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A.J. Jabiyeva

Azerbaijan State Oil Academy, Baku, Azerbaijan

UNIVERSAL TECHNIQUE FOR ERROR CORRECTION IN MEASUREMENT SYSTEMS

The main purpose of paper is the new technique for error correction in measurement systems development applicable to digital dynamic measurement of the scalar physical value. It is dictated by that at present existing methods of increase of accuracy of measurements are one-sided, i.e. they are not intended for suppression of resultant error all components.

Keyword: *Measuring, test and diagnostic work (MTDW), quality parameters (QP) , measuring-diagnosing systems (MDS),Systematic Error, Random Error, Measurement, Measurement System, Precision, Accuracy, Digital Filter, Correcting Filter.*

In information problems of quality assurance systems the large role is allocated to monitoring and measuring, test and diagnostic work (MTDW), which are made by the quality monitoring and management system. The specified tasks are directed on reception and use of the information about parameters of quality and reliability of furnishing options and final product for production management. The efficiency of the accepted decisions, formed managing influence and spent measures on quality assurance in a greater degree depends on completeness and reliability of data MTDW. Therefore responsible stages on a way of maintenance quality intelligent creation systems are development and introduction of the monitoring – industrial test and diagnosing modern methods.

The organization of monitoring problems set in industrial manufacture conditions is dictated by necessity to ensure guaranteed quality parameters (QP) of let out product. A necessity degree and organization level of the MTDW, set of monitoring functions produced at their realization depend on the nomenclature of QP, complexity and variety of let out product, from perfection technology equipment and process. On this at design automated monitoring system for mass manufacture of complex products during set of discrete or continuous – discrete technology cycles the problem of MTDW organization should be solved in view of the factors set and circumstances. To the similar factors are included the follow circumstances:

– plenty and variety of furnishing parts and modules of the final products, which are produced at separate levels of technology process (TP), in various sectors and sites and also at other enterprises of branch;

– not identical levels of perfection and stability of the base technology equipment (TE) operational characteristics owing to that the sensitivity of TP to indignation grows;

– plenty of TP stages and interdependence of its cycles covered by conveyors or assembly lines that causes necessity pf increase of throughput measuring-diagnosing systems (MDS) and puts a problem of synchronization between separate testing-diagnosing stations covering MTDW at various levels of TP.

Therefore the diverse approaches to MTDW organization and increase of technical monitoring system efficiency and quality assurance of finished products in this or that industry are possible. However the special interest represents consideration of the specified problems for the technical monitoring system with reference to discrete manufacturing processes (DMP). The operations of the control in DMP make. a significant part of technological process and are rather labor consuming. Therefore to optimization of the control in a work cycle of manufacture large attention is at the moment given

The main purpose of paper is the universal technique for error correction in measurement systems development applicable to digital dynamic measurement of the scalar physical values.

For solution of this problem the mechanisms of errors' accumulation process in measurement systems is reviewed and two cases have been selected:

- Random steady-flow process (without progressive accumulation of systematic component), i.e. not keeping essential low frequency components.
- Random non-steady process, when systematic error components' function has monotonically progressing nature in time.

In first case all errors of a metering device can legally be estimated as the unified centered random variable and to be characterized by a unified parameter- second central moment (dispersion), as in average value of power of an error change curve. Procedural component of error is represented by the separate component $\varepsilon_n^0(t)$ (quantization error in AD converters, rounding errors in computing devices, etc.). Hereinafter all random components of error are joint in unified component $\varepsilon^0(t)$ of resulting error – $\varepsilon_\Sigma(t)$ .Thus $\varepsilon^0(t)$ is the centered random stationary value accompanying outcomes of single uncorrected digital dynamic measurements of a physical value x(t) at the moments $t = t_i$ of observation in time in initial transformation (sensors) and normalization and analog-to-digital conversion subchannels.

At the second case of errors accumulation in a curve of error $\varepsilon_{\sum}$ (t) is present, except for random changes, also monotonically progressing, i.e. low frequency systematic component. It can be a consequent of a zero drift or sensitivity of metering equipment. Naturally, that the given component having also the random nature can not be esteemed as centered.

Let's take into account this progressing component of error accumulation processes and we shall include it in as systematic error $\bar{\varepsilon}(t)$.

The power of the centered random component of error defined by dispersion σ_{ε}^{2} does not depend on time. The power of progressing component monotonically increases in due course and consequently can not be reviewed disregarding of time both while metrology tests of a metering device, and during solving measurements accuracy increasing problem. Outgoing from this, progressing (drift) component of error is extracted from probabilistic consideration and considered it separately by moving mean.

The moving mean is necessary at metrology tests and in case of usage of averaging method of outcomes of repeated or multi-channel single measurements. However, because of absence of effect of suppression progressing component of errors of single measurements (including constant systematic), the averaging method is used basically in first case of the errors accumulations.

Thus, with reference to suppression of all components of measurement channel resulting error, the problem of a correcting filtration becomes considerably complicated. It dictates necessity of universal technique of measurement results correcting development.

Universality of the proposed method is interpreted as its relevance as to natures, and places of occurrence and previous background of error components of measurement outcome.

The struggle with accumulation of error progressing component conducts to necessity of its localization and suppression (as far as possible) within the single measurements. In a case of presence of the only centered fixed error as a result of single measurements the potent tool of suppression it is usage of averaging method. However, the combination of these two procedures of errors suppression within the framework of one common accuracy increasing method is rather problematic. Therefore are the balanced series of procedures for localization and suppression of all components of error detected and determined, which has resulted in developing a universal technique for correcting digital dynamic measurement results.

The main point of universal technique of digital dynamic measurements accuracy increase, offered us, consists in following.

The uncorrected outcomes of digital single dynamic measurements of physical quantity $x(t)$ is represent able by sequences of values for a system of equidistant points:

$$y_{1} = f_{H}(x) + \bar{\varepsilon}_{i} + \varepsilon_{i}^{0}, \quad i = 0,1,2,... \qquad (1)$$

Here: $f_{H}(x)$ is a nominal function of measurement channel transformation; $\bar{\varepsilon}(t)$ is a systematic error, ε_{i}^{o} is the centered random stationary value of total error.

With allowance for time histories, measurement value is represented as:

$$x(t) = x + \Delta x(t). \qquad (2)$$

Where x is a value of measured quantity in the beginning of measurement cycle; $\Delta x(t)$ is a measured quantity change per cycle of measurements.

Allowing (2) in mathematical model of transformation nominal function, we receive:

$$f_{H}(x_{i}) = \sum_{p=1}^{n} a_{pH}(x + i\Delta x)^{p-1}, i = 0,1,2,... \qquad (3)$$

Now systematic components of factors set of total error polynomial is represent able by the way:

$$\overline{\Delta_{p}}(t) = \overline{a_{p}}(t) - a_{pH} = \sum_{i=0}^{L-1} c_{pl} t^{l}, i = 0,1,2,... \qquad (4)$$

Taking into account of this expression, the systematic component of total error will be described by a polynomial:

$$\bar{\varepsilon}(t) = \sum_{p=1}^{n} \overline{\Delta a_{p}}(t) [x(t)]^{p-1}. \qquad (5)$$

Having substituted (2) and (4) in this expression, we shall receive:

$$\overline{\varepsilon_{i}} = \sum_{p=1}^{n} \left[\left(\sum_{i=0}^{L-1} c_{pl} t_{i}^{l} \right) (x + i\Delta x)^{p-1} \right], i = 0,1,2,... \qquad (6)$$

It is easy to make sure that allowing model (4), the random error ε_{i}^{o} of uncorrected measurement outcome is caused by the centered fixed random changes of polynomial factors (3):

$$\Delta^{0} a_{p}(t) = a_{p}^{0}(t) - a_{pH}. \qquad (7)$$

Thus, the polynomials (3) and (6) allow for change of measurement value while measurements cycle in correcting filtration frameworks of uncorrected measurements (1). Therefore, these models are relevant to dynamic measurements. Apart from it, model (6) allows for systematic changes of factors set $a_{p}(t), \quad p = 1,2,.....,n$ of measurement channel real transfer function.

If to suppose, that the measurements are carried out in real time, it is necessary to limit from above duration $T_{kop} = N_{kop} \cdot T_{o}$ correction cycle or at he expense of quantity N_{kop} of measurements in cycle, or sample time T_{0} (transient time of output signal $y(t)$ indications for preprocessing device). Therefore in models (3) and (6) laws of change $x(t)$ per cycle of corrections is adopted linear : $x_{i} = x + i\Delta x$ (where I is the moment of fulfillment i0th measurement inside cycle; $\Delta x = const$ is increment of measured step inside a cycle).

Basically obtained above models enable approximating chance $x(t)$ per tour corrections by non-linear models.

From expression (6) it is possible to receive models of dynamic errors of the firs and second types.

The firs type dynamic error is caused by changes of parameters of the actual transformation operator $A_p[\cdot]$, and the second type dynamic error – by the change of measured during measurement.

The model of first dynamic error can be received from (6), having accepted $\Delta x = 0$

$$\varepsilon_{\theta li} = \varepsilon_i^o + \sum_{p=1}^{n}\left(\sum_{i=0}^{L-1} c_{pl} t_i^l\right) x^{p-1},\ i = 0,1,2,... \quad (8)$$

For obtaining model of second type dynamic error it is enough to suspect, that the factors of the polynomial (4) $\{c_{pq}\}, q = 1,2,.....,L$ are identically equal to zero. With allowance for it we have:

$$\varepsilon_{\theta li} = \sum_{p=1}^{n} Cpq\left[(x + i\Delta x)^{p-1} - x^{p-1}\right],\ i = 0,1,2,... \quad (9)$$

Having applied Binomial theorem to models (3) and (6), and also allowing (7), sequence (1) is representable by the way:

$$y_i = p_{n-1}(i) + p_{n+L-1}(i) + \varepsilon_i^o,\ i = 0,1,2,... \quad (10)$$

Here $p_{n-1}(i) \equiv f_H(x_i)$ and $p_{n+L-1}(i) \equiv \overline{\varepsilon_i}$ are polynomials of discrete time i, – having orders n – 1 and n + L – 1 accordingly.

The tendered universal technique of correcting fil tration is reduced to implementation of following handling phases of uncorrecting measurands sequence (10).

The first stage is obtaining of finite differences (n+L) order with the purpose of suppression of polynomials in a right-hand member (10):

$$\left\{\Delta^{n+L} y_i\right\} = \left\{\Delta^{n+L}\varepsilon_i^o\right\}. \quad (11)$$

Second stage is recovery of sequence $\{\varepsilon_i^0\}$ by usage of multiple summation $\sum^{n+L}[\cdot]$ operators to sequences (11):

$$\left\{\sum{}^{n+L}\left[\Delta^{n-L}\varepsilon_i^o\right]\right\} = \left\{\varepsilon_i^o\right\}. \quad (12)$$

Here asterisk sign indicates that in outcome the estimations of sequence $\{\varepsilon_i^0\}$ receive.

The third stage is obtaining of n order finite differences for sequence (10):

$$\left\{\Delta^n y_i\right\} = \left\{\Delta^n p_{n+L-1}(i)\right\} + \left\{\Delta^n \varepsilon_i^o\right\}. \quad (13)$$

The fourth stage is recovery of sequences $\{P_{n+L-1}(i)\}$ and $\{\varepsilon_i^0\}$ from(13) with usage of the operator $\sum^n[\cdot]$:

$$\left\{\sum{}^n\left[\Delta^n y_i\right]\right\} = \left\{p_{n+L-1}^i\right\}^* + \left\{\varepsilon_i^0\right\}^*. \quad (14)$$

The fifth stage is introducing of the corrective corrections in sequence (10):

$$\left\{y_j^*\right\} = \left\{y_i\right\} - \left\{\sum{}^n\left[\Delta^n y_i\right]\right\} \equiv \left\{f_H(x_i)\right\}^*, \quad (15)$$

i.e. the solution (14) in expression (15) gives sequence $\{y_j^*\}$ of the corrected outcomes of digital dynamic measurements of a physical quantity x_i on a nominal transfer function. Having parameters of this function. we receive:

$$\left\{x_i\right\}^* = F_H^{-1}\left[\left\{y_i^*\right\}\right]. \quad (16)$$

Basically, the second stage for the purposes of errors correction is unnecessary, but this one is entered for the following statistical analysis of measurement channel random error. With the purpose of the analysis of systematic error of measurement channel it is enough to execute transformation of a kind:

$$\left\{P_{n+L-1}\right\}^* = \left\{\sum{}^n\left[\Delta^n y_i\right]\right\} - \left\{\sum{}^{n+1}\left[\Delta^{n+1}\varepsilon_i^o\right]\right\}. \quad (17)$$

It is obvious, that to this sequence it is better to apply a time-domain analysis.

Let's consider a principle of construction selfcorrected measurement channel, basing on a universal technique of measured accuracy increase.

According to model of the uncorrected outcomes of digital measurements the generalized flowchart of a selfcorrected measuring channel is represented by the way, shown on a Fig.1.

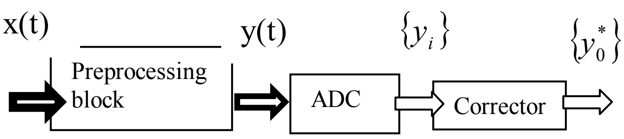

Fig. 1. The generalized flowchart of selfcorrecting measurement channel

The function of a corrector is the allocation of polynomial $\{p_{n-1}(i)\}$ from output sequence $\{y_i\}$, corresponding to the corrected outcomes (3) of sequence $\{x_i\}$ digital dynamic measurements of physical quantity x(t).

In Fig. 2, for the best comprehension of a problem of corrector synthesis, its input sequences are shown separately.

With reference to synthesis of finite memory discrete control systems the problem of synthesis is solved by means of r-th order differences an input signal. Thus is supposed, that the discrete system is under control $S(iT_0)$ and disturbing $V(iT_0)$ signals, and the control signal is the sum of two components:

$$S(iT_0) = g(iT_0) + \varphi(iT_0). \quad (18)$$

Where $g(iT_0)$ is slowly varying function of time, which is possible to present by the way of polynomial depending from iT_0 with final number of members r, and $\varphi(iT_0)$ and $V(iT_0)$ are random stationary functions of time with zero mean.

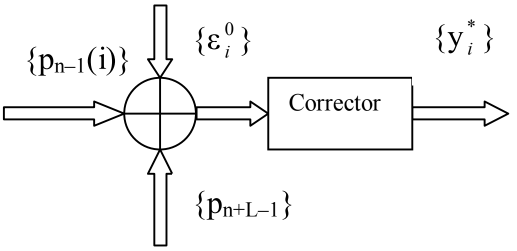

Fig. 2. Self correcting measurements channel with separate inputs

With the purpose of engaging to synthesis of r-th order finite differences, the systematic component of input signal (18) will represent by a polynomial of a degree r–1[1]:

$$g(iT_0) = g(0) - (iT_o)g(0) + ... + \frac{(iT_0)^{r-1}}{(r-1)!} g^{(r-1)}(0). \quad (19)$$

With allowance of this signal, the summary input signal looks like:

$$y(iT_o) = \varphi(iT_0 + g(iT_o) + V(iT_0)\,. \quad (20)$$

Further from a signal (20) undertakes the r order ascending difference:

$$\Delta^r y(iT_0) = \Delta^r \varphi(iT_0) + \Delta^r V(iT_0)\,. \quad (21)$$

Thus, as a result r-multiple usage of finite difference operation the polynomial in (20) is eliminated and the received signal (21) becomes stationary process with zero mean

$$\ldots/\Delta^r y(iT_0) = 0\,. \quad (22)$$

From the formula (22) it is visible, that the polynomial (19) factors do not influence the characteristics r-th increment of process (20). Therefore these factors can be known or unknowns, nonrandom factors or random variables of implementation of other process.

Last concluding has essential value at the solution of measuring problems, for which one always volume of the prior information about signals and noise (errors) is very limited. In our case the mentioned above statute is applicable to factors of polynomial (6) systematic component of error of the uncorrected outcome of measurement. Therefore in a problem, solved by us, it is necessary to know the order of polynomial (6), that is rather easily sold if to know the order of a polynomial nominal transfer function (3) and having accepted model (2) as changes of measured per correction cycle. The problem of synthesis of a corrector is difficult because of availability on its input of two polynomials and fixed random centered sequence (Fig. 2). However idea of formation by a corrector from input sequences of signals with stationary increments is rather useful to the solution of a problem of synthesis. By virtue of availability of two polynomials on an input of corrector the mentioned above stationarity procedure will be utilized by us repeatedly.

At design algorithm of a universal technique of accuracy increase was mentioned, that by virtue of a variety of model components natures (10), the complex errors suppression the uncorrected measurement can be reached by fulfillment of a series of correction stages.

Conclusion

Thus, the tendered method of accuracy increase is universal and effective for complex supression practically of all errors components of digital dynamic measurements $\{x_i\}$ outcomes in measurement channel during looping the uncorrected measurements with the subsequent correcting filtration on described above algorithm.

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Рецензент: д-р техн. наук, проф. Р.М. Маммадов, Азербайджанская государственная нефтяная академия, Баку.

УНИВЕРСАЛЬНАЯ ТЕХНИКА ДЛЯ ИСПРАВЛЕНИЯ ПОГРЕШНОСТИ В СИСТЕМЕ ИЗМЕРЕНИЯ

А.Дж. Джабиева

Анализируется техника для исправления погрешности в развитии систем измерения, применимом к цифровому динамическому измерению скалярной физической величины. Это диктует в существующих методах увеличения точности измерений, и является односторонними, т.е. они не предназначены для подавления возникшей ошибки во всех компонентах системы.

Ключевые слова: *измерение, испытательная и диагностический работа (MTDW), параметры качества (QP), диагностирующая система (MDS), систематическая ошибка, случайная ошибка, система измерения, точность, цифровой фильтр, корректирующий фильтр.*

УНІВЕРСАЛЬНА ТЕХНІКА ДЛЯ ВИПРАВЛЕННЯ ПОГРІШНОСТІ В СИСТЕМІ ВИМІРУ

А.Дж. Джабієва

Аналізується техніка для виправлення погрішності в розвитку систем виміру, застосовному до цифрового динамічного виміру скалярної фізичної величини. Це диктує в існуючих методах збільшення точності вимірів, і є однобічними, тобто вони не призначені для придушення виниклої помилки у всіх компонентах системи.

Ключові слова: *вимірювання, випробувальна і діагностичний робота (MTDW), параметри якості (QP), діагностуюча система (MDS), систематична помилка, випадкова помилка, система вимірювання, точність, цифровий фільтр, коректуючий фільтр.*