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COMPLEX APPROACH TO THE DEFINITION OF MEASUREMENT ERRORS

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Abstract - Complex approach to error definition residing in the fact that the error of measurement is considered as a uniform and indivisible whole, which is transformed with the change of the measurement modes, operation conditions and other factors. It differs from the standard elementary approach by that the resulting error of measurements, instead of its elementary components, is classified at once. In this case the variety of measurement modes and operation conditions is more fully taken into account, the transformation of errors is described from individual positions, the objectivity of their estimations and efficiency of methods of accuracy increase raises, experimental definitions may be simplified.

Keywords: measurements, errors, complex approach.

1. URGENCY AND CONSIDERABLE PROMISE OF THE PROBLEM

Frequency range and the amount of simultaneously measured parameters continuously extend, the conditions of measuring device (MD) operation becoming complicated. Occurrence of microprocessors and micro-computers has resulted in complication of algorithms and increase in volumes of the measuring information processing in measurements. The requirements to the accuracy of measurements simultaneously raise. This situation will not change in the foreseeable future [1].

Therefore the problem of definition and reduction of errors became one of the most urgent and promising problems of the science about measurements.

2. EXISTING METHODS OF THE SOLUTION AND THEIR LIMITATIONS

Now each factor influencing inaccuracy of measurements is taken into account by its elementary error. So, the intrinsic error of MD takes into account only internal noise appearing in a static measurement mode under normal operation conditions. The additional error of MD takes into account the influence of the external factor, while the dynamic error accounts for the lag in the established dynamic mode. The intrinsic and additional errors of MD are summarized separately. By dynamic characteristics of MD the dynamic characteristics of measuring systems (MS) are calculated and by them the dynamic errors of MS are found. Then the elementary errors of MS are summarized [2-4]. For MS with processors and errors of indications the methodical errors of the measuring information processing algorithms are added. Recently developed concept of measurements uncertainty [5] does not solve this problem and concerns first of all characteristics of errors.

Accuracy of measurements in raised as a rule by reduction of elementary errors and methodical errors of algorithms. By statistical processing of indications they simultaneously reduce some elementary errors varying at random.

2.1. Limitations

Such a solution of the problem has the following limitations [6].

1. The performance of the principle of elementary errors superposition is required.
2. There is no unity in the definition of the elementary errors characteristics that does not allow to find and to take into account the correlation between them. For example, the characteristics of the intrinsic error are found experimentally, and those of the dynamic error are calculated.
3. The transient modes of MS operation appearing just after the measured signals begin to influence them are not taken into account.
4. The division of errors into static and dynamic, systematic and random ones is subjective and depends on the chosen mathematical model of their formation.
5. The summation of systematic and random errors of measurements is carried out by means of different formulas and is not scientifically proved.
6. In experimental finding the characteristics of elementary measurement errors it is necessary to solve a task opposite to summation of the error characteristics.
7. The reduction of some elementary errors can result in the increase of others and does not guarantee the minimum of the resultant measurement error.

Because of these limitations the elementary approach to the definition and reduction of measurement errors can not be considered as strict.

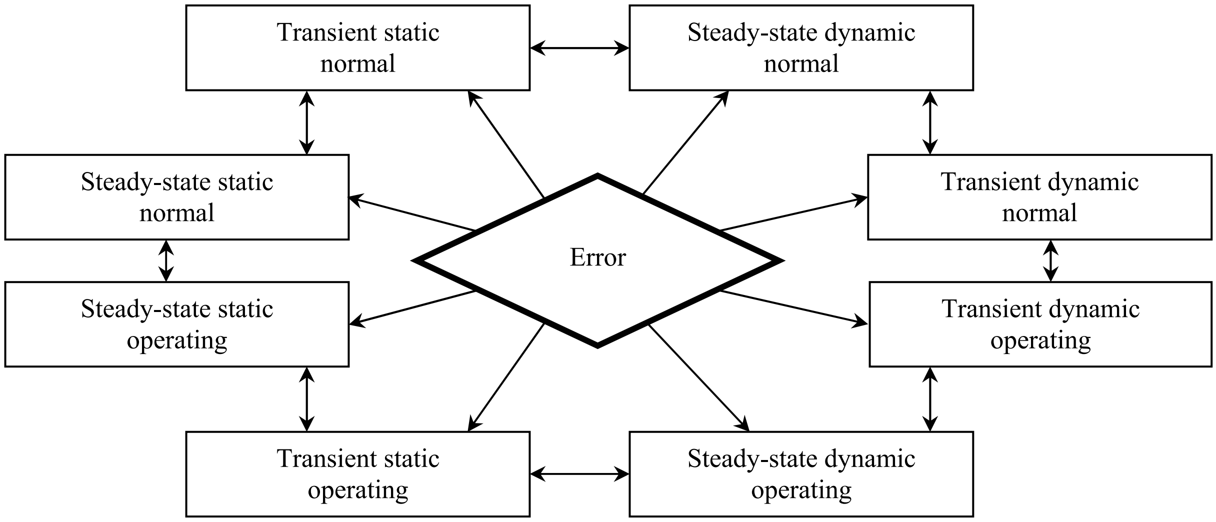

Fig. Errors classification according to the complex approach

3. SUGGESTED APPROACH

3.1. Essence of the complex approach

Recently the complex approach to the definition of measurement errors has been intensively developed [6]. Its essence implies that in any measurement modes and operation conditions the measurement has only one error equal to the difference between the measurement result and the true value of the measured quantity. This difference is transformed only with the change of measurement modes and operation conditions remaining in so doing uniform and indivisible.

3.2. Statements

The complex approach to error definition can be broken up into a number of the following statements.

1. The static error of measurements is considered to be a special case of an error in the dynamic mode, when the change in time of the measured quantity can be neglected [6-8].
2. The intrinsic error is considered as a special case of an error in operating conditions, when the external influences can be neglected [6].
3. The steady-state error is regarded as a special case of a transient error, when the transient processes can be neglected and the mode and conditions of measurement are considered to be established [6].
4. The methodical error of measurement is considered as a special case of instrumental error of the MD realizing the given MD algorithm with the equality of parameters of the latter to nominal values [6].
5. The error of measurement at any moment of time is considered as uncertainty of the measured signal left after the measurement. It is described as a posterior density of probability from which the characteristics of systematic and random errors are found as special cases.

Offered classification of errors according to the measuring mode and operating conditions is shown in the figure.

3.3. Distinction

The complex approach differs from the elementary one in the following.

1. The resultant error instead of its elementary components and characteristics is classified at once.
2. There are no elementary errors because of changes in measurement conditions and no instrument error which are not separated experimentally.
3. The transient and steady-state errors of measurement modes and conditions are entered.
4. The methodical error is distributed on realizing MD measurement method and algorithm and includes the error of the measurement method.
5. There is no subjective division of errors into systematic and random ones.

3.4. Advantages

These differences give the following advantages to the complex approach over the elementary approach.

1. They spare researchers the elementary errors summation.
2. They simplify any experimental finding of the error characteristics.
3. They take into full account the variety of modes and conditions of measurement realization.
4. The extended interpretation of a methodical error allows to reliably estimate the accuracy of measurements.
5. Abandoning the division of errors into systematic and random ones allows from the unified probability position to describe the measurement error transformation, raises objectivity of their estimations and correlates well with the international concept of measurements uncertainty [5].

4. CHARACTERISTICS OF MD ERRORS

4.1. Calculation

Despite the simplicity of the complex approach to the error definition its realization requires the adequate description of the measured signals, external influences, MD, MD verification methods on random signals and algorithms of readout processing. Therefore, normal Markoff's and Wiener's processes were advanced [6], the random signal with the unified law of distribution is offered [9], mathematical models of analog and analog-to-digital transducers [10-11] as well as measuring channels of closed and open structures are developed [6]. On their basis a set of methods and packages of the applied programs for account of the MD error characteristics are worked out [12].

4.2. Experimental definition

For checking the results of error calculations the methods and devices of the experimental finding the characteristics of MD errors on the closest to real random signals are developed, from which we shall note [13]. The results of the experiments which have been carried out in four institutes of Russia and Ukraine have confirmed the basic theoretical statements of the complex approach. So, for analog measuring transducers the discrepancy of the estimated and experimental error characteristics have not exceeded 4,2 % for harmonic signals and 18,5 % - for random ones. For analog-to-digital transducers these figures are 6,9 % and 21,9 % accordingly [14].

5. ERROR CHARACTERISTICS OF STATISTICAL AND SPECTRAL MEASUREMENTS

Another example of the effective application of the complex approach to the error definition are the statistical and spectral measurements [15]. It simultaneously takes into account a priory the information about the measured signal, level quantization and time sampling, final number of readouts and time of realization, the way of signal restoration between discrete readouts [16, 17]. It allows to plan measuring experiment in the optimal way.

6. INCREASE OF MEASUREMENT ACCURACY

The complex approach allows not only to correctly take into account the reasons and to describe the mechanism of measurement errors occurrence, but also to plan effective measures on their reduction or stabilization. So, methods and devices for dynamic MD gauging on random signals allowing in realization of readouts on MD input to take into account their lag and influence of the external factors are developed [18, 19].

For crucial measurements in unfavorable conditions of MD operation the effective methods and algorithms for detection and restoration of failure readout are developed [20].

For MD having reserve on speed of response the algorithms of error reduction are offered at the expense of averaging the MD indications. The recommendations for the optimal exchange of the MD speed of response on their accuracy are given [21].

The algorithms of statistical measurements are developed, in which at the expense of the correlation account of the nearest readout the measurement error of the probability characteristics of random processes decreases by 2-4 times [22].

7. CONCLUSIONS

Thus, the complex approach to the error definition allows to more precisely take into account the features of MD application during measurements in comparison with the well-known elementary approach. It allows to plan effective methods of immediate reduction of the resulting measurement errors. At this expense the measurement accuracy can be increased by 2-10 times.

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REFERENCES

[1] Proceeding XVII IMEKO World Congress "Metrology in 3rd Millenium", Dubrovnik, Crovatia, 2003.
[2] G.J. Born, E.J. Durbin, "Theory of Measurement", *Instruments and Control Systems*, № 11, 63-68, 1968.
[3] L. Merz, "Die Fehlerfortpflanzung in der Meβkette-Einekleine Fehlerheorie für Praktiker", *Archiv für Technisches Messen,* № 6, R81-R86, 1972.
[4] M.A. Zemelman, "Procedure of error calculation in information measuring system", *Izmeritelnaya tekhnika*, № 5, 6-9, 1973.
[5] Guide to the Expression of Uncertainty in Measurement: First Edition, ISO, Switzerland, 1993.
[6] A.I. Zaiko, *Accuracy of analog linear measuring channels in IMS,* Izdatelstvo standartov, M., 1987.
[7] T. Kalewski, "Analiza powstawania bledon statycznych i dinamicznych przy automatycznei kontroli wymiarow", *Pomiary, Automatyka, Kontrola,* № 9, 387-390, 1971.
[8] *Handbuch der industriellen Mestechnik*. 3 Aufgabe. Prof. Dr. P. Profos Heraufgeber, Vulkan-Verlag, Essen, 1984.
[9] A.I. Zaiko, "Random signal with uniform distribution", *Measurement Techniques,* v. 42, June, 11-13, 1999.
[10] A.I. Zaiko, "Dynamic Model of Bitwise-Balancing Analog-to-Digital Converter", *Measurement Technique,* v. 43, December, 627-631, 2000.
[11] A.I. Zaiko, "Dynamic Model of Bitwise-Balancing Analog-to-Digital Converter", *Measurement Techniques,* v.43, December, 627-631, 2001.
[12] A.I. Zaiko, V.K. Timerbaev, "A Set of Procedures and Application Programs for Computing Errors of the

Measuring Channels of Information Measurement Systems", *Measurement Techniques,* v.34, July, 118-119, 1991.
[13] Pat. 2024890 RF, "Device for static error definition in measuring devices"/ A.I. Zaiko. – Publ. 15.12.94. – Bul. № 23.
[14] A.V. Gryazin, A.I. Zaiko, A. Kh. Sakhipgareyev, "Experimental check of the general approach to error definition in measuring converters during transient modes" in proc. *Theory and designing automated control systems and their elements,* USATU, Ufa, 1996, 143.
[15] A.I. Zaiko, N.A. Zaiko, "Accuracy of statistic and spectral Measurements", *Proceeding XVII IMEKO World Congress "Metrology in 3rd Millenium"*, Dubrovnik, Crovatia, 2003, 1275-1279.
[16] A.I. Zaiko, "Theory of accuracy in statistic and spectral measurements", Vestnik USATU, № 2, 175-182, 2000.
[17] A.I. Zaiko, "Definitions and algorithms for measurement of ergodic processes characteristics", *Metrology,* № 4, 3-15, 2000.
[18] A.c. 1275343 USSR, "Device for gauging of measuring instruments"/A.I.Zaiko, V.M.Lisovsky, V.K.Timerbaev – Publ. 07.12.86.-Bul. № 45.
[19] A.I. Zaiko, A.V. Gryazin, "Device for gauging of measuring transducers on random signals", *Pribory I sistemy upravleniya*, № 4, 20-21, 1992.
[20] A.I. Zaiko, "Detection and restoration of abnormal readings in measuring channels", *Metroligy,* № 4, 3-12, 1992.
[21] A.I. Zaiko, "Decreasing the Errors of Measurement Cannels by Averaging Their Readings', *Measurement Techniques,* v.35, February, 999-1001, 1993.
[22] A.c. 1300511, USSR, "Device for calculation of mathematical expectation"/A.I.Zaiko – Publ. 30.03.87.-Bul. № 12.

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