ABSTRACT

of the dissertation thesis on the theme:

«DEVELOPMENT AND RESEARCH OF COMBINED PRESSURE AND TEMPERATURE SENSORS»,

proposed for the PhD degree competition

by the specialty: 6D071600 – «Instrument engineering»

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Evaluation of the current state of the scientific and technological problem being solved (objective)

A characteristic feature of the global development of information and control systems is seen vividly in the constantly increasing use of various physical quantities' sensors, mainly non-electric, in all spheres of vital activity. Physical quantity sensors (PQS) are used in industrial control, automation of manufacturing processes, in automobile, aviation and railway transport as well as aviation engineering and nuclear energy. Their role in the measurement of PQ under extreme operational conditions of shock loads, radiation, vibrations, temperature, is especially great.

PQSs are becoming the main elements for determining the technical level and cost of informational and control systems. At the same time, in addition to high metrological characteristics, PQSs should possess a high degree of reliability, durability, stability along with small dimensions, weight and power consumption.

It should be noted that modern industrial information systems have a pyramidal multilevel structure, while information on the state and functioning of the object is transferred from the lower level to the upper level. The amount of information decreases with each new level, whilst its significance increases. The lowest (zero) level represents the networks of sensors and actuators.

Through digital (RS485, 1-Wire, CAN) and analog interfaces (0-5V, 4-20mA, 0-16mA, 0-24mA) sensors and actuators are connected to industrial controllers or special data transmission devices manufactured for a specific type sensor.

A peculiar feature of this level is in its increased information content and the variety of measuring instruments as well as the difference in the types of signals by amplitude, type (analog, digital, electric and non-electric), in the frequency range, and etc. With the correct functioning of the PQS, the remaining levels of control systems will also operate in a standard mode, converting the information from the PQS into an appropriate form.

Typically, the majority of PQSs perceive one value, for example, pressure, displacement or temperature. Besides, the removal points of PQS vary considerably, which makes it difficult to ensure the construction of a unified object model.

At the same time, the practice of measurements in instrumentation demonstrates that of all the measured parameters in engineering, industry and technology, pressure (30–40) % and temperature (10–20) % are regarded as the most significant.

In addition, temperature is often only an indirect parameter used in the main measurements of other parameters. Hence, when measuring the flow rate of gas and liquids, temperature measurement is mandatory, since its value is amended. In some measurement methods, temperature is the main controlled variable: heat flow meters, thermal catalytic gas cells, humidity sensors, etc.

Thus, the share of total pressure and temperature measurement accounts for about 45-55 % of PQ measurements; therefore, the creation of measuring transducers (MTs) that simultaneously measure pressure and temperature under extreme operating conditions is a very relevant issue.

This issue is mainly considered by foreign companies, research teams and scientists, including such as follows: Endevko, Kulayt (the USA), Mida, Metran, Signal (Russia). Unfortunately, Kazakhstan does not have its own sensors' manufacturing body, so that only imported ones are utilized.

In the field of development and modeling of measuring transducers, it is necessary to note such Russian scientists who have made significant contributions to this area, such as Panich A.E., Stuchebnikova V.M., Raspopova V.Ya., Mikhailova P.G., and also foreign ones, including Eller E.E., Jaffe H., Jackson RG, Fraden J., Kurtz A.D. and many others.

In this dissertation, for the first time, the problem of measurement compatibility is brought up and, based on mathematical modeling, the possibility of creating combined pressure and temperature sensors based on the use of MEMS designs and technologies is shown.

The basis and initial data for the development of the theme. Government programs and regulations aimed at reducing dependence on foreign supplies suggest the creation of import-substituting products with high added value in the Republic of Kazakhstan, such as microelectronic pressure and temperature sensors (ME PTSs). Such issues were put forward for grant financing through the MES RK, therefore, at present, it is being actively developed both in the scientific and manufacturing areas.

As shown by marketing research, combined pressure and temperature sensors are highly demanded in the Commonwealth countries.

Equipping new or modernized production in the petrochemical industry, oil production and the pipeline system with imported sensors is impractical due to their high cost.

In connection with the need and necessity of import substitution, the topic of the thesis is relevant and widely demanded.

Relevance of the issue. Due to the expansion of the scope of PQSs' application, it has become necessary to create a series of combined pressure and temperature sensors that are resistant to the effects of extreme external factors (EF), in particular, temperature, corrosive environment, vibrations and accelerations. Such EF are typical of deep oil wells, aviation, launch vehicles, and so on. Therefore, when manufacturing, it is necessary to take into account the impact of EF on the sensitive structures of PTS, which are manifested in the decrease of reliability, strength, and the increase in error resulting from the

generation of mechanical and thermal deformations in nodes and elements of sensors, which are very difficult to measure and take into account.

It should be noted that currently microelectronic multifunctional PQSs are becoming the most promising, as they allow simultaneous measurement of several EFs at one point, for example, pressure and temperature, temperature and humidity, pressure and vibrations, and so on. At the same time, their models and designs represent distributed multidimensional structures that are very difficult to model.

Due to the complexity, laboriousness and high cost of the development and manufacturing processes of PQSs, mathematical modeling methods acquire a special role in their design process, the use of which significantly reduces the peirod and cost of sensor development.

In the course of research, it was revealed that there are isolated expensive programs and techniques that allow to perform modeling heat and deformational fields in the sensors. Unfortunately, these licensed programs based on finite-difference methods are very expensive, and they are also laborious to master. Therefore, the traditional engineering approach to the calculation of sensor elements, supplemented by practical results, makes it possible to simulate PTSs quite effectively.

In this regard, the thesis is devoted to the development of microelectronic combined pressure and temperature sensors, designed for operation under extreme conditions.

The aims of the research work:

- development of new constructions of combined PTS's components
- creation of mathematical models, algorithms and programs to compensate for the influence of external factors;
- production and testing of experimental layouts for combined PTSs.

The objects of research are combined multifunctional microelectronic pressure and temperature sensors designed for extreme operating conditions.

The subject of the research is theoretical analysis and experimental studies of the creation and functioning of PTS's elements under both normal and extreme conditions.

The objectives of the study, their place in the completion of scientific-research work in general:

- to analyze the conditions and modes of operation and influence of external destabilizing factors on the characteristics of the PQSs.
- to investigate and select compatible methods of pressure and temperature conversion in the PSE MES;
- to develop constructions of SE and MM for combined PTS;
- to investigate the issues of electrophysical, constructive and informational compatibility of the components of ME PTS;
- to develop algorithms and programs for mathematical modeling of combined PTS's structures ;
- to manufacture and test experimental samples of PTS.

The scientific novelty of the thesis:

- studies on the analysis and selection of compatible physical methods of pressure and temperature transformation with consideration of the extreme operating conditions were conducted;
- algorithms and programs for modeling and optimizing RM and PSE have been developed;
- new design and technological solutions for optimizing the topology and choice of compatible functional materials were proposed;
- developed and tested new designs of modular PSE with deformation and thermo-dependent sensor elements were developed and tested;
- methodic and models of film compensators were developed and proposed for further approbation..

The provisions for the research defense

The proposed hypotheses

- the influence of mechanical and thermal stresses on the electrical characteristics of SE and PTS MM was established, methods and ways of compensation were determined.
- compatible methods for transducing pressure and temperature in a single SE were determined.

On the basis of the proposed hypotheses, the following issues for the research defense were developed:

- compatible methods for transducing power and thermal parameters, taking into account extreme conditions of sensors' exploitation.
- mathematical models of SE and PTS MM, providing the possibility to predict informational and metrological characteristics, which improve the measurement accuracy.
- results of the analysis of the mechanical stresses' impact on the characteristics of SE and PTS MM as well as the developed methods for their compensation.
- the research results of the developed, manufactured and tested experimental samples of PTS, equipped with micromechanical SE and MM.

The practical significance of the research

The possibility of launching the manufacture of a new import-substituting product in Kazakhstani conditions was demonstrated. The product includes a series of microelectronic pressure and temperature sensors with high added value. Based on the application of the developed unified SE and MM, it is possible to collect and adjust PTS in small enterprises, with minimal investment in equipment.

Publications and approbation of the research results.

13 scientific articles on the topic of the thesis were published, including one with a non-zero impact factor, 4 articles in scientific journals recommended by CCDES of MES RK.

The main results of the thesis were reported and discussed at the seminars of the "Robotics and Technical means of Automation" Department at KazNRTU after K.I. Satpayev (Kazakhstan, Almaty); at XII International Scientific and Practical Internet Conference called “Youth. Science. Innovation”, PB MSUTM after K.G.

Razumovsky (FCU) (Russia, Penza, 2016); III Annual intercollegiate students' SPC called "Information Technologies in Science and Education. Problems and prospects" "PSU" (Russia, Penza, 2016); Regional youth scientific conference called "Youth Initiatives in Science, Education, Culture" "Mordovia State Pedagogical Institute after M.E. Yevsevyev" (Russia, Saransk, 19-20 May 2016); XIII Mezinárodní vědecko - praktická conference «Aktuální vymoženosti vědy - 2017» (Česká republika, Praha, 22-30 června 2017); XV Mezinárodní vědecko – praktická conference «Efektivní nástroje moderních věd -2019» (Česká republika, Praha, 22-30 dubna 2019); International conference called "Modern innovative technologies for engineering personnel for mining and transport, 2019" (Ukraine, Dnieper, April 26-27, 2019).

The structure and volume of the dissertation thesis.

The dissertation thesis consists of the introduction, 4 sections, the conclusion and the list of references. The main text of the work is set out on 140 pages of typewritten text, containing 91 figures, 6 tables, whereas the list of references consists of 128 items.