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THE DEVELOPMENT OF MEASUREMENT SYSTEMS AND THEIR METROLOGICAL SUPPORT

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The stages in the development of measurement systems, their properties and structure, and terminology and metrological support are discussed.
Keywords: *automated systems, measurement systems, metrological support, stages of development.*

Developments in science and technology have led to the replacement of single-channel devices by multichannel devices and of analog systems by analog-digital systems. With the appearance of the first computers, scientists received a new instrument: automatic systems for scientific research in the form of software-hardware combinations consisting of a number of measurement modules. Automatic systems could be reconfigured with suitable software-hardware combinations by adding new modules and modifying the programs to solve any scientific problem.

As the objects requiring monitoring became more complicated, the systems were improved: distributed, computerized systems were supplemented by smart systems capable of developing decision making algorithms.

This article analyzes measurement systems (MS) of an approved type using data represented in the Federal Information Foundation for Ensuring the Uniformity of Measurement (FIF OEI).

The first means of measurement (MM) designated as "systems" were entered in the registry of means of measurement at FIF OEI in the 1970's. The first was the TAK-011P system, which in the current sense is not an MS, but a thermocouple emf converter with error limits of ±2% (neglecting the error introduced by the thermocouples). Next, was the SID-2 system for measuring deformation in plastic, which converted the strain on an elastic component with glued-on resistive strain gauges into an electrical signal proportional to the deformation of the test sample. The reduced error limits were also ±2%.

The first system of an approved type must be regarded as the K200 data-measurement system intended for successive measurement of dc electrical voltages from many sources (with a maximum channel switching rate of 25 Hz) with display of the measurement results on the panels of digital measuring devices and recording of the results by digital printer or perforator.

In 1974, a first recording system type was approved: the IISE1-48 automatic data-measurement system for recording and monitoring electrical energy with a maximum (up to 48) number of attached three-phase electrical energy readouts equipped with pulse sensors. The correction for the setting of the electric clocks was ±1 min/day.

Thus, during the *first stage* of development, the systems were intended only for measuring and recording data. They were localized (not distributed in space) and did not include a computer, so they did not process the measurement results or generate control actions.

After a few years, the development of microelectronics raised all MM (including MS) to a new level. In 1982, a system for automatic readout of electrical energy and monitoring of energy demand (SAUKE) was entered into the MM register at FIF OEI. That system made it possible to automate the process of obtaining information on electrical energy consumption

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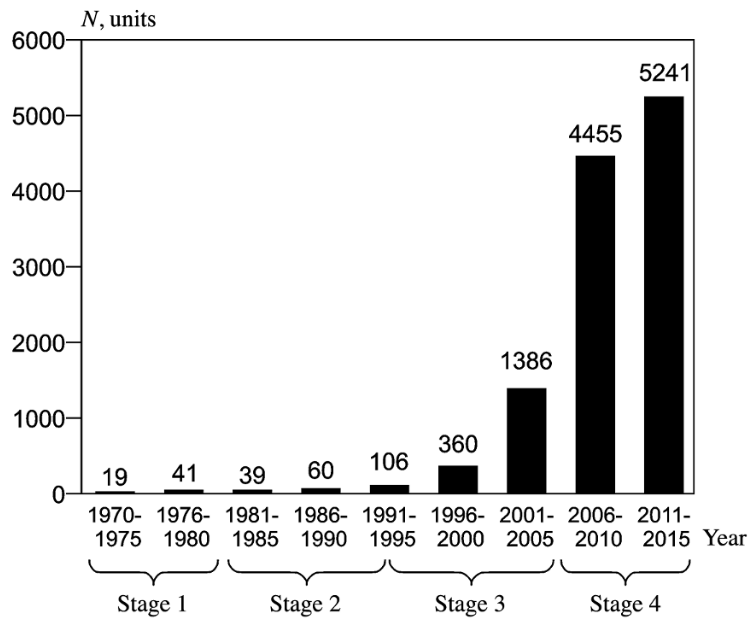

Fig. 1. The number of measurement systems of certified types.

based on two-rate charges and to monitor the electrical consumption at up to 30 substations, with as many as 256 electrical energy readouts and data transfer over distances up to 25 km. The error in the electronic clocks was ±0.01%.

Some typical representatives of systems from the *second stage* might include the UTRO-3 measurement systems for the mass of petroleum products in tank farms, as well as the UGR1 system for level measurements in horizontal tanks, which made it possible to service up to 30 tanks, and was intended for measuring the mass of petroleum products by a hydrostatic method based on the calibration characteristics of a tank.

The SBE-1 system for biological experiments showed up in this same stage. It was an eight-channel MS (that included a computer). It could measure the concentrations of osmotically active substances, determine the activity (*pX*) of potassium, sodium, calcium, chlorine, and nitrate ions, and estimate the amount of oxygen in biological objects and water solutions based on a diffusion current.

In the second stage, systems became distributed and the inclusion of computers in the setup of MS made it possible to measure and record data, but also to process them. Analog-to-digital converters (ADC) were not, however, widely available, so that sensors were connected to ADCs in sequence with switches. Thus, the productivity of the MS was low.

The further development of MS was facilitated by structural changes. While in the past a single ADC served several primary measurement converters, i.e., sensors, in the *third stage* each sensor was attached to an individual ADC. This influenced the productivity of measurement systems. The massive introduction of personal computers, especially as part of measurement-computational complexes, the so-called complex components [1], lead to a rapid increase in the number of measurement systems in use.

Typical representatives of systems from the third stage include the following: ASKUE-S, automated systems for commercial readout of electrical energy; TOK systems for commercial readout of energy reserves; PIRAMIDA systems for data-measurement control and readout of energy consumption, etc.

The fourth stage is characterized by rapid development of means of communication and wireless connectivity using 3G, 4G, and Wi-Fi technologies which provide essentially unlimited possibilities for access to information, including the internet, and for system modernization. It should be noted that the available prospects for system modernization in the fourth stage do encounter a major technological barrier in the area of legal metrology: the impossibility of modernization without making changes in the description of the types of means of measurement [2].

We now make a qualitative analysis of the evolution of measurement systems. The figure shows the number of types of measurement system entered in the MM registry of the FIF OEI over five year intervals. The number of types of MS increases steadily, although the rate of growth has slowed down in the fourth stage. An analysis of the percent amounts of the certified MS in terms of forms of measurement [3] showed that during 1972–2002 the dominant types of measurement were electrical (32%), physicochemical composition and properties of materials (18%), flow, feed rate, level, and volume parameters of materials (16%), and mechanical (12%). From 2002 through 2015, the fraction of electrical measurements rose by more than a factor of two (from 32 to 70%), while measurements of the composition and properties of materials fell from 18 to 3%.

In 2014, of the 1252 MS of certified types, 899 (more than 70%) were automated data-measurement systems for commercial reading of electrical energy, 83 (less than 7%) were systems for measuring the amount and quality indicators of petroleum, 39 were automated systems for automatic process control, 36 were monitoring systems, 22 were safety systems, and 8 were automatic systems for commercial readout of thermal energy. A large fraction (91%) of the MS are designed for specific objects.

The term *measurement system* has changed, along with the measurement systems themselves. The following definition corresponding to MS in the first stage is given in [4]: "*5.24. Measurement system – a set of means of measurement (gauges, measurement instrumentation, measurement transducers) and auxiliary devices connected by communication channels that is intended for processing measurement data signals in a form convenient for automatic processing, transfer, and (or) use in automatic control systems*."

The definition of MS takes on a slightly different sense in stage two [5]: "*5.14. Measurement system – a set of functionally combined gauges, measurement instrumentation, measurement transducers, computers, and other technical devices located at different points in a monitored object, etc., for the purpose of measuring one or more physical quantities inherent to this object and for processing the measurement signals for different purposes.*

Notes. 1. Depending on their purposes, measurement systems differ in terms of their systems for data, monitor measurement, control measurement, etc.

2. Measurement systems that can be adjusted as the measurement problem is changed are referred to as flexible measurement systems."

A similar definition is given in [6]. Here the MS includes a computer and the MS can be used for automation of control functions, as well as for automation of monitoring operations and data collection but, most importantly, it may be adjustable.

In Russia, after adoption of the law of 1993 [7], an important feature of MS was eliminated from the terminology: flexibility of MS. This was confirmed in later definitions [1, 8]. The current definition of MS, which holds for MS in the third stage, is regulated by the GOST standards document of Ref. 1. "*3.1. Measurement system – a set of measurement, communication, and computational components which form measurement channels, and auxiliary devices (components of the measurement system), operating as a unified whole intended for the following: acquisition of data on the state of an object using measurement transducers, generally of a set of time varying and spatially distributed quantities characterizing its state; computer processing of the measurement results; recording and readout of the measurement results and the computer processed results; conversion of these data into output signals from the system for various purposes.*

Note. MS have the major features of means of measurement and are forms of means of measurement."

Everyone has gotten used to this definition of MS, but it does not reflect the features of MS in the fourth stage, i.e., the unlimited possibility of modernizing MS and of access to data contained in an MS from different computers, including those connected to the internet.

It should be noted that other definitions [9, 10] do not reflect these features.

Besides the evolution of MS, the approaches to their metrological support have changed. For MS in the first stage, comprehensive testing was used, and was fully justified. Here it was necessary to prescribe the normal conditions for testing, as well as a brief interval between tests.

In the second stage of the development of MS, the sensors predominantly transformed quantities of one kind into another (e.g., linear variables into a voltage, force into a frequency, pressure into a current, etc.), which were then converted into code after switching and an analog-to-digital converter. This state was the start of the transition from comprehensive testing to element-to-element testing. The intervals between tests remained brief.

In the third stage of the development of MS, in connection with the mass appearance of measurement-computational systems, testing became partially comprehensive: the sensors were taken apart and tested one by one while the measurement-computational systems and the communication lines were tested as a whole. Here standard conditions were specified for the nondemountable parts of the MS (the measurement-computational systems and the communication lines) and the times between tests of the MS were mostly coincident with times between tests of the measurement-computational systems. The calibration of MS introduced in 1993 was done is similar fashion [7].

Toward the end of the third stage, the number of sensors with analog outputs began to fall off rapidly. Ultimately, in the fourth stage of the development of MS, most of the sensors were combined with ADC. For these MS, the specification of normal conditions [11] lost its significance and the times between tests were no longer determined by scientific methods [12, 13], but were set externally [14].

The increasingly frequent selective and remote testing of MS in recent times should be noted. Here the current order of testing [15] allows selective testing only initially, before the system is brought into operation. Some aspects of remote testing of MS have been discussed in [16].

It should also be noted that at present the term calibration is understood in a different way [9,10] and demands for comprehensive calibration of MS under operating conditions are rising. The basis of these demands and a possible method for such testing have been discussed by the author [14, 17].

During the second stage of the development of MS, the standard of Ref. 18 came into force; its paragraph 1.5 advanced a reasonable specification: testing of MS, as a rule, “should be automated.” All of the next decade was devoted to the creation of a set of calibrators for inbuilt metrological monitoring of MS built mainly using precision analog-to-digital converters, some with the author’s participation [19]. Subsequently, however, this specification met a mass of protests associated mainly with the fact that it was unacceptable that the standard should always be under the same working conditions as the components of the MS.

Conclusion. One of the advantages of measurement systems (flexibility, modernizability, reconfiguration for new measurement problems) has encountered a substantial bureaucratic barrier – the need to introduce changes in the description of the type of measurement systems employed in the sphere of government regulation for support of the uniformity of measurements. To overcome this barrier in terms of existing law, it can be recommended that potential users of measurement systems acquire, or order the design and installation of, systems (predominantly in class IS-1 [1]) that will be capable of modernization in the number and type of measurement channels.

Promising directions for reducing the time and labor spent in testing MS include automatic operation, and the use of selective and remote testing.

One effective way of increasing the accuracy of MS is comprehensive testing under operational conditions [14, 17].

REFERENCES

1. GOST R 8.596-2002, *GSI. Metrological Support of Measurement Systems. Basic Assumptions*.
2. Decree No. 97 of the Ministry of Industry and Trade of the Russian Federation, *On Approval of the Administrative Rule for Provision by the Federal Agency for Technical Regulation and Metrology of Government Services for Approval of the Type of Standard Samples or the Types of Means of Measurement*, June 25, 2013.
3. MI 2314-2006, *GSI. Codifying Groups of Means of Measurement*.
4. GOST 16263-70, *GSI. Metrology. Terms and Definitions*.
5. MI 2247-93, *GSI. Metrology. Basic Terms and Definitions*.
6. RMG 29-99, *GSI. Metrology. Basic Terms and Definitions*.
7. Law No. 4871-I, Russian Federation, *On Ensuring the Uniformity of Measurement*, April 27, 1993.
8. MI 2438-97, *GSI. Measurement Systems. Metrological Support. Basic Assumptions*.
9. RMG 29-2013, *GSI. Metrology. Basic Terms and Definitions*.

10. *International Vocabulary of Metrology. Basic and General Concepts and Associated Terms* [Russian translated], VNIIM, BelGIM, Professional, St. Petersburg (2010).
11. A. A. Danilov, "Transfer of the dimension of units of quantity and the conditions for testing as applied to measurement systems," *Izmer. Tekhn.*, No. 4, 63–65 (2007).
12. RMG 74-2004, *GSI. Methods of Determining Times between Testing and Calibration for Means of Measurement*.
13. A. A. Danilov, "Methods of determining and correcting the times between testing and calibration of means of measurement," *Glav. Metrolog*, No. 6, 29–36 (2005).
14. A. A. Danilov, *Metrological Support of Measurement Systems*, Politekhnika-Servis, St. Petersburg (2014).
15. Decree No. 1815 of the Ministry of Industry and Trade of the Russian Federation, *On Establishing the Order of Testing of Means of Measurement, Specifications on the Test Signature, and Content of Test Certification*, July 2, 2015.
16. E. M. Sheinin, "Metrology of large readout systems for energy resources," *Izmer. Tekhn.*, No. 12, 55–58 (2012).
17. M. V. Berzhinskaya, A. A. Danilov, Yu. V. Kucherenko, and N. P. Ordinartseva, "Calibration of means of measurement under working conditions," *Metrologiya*, No. 1, 19–22 (2014).
18. GOST 8.438-81, *GSI. Data-Measurement Systems. Testing. General Assumptions*.
19. A. A. Danilov, *Methods and Means of Evaluating the Nonlinearity of Conversion Functions of Measurement Transducers*, Izd. Penz. Gos. Univ., Penza (2001).