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INTELLIGENT MEASURING INSTRUMENTS. MAXIMUM RELIABILITY OF MEASUREMENT INFORMATION, MINIMUM METROLOGICAL MAINTENANCE

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Abstract – It is shown that for increasing the reliability of measurement information received from instruments built into the equipment, these instruments should have the "intellect" and structural redundancy.

Besides of capability to operate under changing conditions and noise, they can realize automatic check of metrological serviceability, and when a single defect occurs, they can change the structure and/or algorithm of input data processing, inform an operator about the defect appearance. The verification period for them is commensurable with their service life.

A new definition of an intelligent measuring instrument is suggested, which takes into account these peculiarities.

The main requirements to intelligent instruments are formulated.

The description of an intelligent instrument for control and diagnostics, which is used in the control and safety system of a nuclear power plant in Russia, is presented.

Keywords: intelligent measurement instrument.

1. INTRODUCTION

By the beginning of 21st century the processes of complication of technical systems and computerization of control and manipulation, have intensified.

These processes are accompanied with increasing requirements to the operation accuracy and economic efficiency of systems.

One can notice the tendency to decrease the number of engineers working in-situ, to arrange the remote consultative assistance for production from one center. If any accidence occur, specialists from this center can go to the place to correct a trouble, if necessary.

The importance of consequences of metrological failure has increased dramatically. It often leads to both considerable material losses and human victims.

Let us remind you that the tragedy of soviet atomic submarine K-19, about which a film was made in the USA, was, to a great extent, the result of a metrological failure.

. In this connection, the problem of development of the malfunction diagnosis of equipment and increasing the measurement information reliability of measuring instruments built into the equipment has become very urgent.

The problem is connected with the fact that periodic verification of such instruments is not always possible or very difficult, low effective. Moreover, the positive results of verification can not ensure the maintenance of the rated characteristics during the verification period.

For example, when a thermocouple previously dismounted for verification, is installed into reactor, it can happen that its junction doesn't reach the end of a channel. The error of a measuring instrument (e.g., thermocouple) can become unacceptably large under the influence of operating conditions (high temperature, vibration, radiation, etc). As a result, a latent defect of production can show up.

The traditional methods of verification have one more very important drawback: they often require for stopping the equipment, where the instruments verified are built in.

An obvious contradiction appears. Based on the preference of a continuous technological process, it is necessary to verify measuring instruments as seldom as possible.

However, a non-detected metrological malfunction will decrease the efficiency of equipment, the level of its safety, lead to failures. The risk of such outcome is the higher, the longer is this period, and the more severe are the conditions, in which the instrument operates during this period.

This contradiction makes us search for new ways.

2. A WAY TO INCREASE THE MEASUREMENT INFORMATION RELIABILITY

2.1. Intellectualization of measuring instruments

The progress of measuring equipment is associated in literature with the appearance and development of intelligent measuring instruments [1-3].

Under intelligent measuring instruments one understands, as a rule, usual instruments, but provided with a set of software and hardware equipment. This equipment on the basis of results of initial processing of measurement data is automatically adapted to a specific measurement problem.

Under adaptation one means that they automatically set to zero, filtrate current signals, account for the known influencing factors, convert an analogous signal into a digital one, calculate uncertainly of a measurement result, carry out self-diagnosis, etc.

In our opinion, the intelligent measuring instrument is first of all, an instrument capable to provide "survival" in the metrological context. In other words it is an instrument capable to give reliable information under changing conditions, when noise or a single defect can appear, not requiring for regular service (including verification) during the whole service life.

This definition is associated with an idea of the intellect of biological system, which turns out to be the most powerful factor of evolution favouring survival under changing condition.

It is obvious that metrological failures can occur due to both monotonous and spasmodic changes of error.

Taking into account the above-mentioned, it is clear from our definition of an intelligent measuring instrument that it should have, at least, the following two properties.

Firstly, it should give information about undesirable changing of its parameters, which will let the staff correct a growing defect in good time and, hence, exclude the risk of a possible metrological failure.

Continuing, the analogy with a living organism, one can say that this property means capability of intelligent instrument "to feel in disposition" and to take necessary precautions.

Secondly, an intelligent measuring instrument should be capable of giving a signal to the staff when signal defects appear suddenly, i.e. to call for assistance and to wait for it maintaining capacity for work.

The above properties, besides the inclusion of this or that computer or microcontroller instrument, presuppose also the presence of certain redundancy.

Hence, if one means an intelligent sensor, this redundancy should be ensured on the level of a primary transducer. If one means an intelligent measuring system, the redundancy should be provided by all sensors used.

Redundancy can be of different nature.

Information redundancy depends on the presence of the a prior and/or a posterior information.

Structural redundancy means that a greater number of sensitive elements are used than it is required for receiving the measurement results with a given accuracy.

In addition, though a priori information about possible limits of the rate of changing the quantity to be measured are sometimes sufficient for diagnostic control of the metrological serviceability of a measuring instrument, they are not enough for maintaining the capacity for work (in the metrological sense), which requires for the structural redundancy of a measuring instrument facilitating, by the way, the solution of a problem of improving the reliability of measurement data.

In this connection, the known definitions of intelligent measuring instruments should be expanded.

2.2. Peculiarities of the structure of intelligent measuring instrument.

It is suggested for realization of diagnostic control of the metrological serviceability to use the fact that the reasons for the error falling outside the tolerance limits are far from equivalent, and they can be classified for each instrument by probability of occurrence and can be grouped by attendant indications. The growth of this or that expected "dangerous", dominant or inclined to fast growth, error component can be detected therewith in a quite simple way, without application of a measuring standard.

It is enough for this purpose to provide the intelligent measuring instruments with sub-systems of the automatic check of stability of metrological characteristics evaluated individually during initial verification.

These sub-systems can be realized on the basis of redundancy found out and/or created artificially in the system: measuring instrument – medium - object of measurement. One can use therewith both determinate and statistic regularities.

These sub-systems should automatically estimate the assumption about the metrological characteristics of a measuring instrument being within the prescribed limits, which is carried out by comparison of metrologically equivalent signals or parameters (with similar accuracy), and inform an operator if the established tolerance is exceeded

For considerable improvement of the measurement information reliability it is enough to carry out the above simple metrological operations controlling the 'dangerous" error components. The verification should be only performed at the moment of production, after repair, during the period of scheduled outage of the equipment.

The structural redundancy of an intelligent instrument should be sufficient to provide for metrological "survival" by changing a structure of the instrument and/or algorithm of input data processing, when a single defect occurs in a measuring instrument, fist of all, sensor).

Simple duplication or triplication of the structure of a measuring instrument is often unacceptable. Firstly, it is far from everywhere that it is possible to increase the overall dimensions and the number of fastening holes. Secondly, it is quite expensive. And at last, thirdly, when identical instruments operate under the same conditions, they can demonstrate synchronous changing of there metrological characteristic that does not allow for finding out a growing defect by means of comparison of output signals and for preventing a metrological failure.

The redundancy of the structure of an intelligent instrument must be guaranteed by minimum technical means, but it must be enough for serviceable transducers, if a defect occurs, to give measurement information sufficient for preserving the error, though increasing but staying within the limits acceptable by a consumer.

Accordingly, the software of an intelligent instrument should stipulate an opportunity to determine quantity to be measured by several means.

If a malfunction appears, the data processing algorithm should be changed automatically taking into account localization and nature of malfunction.

Introduction of redundancy into a primary transducer and carrying out the maximum volume of measurement information processing on the level of an independent secondary transducer provides for the most effective results.

.To perform this very important function, the computation resource of an intelligent instrument can be redistributed and the service function of lower importance can be excluded.

Application of the information redundancy facilitates the development of operation algorithms of an intelligent instrument. However, it is necessary to take into account therewith that the information redundancy is more closely connected to specific operation conditions of an instrument and problems to be solved.

As the a prior information the data about permissible limits of input signal parameters in a specific situation and also about correlation dependencies between the total values which are measured by several instruments including a given intelligent transducer.

The basis for development of such systems (according to the given interpretation) is the invariance theory and the theory of noise-immune transmission of information.

The known documentary standards concerning intelligent measurement instruments and there measurement assurance do not cover completely the requirements to them and recommendations for their development stipulated by the above conception. Moreover, all of them have limitation due to the status of national documentary standards.

2.3. The examples of realization

At present, the number of publications devoted to the development of primary transducers for intelligent sensors of high reliability, has increased in connection with sharply growing requirements to the reliability of measurement information and the service life of measuring instruments built into the equipment.

For example, it is suggested in [6] to build a thermal transducer on the basis of junction of free wires. Two of them are made of the same material but have different diameters. The mentioned two thermocouple wires posses different susceptibility to the destabilizing factor that makes it possible to find out the effect of thermocouple aging and to apply the corresponding correction, if necessary.

It is suggested in [7] to use together a thermal resistance transducers and thermocouples in one sensor.

The effectiveness of the above instruments is illustrated by an example of the intelligent measuring and diagnostic instrument [3] developed under the authors' supervision. It has been operating during four years in the control and safety system of a nuclear power plant in Russia.

This intelligent instrument, which primary transducer operates in the first circuit of a nuclear reactor (temperature above 300 ^{o}C), strong radiation, pressure up to 16MPa, vibration) is intended for determination of the position of the control rod of a nuclear reactor and for diagnostics of the drive, which it is built into.

The primary transducer error is less than 0.5% over the whole range of influencing factors, the threshold sensitivity (an important parameter for the drive diagnostics) is not worse than 0.005%.

The life-time expectancy of the primary transducer is over sixty years.

To improve the information reliability and to reduce the maintenance expenses, the primary transducer has, alongside with the main functions, the structural redundancy: the number of sensing elements is higher than it is necessary by minimum to ensure the required accuracy. The information redundancy, i.e. a priory data about the features of the drive operation, is although used in the intelligent instrument.

As a result, the developed intelligent instrument ensures:

- filtration of noise, protection from interference, correction for effects of temperature variations, "aging" of materials and components, defects of contact connections,
- automatic check of metrological characteristic stability,
- diagnostic information about forecasted and found-out defects and recommendations in the text form for their elimination,
- maintenance of serviceability under disconnection or open-circuit or short – circuit of any primary transducer component, under disconnection of any part of the circuit from the sensor.

3. CONCLUSIONS

The concept of building intelligent measurement instruments with high reliability of information and verification interval commensurable with the service life has been suggested and proved by the example.

This concept stipulates changing the emphasis in metrological assurance of measuring instruments during their operation from the problem of periodic verification (using working standards) to the problem of intellectualization, introduction of the redundancy and organization of the metrological check of the metrological characteristic stability.

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