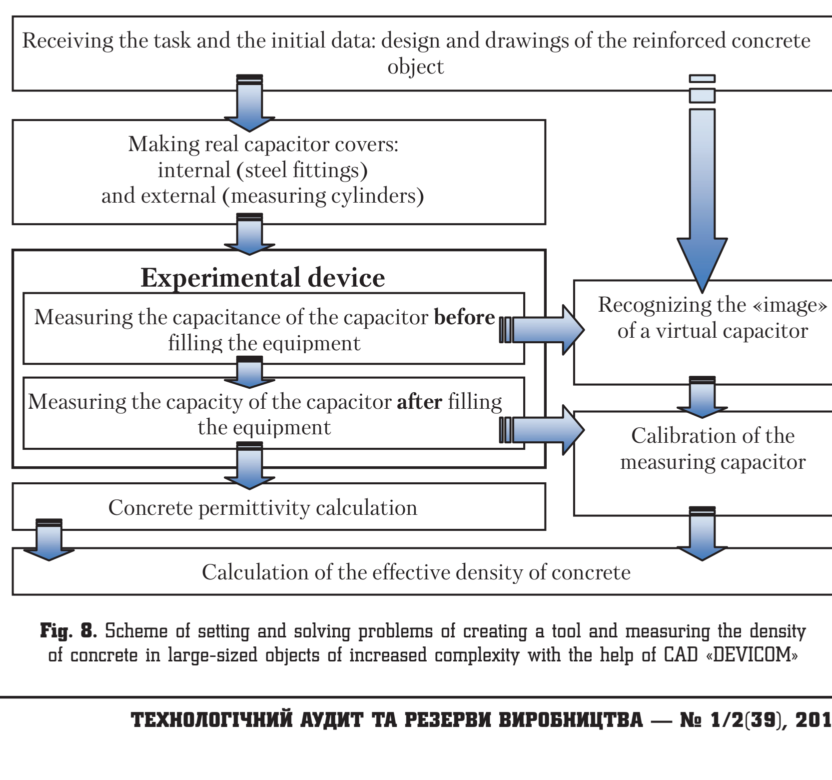

Fig. 8. Scheme of setting and solving problems of creating a tool and measuring the density of concrete in large-sized objects of increased complexity with the help of CAD «DEVICOM»

It is also important to take into account the shapes and dimensions of the products (beams, slabs, columns, massive elements with inclined surfaces), the type of concrete (heavy, porous, lightweight aggregates), as well as the accuracy requirements of the results and the convenience of testing.

A common system for automated design of elements of metrological means «the DEVICOM» (deviation compensation) and its subsystem for practical use is developed. CAD «DEVICOM» allows to design large measuring devices, protected from external static, technological and dynamic loads.

With the help of CAD «DEVICOM» 3-D shock absorbers for the capacitive measuring system of filling density of the concrete mix with concrete are designed. Shock absorbers are designed to compensate for dynamic deviations during the movement of the outer ring of the measuring capacitor along the reinforced concrete support 20 m long.

In the production areas of JSC «Galenenergobudprom», such measuring capacitor is tested. The device is involved in the control of the technological process of manufacturing the reinforced concrete product «Power transmission line support», which, as a result, reduced the number of defective products by 7.4 %.

7. SWOT analysis of research results

Strengths. The main positive influence of the research object on its internal factors is the ability to:

– at the design stage, choose the method of compensation for the deviation of the elements of the measured means and devices;
– to develop appropriate parts and mechanisms of the compensation unit;
– due to the available models, to predict the degree and reliability of compensation.

This allows to significantly improve the efficiency of CAD in general, in particular – when using the results of design in the management of technological processes.

Weaknesses. The main negative influence of the research object on its internal factors is the need to return to the design stage of the measured medium after changing the design of the measured object.

Opportunities. Opportunities for further research in this area are related both to the development of the theoretical base in the creation of new methods and models for the design of measuring technology, and to the improvement of methods and means to improve the accuracy of measurement and the reliability of the latter's results.

Threats. As in any case of computer-aided design, the main threats for this activity stem from the adequacy of the CAD models used in the subject area. Weighing the large dimensions of design objects and their complexity, as well as the natural divergence of technological parameters for production of successive objects in the series, which leads to their permanent deviation, the confirmation of adequacy needs to be made more often.

Previously, compensation nodes were used to counter high-frequency oscillations at relatively small objects. Therefore, there are no complete analogs of the proposed models and methods in the design.

8. Conclusions

1. Theoretical and experimental virtual models of electrical characteristics of the elements of measuring instruments and models of their deviation are obtained. Models are used in automated design systems for complex means of capacitive measurement of concrete density required for controlling the technological process of manufacturing reinforced concrete products of large dimensions with geometrically complex fittings.

2. Methods of compensation for undesirable static, technological and dynamic displacements at the stage of automated design of metrological means are proposed. Methods fall into two classes. The first is mathematical, in which compensation is performed solely by making changes to the measurement results. The second is mechanical, in which compensation is made by changing the geometry of the measuring tool (with static deviation) or depreciation of their elements (with dynamic).

3. Research results were implemented in the CAD subsystem «DEVICOM», with the help of which 3-D shock absorbers were designed for the system of complex capacitive measurement of the filling density of the concrete mix. Shock absorbers are designed to compensate for dynamic deviations during the movement of the outer ring of the measuring capacitor along the reinforced concrete support 20 m long. In the production areas of JSC «Galenenergobudprom» (Lviv region, Ukraine), such measuring capacitor was tested. The device was involved in the control of the technological process of manufacturing the reinforced concrete product «Power transmission line support», which, as a result, reduced the number of defective products by 7.4 %.

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КОМПЕНСАЦИЯ ПРОСТРАНСТВЕННЫХ ДЕВИАЦИЙ ЭЛЕМЕНТОВ СРЕДСТВ ИЗМЕРЕНИЯ В САПР

Показано, что при измерениях крупногабаритных сложных объектов иногда приходится располагать часть элементов средства измерения внутри объекта, а часть – снаружи. В этом случае, особенно когда внешние элементы подвижны, возможна девиация последних от запланированного расположения их в пространстве. Предложены методы, осуществляющие проектирование средств измерения таким образом, чтобы они адаптивно противодействовали таким явлениям, что позволяет снизить погрешность измерения и повысить его достоверность.

Ключевые слова: элементы метрологических средств, пространственная девиация, автоматизированное проектирование, погрешность и достоверность измерений.

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