

MULTI-CHANNEL INTELLIGENT MEASURING SYSTEMS

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Abstract - The paper deals with the ambiguity of the concept "measuring system" in the International Vocabulary of Metrology. Proposals are put forward to change the definition of this term. Taking into account these proposals, consideration is given to a specific character of intelligent multi-channel measuring systems, the distinguishing feature of which is the function of a metrological self-check. Multi-channel systems, that process measurement information coming from intelligent and data redundant sensor devices, have significant advantages in comparison with other intelligent systems. However, intelligent measuring systems can be realized on the basis of conventional sensors. Under certain conditions, it is possible to intellectualize measuring systems set in operation even without their dismounting. An example of metrological self-check in a measuring system is considered. The efficiency of intelligent measuring systems in various fields is justified.

Keywords: measuring system, multi-channel measuring system, intelligent measuring system, metrological self-check.

1. INTRODUCTION

In scientific literature, the terms "sensor system", "measuring system", "multi-channel sensor system", as well as "multi-channel measuring system" are widely used.

According to VIM [1], the "measuring system" is a "set of one or more measuring instruments and, often, other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds.

NOTE

A measuring system may consist of only one measuring instrument".

Thus, according to [1], the "measuring instrument" and "measuring system" can be apprehended as identical devices.

In [2, 3] it is proposed to rest upon Russian guide [4], where the specific characters of measuring systems, such as the presence of many channels as well as "a set of functionally combined material

measures, measuring instruments, measurement transducers, and other technical means located in various points..." were emphasized.

The same features are present in Russian standard [5], where the measuring system is interpreted as "a set of measuring, linking, computing components forming measuring channels, as well as of auxiliary devices..., operating as a single whole, intended to provide information about the state of an object (in a general case, about a set of quantities changing with time and distributed in space, which characterize this state)..."

At present, in Russia a new edition of the guide on basic terms and definitions in metrology, [6], has come into force, which was harmonized with [1] to a significant extent. However, in this document there is an attempt to correct some drawbacks of [1].

In particular, the "measuring system" is defined as a "set of measuring instruments and other means of measurement techniques, located in various points of a measurement object, which are joined functionally with the purpose to measure one or a number of physical quantities that are characteristic for this object" [6].

"Examples

1. A measuring system of a thermoelectric power station which at its output provides measurement information about a number of quantities in various power units. It can include hundreds of measuring channels.

2. A radio-navigation system intended for defining the location of various objects. It consists of a number of measuring-calculating complexes, distributed in space at a significant distance" [6].

(Since this definition of "measuring system" include the term "means of measurement techniques", in [6] its definition is also given: a "general concept covering technical means, especially intended for measurements", e.g., measuring instruments, measurement standards, measuring systems, measuring setups and accessories, comparison means, reference materials, etc.)

The authors of the present paper use the above definition of measuring system in the text below and propose to take it into consideration while preparing a new edition of the International Vocabulary of Metrology.

2. SPECIFIC CHARACTER OF INTELLIGENT MEASURING SYSTEMS

According to Russian standard [7], a measuring system or sensor device with a metrological self-check is called intelligent. A detailed justification of the choice of such a definition is given in [8, 9].

In the intelligent measuring system (IMS) or intelligent sensor device the deviations of metrological characteristics from their values set by calibration, are automatically monitored.

The “metrological self-check of a measuring system” is interpreted as “an automatic check of the metrological health of the measuring system within an operation process, which is carried out by using embedded hardware and software” [7].

“Metrological self-check of a sensor device” is “an automatic check of the metrological health of the sensor device carried out using a reference value generated with the help of an additional (redundant) embedded component (a sensor, secondary transducer, or material measure) or an additional parameter for an output signal” [7]. The term “reference value” corresponds to the same term given in [1]. If the metrological self-check is accompanied by evaluation of uncertainty or error, it is usually called “self-validation”.

The IMSs can be realized on the basis of the redundancy of various types.

Structural redundancy of the IMS is characterized by the use of additional material measures or measuring channels.

Temporal redundancy is provided by additional measurement operations carried out at or around the frequency, which notably exceeds the measurement frequency that is sufficient for solving the task assigned.

Functional redundancy arises if output signal values of the measuring channels are interrelated. In particular, their dependences are determined by a specific character of technological processes, equipment, influencing factors, etc.

It is also possible to combine these types of redundancy as well as use additional information about characteristics of measurand changes.

Two versions of the metrological self-check can be applied in the IMS:

- an automatic check of separate measuring channels or their components (this version can be called a “componentwise” check);
- a check of the whole system, i.e., all channels at the same time (this version can be called a complex check) [7, 10].

In case of the first version, the best variant of the metrological self-check can be provided by application of intelligent and/or data-redundant sensor devices.

(The “data-redundant sensor device” is “a sensor device that in the event of connecting to an external

signal processing unit, can provide the functions of an intelligent sensor device” [7].)

To check the transducers of electric quantities as well as intermediate or secondary transducers, not included in the sensor device, it is possible to apply embedded sources of electric voltage or current with the accuracy higher than that of the corresponding measuring transducers.

The use of the IMS increases the reliability of measurement information and decreases operation costs. The metrological self-check gives grounds for setting a calibration (verification) interval of many years and forecasting the time interval, within which metrological failure has a low probability.

In a number of cases, if a measurement uncertainty approaches a limit specified, the IMS can automatically correct metrological characteristics or turn to another operation algorithm. For the IMS, the calibration interval much longer than for its non-intelligent analog, can be justified [8, 9].

As a rule, the tendency to use the intelligent and data-redundant sensor devices in the IMS requires developing and producing such sensor devices, but this process is very slow.

In this connection, the interest has been significantly increased in the IMSs with the complex check, which can be developed on the basis of mass-produced sensor devices of conventional types. However, for the IMS special software should be developed.

The complex check of the IMS can be provided by:

- forming an equalized field of a measurand in the space of sensor device location during the metrological self-check operations, the uncertainty of the measurand being at a so low level that enables acceptance this measurand as a reference;
- or application of software and hardware performing an analysis of the correspondence between the measurement results obtained in various channels.

The limitation of the complex metrological self-check of the IMS is caused by the possibility to meet the requirements for the accuracy of equalization of measurand field parameters while carrying out the metrological self-check or for the accuracy of the correspondence between measurand values being measured in various channels.

3. THE EFFICIENCY OF IMS APPLICATION

An important field of the IMS application is diagnostics of equipment, particularly, if this equipment is used for production that is hazardous to the environment and people (e.g., nuclear reactor) or for generation and consumption of significant energy.

A characteristic example is intellectualization of a force measuring system (FMS) that provides the diagnostics of threaded connections fastening a cover to a turboset body at a hydroelectric power plant.

A changing pressure of water and turbine vibrations can result in weakening of these connections. Their reliable diagnostics as well as early warning about the beginning of the breakout process is a guarantee of the safe turboset operation.

However, the measuring system calibration is possible only in case when the turbine is shut down, i.e., after no less than 4 years of operation.

The FMS includes a set of 8 load washers (LWs), mounted under internal screws on double-end bolts fastening the cover, and an electronic unit connected with the LWs by high frequency cables [11].

The LW contains three measuring channels. Each of the channels is made on the basis of a quartz resonator. The LWs operation is based on the usage of surface acoustic waves [12].

The experimental operation of such FMSs (without a metrological self-check) took place at one of the hydroelectric plants in Russia. The analysis of the operation results has demonstrated:

- Necessary reliability of the FMS can be provided only in the presence of the metrological self-check function.
- Drift of the LW metrological characteristics lies within the limits which allow the 4-years calibration interval to be specified for the FMS with the metrological self-check.
- Variation of the LW metrological characteristics is of a step-wise character; after technology debugging the failure probability can be reduced to a level acceptable for the lifetime equal to 10 years.
- Self-check can be arranged taking into account the following data:

- variations of a compression force for various LWs of the FMS correlate with each other;
- variations of values of the force measured, which are caused by defects appeared in measuring channels or by weakening of some of threaded connections, do not take place in several LWs concurrently.

- Channel, measuring the maximum compression force, is characterized by the most stable signal for the most part of the LWs.

The developed method of the metrological self-check rests upon the structural and functional types of redundancy. It allows the metrological self-check to be realized in the above FMS by means of processing the data entering from the measuring channels. This processing is carried out by multi-operation cycles with a delay between them.

Among the main procedures of an operation algorithm there are:

- acquisition of data from all the LW channels included in the FMS;
- determination of the channel for which the value of the compression force is maximum for each LW;

- evaluation of signal variations in the channels with the maximum compression force in each LW during a given number of cycles;

- correlation analysis of the signal variations; the choice of the channel being considered to be the basic for the whole FMS;

- determination of the coefficients of the cross-correlation between signal variations in the basic channel and those in the channels with the maximum compression force, which are included in the rest of the LWs;

- monitoring of the variations of the cross-correlation coefficients within the process of FMS operation;

- in case that these variations exceed a specified limit:

- estimation of a metrological health of the channels;
- correction of the channel metrological characteristics, if necessary,
- or acknowledgement of a channel as a faulty one and corrective action with regard to the algorithm of the metrological self-check.

The results obtained within the frames of the metrological self-check procedure are able not only to increase the reliability of measurement results, but to contribute to revealing defects of threaded connections, if they arise. This is possible since such defects are accompanied by a decrease of the compression force values and by an increase of the amplitude of their variations.

The method developed can serve as the basis for arranging the metrological self-check in measuring systems of different types.

In the first place, the interest in development of the IMSs has been increased with regard to objects of energetic and defense industry. This is logical since the safety and operation efficiency requirements forces to provide reliable and continuous diagnostics of the equipment and to extend the duration of the periods between maintenance works.

However, the IMSs with the complex metrological self-check are necessary also for safe and efficient functioning of municipal services.

The development of perspective cyberphysical systems such as “smart building”, “smart production”, “smart and safe town”, etc. implies the development of measuring systems that join tens and hundreds of thousands channels the number of which will increase every year.

A system for measurement of pure water flow intended for water commercial accounting within a town or several its districts, can be called cyberphysical one. The channels with flowmeters are connected, practically, to the input of each house. A flowmeter evaluates a total consumption of water in all apartments located in the house. Measurement information from each house is transmitted to a remote server of the measuring system, which

calculates the cost of the water consumed. The increase in uncertainty of flow measurements and errors of data communications can result in significant financial consequences and conflicts. Application of conventional methods of metrological maintenance for such systems is not efficient.

Conversion of the system into an IMS is the alternative.

For one of the systems, about 20000 channels of which have been already set in operation, a metrological self-check was not provided, but the decision was made to organize metrological maintenance of the system.

In this case, it is necessary to solve the task of intellectualization step by step, taking into account that the flowmeters installed in houses were verified before their connection to the channel. On the first step, first-priority changes of the system server software will be made and a number of mobile working place (MWP) for metrologists will be developed and produced. The MWPs should provide the communication with the system server and a possibility to receive automatically information about the values of water flow, which come to the server from any measuring channel.

The modification of the software should rest upon the features of water flow dynamics for various consumers. Taking into account these features will make possible to reveal abnormal variations in the data received. The character of the variations and their localization will enable the determination of priority level with regard to the metrological maintenance of individual channels.

The MWPs will give a possibility to perform a “componentwise” verification of the system by the comparison of measurement results obtained in a ensuring channel with the help of the flowmeter verified and the corresponding data received from the system server. On the next steps it is planned to develop the metrological self-check further with the aim to reduce maintenance costs.

Another example is a measuring system with “living sensor devices”. The potability of water is often assessed on the basis of crawfish behavior. Recently the measuring systems have appeared in which the values of crawfish heart rhythm are used as a quantity characterizing the water purity [13]. For wide application of such systems it is necessary to develop the methods of “metrological self-check” of these “sensor devices”. The check will enable the decrease of the risk to make the wrong decision and interrupt the water supply due to the anomaly of the rhythm being measured. The thing is that such anomaly can be caused not by water pollution, but an illness of a crawfish or another reason.

The list of examples can be continued. Therefore, in the high-duty measuring systems the metrological self-check should be provided.

4. CONCLUSIONS

The definition of the term “measuring system” used in the new edition of the Russian guide [6], set the definitions of general terms in metrology, makes it possible to avoid the ambiguity. The authors propose to take into account this experience for the next edition of the International Vocabulary of Metrology.

The multi-channel measuring systems with the metrological self-check (intelligent measuring systems) are characterized by a high efficiency; they are being applied more and more.

At present, the assortment of mass-produced sensor devices with the metrological self-check is very limited. Therefore, the measuring systems with the complex metrological self-check become particularly relevant. They can be developed on the basis of conventional sensor devices. In addition, such intelligent systems can be developed by modernization of operating ones.

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