RELIABILITY OF MEASUREMENT INFORMATION IN THE "INDUSTRY 4.0" ERA

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Abstract: The coming era of "Industry 4.0" stipulates that the requirements for the reliability of measurement information formed by measuring instruments should be increased. Measuring instruments will present in all life spheres. According to economical reasons, these means should operate without any metrological maintenance for many years (up to their replacement with improved ones). Trends in metrological investigations are considered that contribute to justifying the calibration intervals of many years. It is shown that together with the work on enhancement of common reliability, organization of the metrological self-check of measuring instruments and multichannel measuring systems, as a rule, makes it possible to exclude application of usual methods of periodic calibration and verification.

Keywords: calibration interval, verification interval, metrological reliability, metrological self-check, level measurement, force measurement

1. Introduction

Automatic systems intended for data acquisition and processing, as well as automatic control systems, are widely used in industry, transportation, community facilities, defense industry, healthcare, etc. All these systems apply information from measuring instruments (MIs) embedded into them. Such means are often called analytical, control, diagnostic, navigation instruments, etc.

The value of information produced by these instruments depends on their operability that sometimes is not obvious, as well as on the conditions and methods of their usage, which should make it possible for any expert to interpret the obtained results equally. That is why the methods of metrological maintenance of measurement reliability, which are usual for measurement technology, since recently have been used in such fields as medicine, chemistry, and some others. Meanwhile, a number of various MIs and multichannel measuring systems (whatever they are called) is growing so quickly that this process is considered as one of the indications of the fourth technological revolution called "Industry 4.0".

Appearance of products of wide use transmitting measurement information and obtaining control signals via the Internet and start of cyber-physical system development, have resulted in originating and growing the problem of economically efficient provision of measurement reliability.

Periodic verifications and calibrations of MIs have become more difficult since these processes need dismantling of MIs from equipment, transportation them to a metrology laboratory, and then bringing back after verification and calibration. Nowadays, in many cases, dismantling of MIs is impossible, so this approach cannot be used. Moreover, the fast growth of the measuring system number heightens the problem gravity. When hundreds of thousands or, perhaps, millions of MIs per one million of inhabitance are applied, the usage of conventional metrological maintenance methods will be practically unrealistic.

According to the current normative documents, the usual duration of initial verification or calibration intervals is equal to 1-2 years, which makes the volume of the work on metrological maintenance incredible. What is more, nowadays, according to European metrologists' data, up to 12 % of MIs that come for calibrating, have the uncertainty value exceeding a permissible value [1]. The transition to the methods of simplified calibration (verification) [2] or verification without dismantling, reduce costs, but to apply them is not always possible. Their usage cannot radically change the situation.

It is hopeless to think that the common reliability of integrated circuits and other components as well as MIs will grow many times in the nearest future.

As the automation of control systems decrease the level of subjective observation, this fact makes requirements for the metrological maintenance of MIs stricter.

At the present situation, the danger of the usage of unreliable information in control systems goes up quickly, which can lead to spoilage in production, misleading diagnostic decisions, accidents, and catastrophes, including those with human losses.

Understanding of the scale of the issue, gave rise to a great number of publications about the establishing of calibration intervals and became a reason to change the laws that concern reducing state interventions in the measurement field.

According to the new law of the Federal Republic of Germany [3], periodic verifications have excluded as inefficient measure of the state regulation. Accordingly, the responsibility of MI owners for the reliability of measurement results has increased. The last circumstance will inevitably require to involve insurance companies to solving the conflicts caused by impermissible measurement errors.

Against this background, the process of decreasing the prices of sensors, which lead to their quick payback, is more and more noticeable. Consequently, the MI obsolescence time becomes shorter. According to up-to-date conceptions, in 10-12 years of operation, for many MIs it will be economically reasonable to replace them rather than calibrate.

The calibration interval of many years, which is recommended by a manufacture of MIs, becomes an important advantage that justifies the costs of its grounding.

All these statements actualize the following tasks:

• improvement of reliability of measurement information produced by a MI;

• justification of calibration interval duration of many years recommended for a MI.

2. The methods of calibration interval increasing

A calibration interval implies the maximum time interval (taking into account a safety factor), during which a cumulated error (uncertainty) does not exceed a permissible value with the given confidence probability (usually it lies within the range from 0.9 to 0.99 depending on the significance of possible consequences of using inadequate information).

The determination of error components and estimation of the dynamics of their variation in time, should be based on the results of a metrological analysis, which can lead to establishing the duration of the recommended calibration interval for a new MI (or a new modification of an instrument produced before).

According to [4, 5] the following data can be taken into account for this purpose:

• MI reliability indices;

• test results of the MIs or its separate units;

• information on the instability level of MI components;

• data concerning the calibration interval of analogues MIs.

At present, this list cannot be considered to be satisfactory, because it should be clarified and supplemented.

First of all, the metrological reliability of a MI is specified not only by the level of the components, which rise in the course of operation period as a result of component ageing caused by a predictable variation of material characteristics.

Metrological reliability depends on the components concerning a substandard technology of manufacturing, and, consequently, failures originating due to it. That is why the reliability of basic procedures included in the technological process of MI manufacturing, should be analyzed in order to establish calibration intervals.

Due to various reasons including economical ones, a MI designer, as a rule, cannot get data on the reliability of components which the designed MI contains as well as on the reliability of the MI as a whole. However, it is not everything.

The thing is that the above list is focused on providing the required metrological reliability of MI, which is interpreted, according to [5, 6] as "MI reliability with regard to keeping its metrological operability" (during a calibration interval).

Meanwhile, in the course of embedding MIs including sensors in equipment, and its subsequent operating, a number of component errors can appear, which were not detected during the initial calibration.

In a number of cases, such errors are not taken into account in the course of following usual operations of metrological maintenance. These components can be caused by:

• inconsistencies between the quantity influencing the sensor and the quantity that a customer intends to measure;

• incorrect mounting of the sensor into the equipment;

• nonpresumable variation of measurement object characteristics;

• changing of the environment characteristics in the area between the sensor and the measurement object.

A typical example of the MIs characterized by significant error components that were not considered at the stage of the initial calibration, are string transducers intended for force measurements.

They are used for measuring tension of reinforcing steel ropes in the systems intended for providing protective concrete constructions.

Experimental study of production samples of such transducers has shown that their metal support has often got some heterogeneity, which was not taken into account at the stage of development of a manufacturing technology.

As a result, such a support can be asymmetrically "rumpled" (pressed). At that, the axis of the transducer can incline and depending upon the direction of the slope and the slope angle towards the string direction, instead of the force acting in the expected direction, the force acting in another direction will be measured. Its value will be lower [7].

Unplanned situation can also appear due to fastening the steel ropes. As a result, the measurement reliability can additionally decrease.

Data analysis of such a system has indicated that only 20% of string transducers arranged in groups give output measurement results that conform to the expected ones. In other words, the probability of invalid information on steel rope tension is inadmissibly high.

Another example is a flow meter, which measures the volume of fuel of certain density. In some cases, while selling a large volume of fuel (for instance, to merchant ships), in addition to the fuel, some portion of air was pumped. Such a situation leaded to incorrect output of the flowmeter that measured the total volume of the fuel and air pumped through it.

Unexpected components of error can also appear in a turbine unit if eddy-current transducers are used for measuring the gaps between rotor blades and stator case there. During operation, a metal of rotor blades can magnetize causing variations in magnetic permeability, which results in invalid measurement information [8].

Under such conditions, a metrologically "healthy" MI will output measurement results with the inadmissible level of error.

Therefore, the term "metrological reliability of measurement information" has been introduced [9]. Its meaning does not coincide with the term "metrological reliability of MI".

"Metrological reliability of measurement information" implies the reliability of providing customers with credible measurement information in the course of the calibration interval. At that, information is considered to be credible if its error lies within the limits specified in the documentation on the measurement procedure and/or on the corresponding MI.

For this reason, while justifying the calibration interval, to aim at providing the metrological reliability of measurement information is expedient.

As a result, the metrological analysis that is necessary for justifying the calibration interval duration of many years should include the following procedures:

- Collection and investigation of data concerning the operation experience of analogues of the MI under development.
- Development of a measurement model as applied to this MI basing on the results of experiments and data on the operation experience of analogues in order to evaluate model parameters and their influence on the error growth.
- Studies of the technological procedure sequence applied in manufacturing of this product; detection those procedures that influence the error growth in the course of the MI operation to the maximum extent.
- Developing the program of accelerated tests of the MIs and their implementation [10].
- Ranking of the error components and their variation over time according to the degree of danger; subsequent correction of the measurement model, if necessary.
- Determination of critical error components, the growth of which limits the calibration interval durability most likely.

If a MI under development is mainly planned to be installed at concrete objects, the above list should be supplemented by the studies of the influence of possible variation of measurement conditions in this case.

It should be emphasized that the development of measurement model (as applied to the specific MI) and studies of the technological procedure sequence, decrease the probability of superfluous costs if is necessary to correct manufacturing technology or change a component supplier. Information obtained will enable prognosing the consequences of these changes and necessity to carry out additional tests.

The above requirements for the metrological analysis while justifying the calibration interval of many years, show that the analysis stipulates rather deep and costly studies. As a result of these studies, in maintenance documentation, to specify the recommended calibration interval durations for several versions of operation conditions, is expedient.

Nevertheless, in our opinion, if a corresponding MI should be applied at the objects of responsible designation, the uncertainty of input data does not allow recommending the calibration interval longer than 6-8 years basing on the results of such an analysis.

Determination of the critical error components provided by the metrological analysis together with the measures contributing to enhancement of the common reliability of the MIs, enables realizing an economically efficient metrological self-check and automatic error correction. Thereby, the MIs becomes an intelligent one [11]. Such a fundamental solution makes it possible to increase the calibration interval up to the values required.

Methods of organizing the metrological self-check and error correction as applied to measurements of many non-electric quantities such as pressure, temperature, specific electrical conductivity, displacement, etc. are considered in a number of papers, books, and national standards, e.g., [11-18].

In the present paper, it is sufficient to mention some intelligent MIs that were in operation for many years.

One of the possible versions of the metrological self-check is associated with the realization of a code scale in a MI, each gradation of the scale corresponding to a certain binary number. At that, any arisen failure, including those caused by unacceptable variation of metrological characteristics will lead to deterioration of the code sequence used.

Consequently, in case of the metrological failure, variations of a measurand will result in either appearance of an unspecified code or unspecified transition from one code to another one. To detect such an effect indicating the fact of the metrological failure is easy.

Such a version of the metrological self-check was realized in the sensor of the DPL-KV type. Three measuring complexes including such sensors were operating during many years within the system intended for the automatic control of the control rod position inside the VVER-1000 reactor at the Kalinin NPP, Russia. In these sensors, stationary set including 18 inductance coils fixed inside the sensor housing, was applied as sensitive elements reading the codes reflecting the position of the control rod. To provide a required lifetime and metrological reliability of the sensor, the coils were made of specially designed heat-resistant wire. The wire was based on Ni-Cr alloy covered by nonorganic insulation. A set of bushings made of magnetic and nonmagnetic steel was located inside the cavity of the drive rack rigidly connected with the control rod. It played the role of the movable part of the measuring transducer. The code scale was formed in such a way that control rod position was identified with the required accuracy even if any signal wire broke or any coil failed. In such a case, information on the failure arisen would come to a control board. The analysis of 10-year operation of these sensors has shown that they could operate inside a nuclear reactor up to 60 year and even more [14-19].

Similar type of the scale but with a lesser degree of redundancy has been used in the magnet float level gauges. In them, magnetically operated sealed switches (reed switches) were located along the axis of a tank filled with liquid. When a magnet element placed at a float appeared opposite a reed switch the switch triggered. The experience of operation of such level gauges, shows that, at least, for 8 years, there was no need for their calibration.

In such a level gauge the calibration interval can be of many years since every failure can be fixed and eliminated. Output information is not used until the defective reed switch is replaced. At the same time, economic consequences of such a failure are not economically significant.

In other words, realization of calibration interval that is sufficient for excluding periodic metrological maintenance of MIs in the coming era of their mass distribution, is technically possible. Costly procedures of periodic calibrations or verifications in the course of the MI operation will be a thing of the past.

3. Conclusions

Technological revolution “Industry 4.0” is unrealistic without solving the problem of economically efficient providing the reliability of measurement information being formed by measuring instruments that will become a necessary component, practically, in all the aspects of everyday life of people and society.

The requirements for information that should be taken into account while justifying the calibration interval, which are given in the international recommendations, are insufficient in case of the calibration intervals of many years. The expanded list is given. The necessity is shown to provide not only the metrological reliability of measuring instruments, but also the metrological reliability of measurement information. It is noted that the experience of application of measuring instruments with the metrological self-check proves the possibility to exclude traditional procedures of metrological maintenance in the course of measuring instrument and multichannel measuring system operation.

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