Patterns of calibration virtual characteristics

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Abstract. Analyzed patterns of calibration from binary modes the integral characteristics of the prototypes to multiple modes their derivatives with respect to the virtual characteristics of innovation in the adaptive range program controlled standardized measures. The author's innovations protected by patents for inventions of the Russian Federation prove the increase of metrological efficiency to the level of automatic calibration.

1. Introduction
At present, joint and aggregate measurements are realized by rigid calibration characteristics of statistical analysis of the non-normalized set of measurement and control variables, dictated by the hardware-controlled structure of highly specialized testers, for direct and indirect measurements [1, 2]. The calibration characteristics of the testers are inadequate to the physical phenomena due to the set due to the set of non-normalized coefficients, identical to the number of measurement and control variables, the lack of adaptive parameters and stores of calibration measures for automatic normalization of the samples of the actual results of joint and cumulative measurements. Low metrological efficiency of testers is limited to hardware-driven assessment of non-normalized multiple conversion results at the expense of the standard algorithms of differentiation, mimicking a primitive algorithm "differential relations" [3] the graphical analysis automation [4-10]. The difference ratio algorithm forms approximate characteristics of derivatives due to the linear approximation of the set of measurement and control variables with uncertain coefficients regulated by the subjective boundaries of the difference range exceeding the differentiation limits by several orders of magnitude. The absence of mathematical models and identical characteristics of the higher order of differentiation leads to low-efficient calculations of informative parameters of calibration characteristics of speed and acceleration with increasing noise level due to temperature, time and parametric drift of the primordial.

For the improvement of computer automatic control it is possible to replace the standard algorithm of tester's calibration on the information technology using the calibration of virtual characteristics. This replacement may improve metrological efficiency to the level of automatic control. The purpose of the study: improved metrological performance to the level of automatic control through information technology is the calibration of the virtual characteristics. To achieve the goal we have to perform standard modes and automated control testers for the subjective algorithms differential relations; then, to identify patterns of auto-calibration for virtual characteristics; prior to create optimization algorithms are the limiting parameters derived by the integral of the function of pulse dynamic characteristics (PDC); and, finally, to prove the metrological efficiency of the technology of calibration by virtual characteristics for the design of computer systems of automatic control.
2. Mathematical software
According to the information concept of integration of information processes [1-3], differentiated according to the principles of microelectronics, mathematical software is developed according to the laws of redundancy from nonlinear models and methods of statistical analysis and iterative synthesis to the information technology of designing microprocessor-based energy saving and power supply, analytical control and biomedical monitoring with adequate experimental physics automatic methods of adaptive control with linear measurement modes and optimization parameters of linear and virtual characteristics, normalized by exemplary measures of range boundaries.

The architecture of microprocessor means of energy saving and power supply technologies, analytical control and biomedical monitoring is regulated by mathematical software. Mathematical support is an indivisible set of models and methods of their design, methods and algorithms of analytical control. The universality of mathematical support is determined by structural optimization when choosing a model (physical, mathematical and substitution) and the method of their design (principles, number and calculation), as well as parametric optimization dictated by measurement methods (calibration, correction and calibration) and identification algorithms (random variables and approximate coefficients of statistical analysis, normalized samples and optimization parameters of analytical synthesis) [11-14].

The indivisibility of the set of mathematical support is due to the information concept of integration of information processes and information principles of differentiation of components of mathematical support. The principles of analogy and equivalence, inversion and symmetry systematize the regularities of the methods ofnumeration and calculus in the information technology of designing microprocessor means, and in particular, universal mathematical software with consistent components.

The regularities of mathematical support are most clearly represented by calibration in the standard binary mode of analogues and in innovations in virtual characteristics of analytical synthesis of algorithms for optimization of calibration characteristics [11].

3. Binary modes
Binary modes [2,10,11] are a particular result of power modes for the degree \( n = 2 \) multiple of two, and the power polynomial is represented by a square equation. Binary multiplicity on the degree reduces the order of quadratic functions, and solving linear equations simple and technological, in an explicit form with a precise algorithm, eliminating the sequential approach and the iterative analysis.

For pulse dynamic characteristics (PDC) at binary time intervals \( t_2 = 2t_1 \), when \( i = 1,2 \), the systems of equations are valid

\[
\begin{align*}
U_i &= E(1 - e^{-t_i/T}) \\
t_i &= -T \ln(1 - U_i / T)
\end{align*}
\]  

(1)

The time constant \( T \) is found from the ratio \( U_2/U_1 \) of the direct system of equations (1) and after logarithm is represented explicitly by the algorithm for calculating the time constant

\[
T = -t_i / \ln(U_2 / U_1 - 1)
\]  

(1a)

Similarly, the limit potential \( e \) is calculated from the binary multiplicity \( t_2/t_1 = 2 \) of the inverse system of equations (1)

\[
E = U_1 / (2U_2 / U_1 - 1)
\]  

(1b)

The elegance and explicit form of the algorithms (1a, b) are due to the reduction technique to the linear dependence of the square equation as a particular solution of the power polynomial for the binary multiplicity of degree \( n = 2 \). However, the binary characteristics reduces the flexibility of the modes by an order of magnitude and, as a consequence, limits the range width by an order of magnitude at a fixed accuracy or regulates the error by an order of magnitude at a given range of analytical control. Simplicity and manufacturability of binary mode algorithms are of the greatest
value for calibration characteristics of testers with a rigid structure and are the basis of GOST rules for design according to the standards of highly specialized measuring instruments.

The practical significance of binary regimes is proved by new technical solutions at the level of inventions of the Russian Federation: "a method for determining the components of the impedance of a biological object" [2] and "a method for determining the dynamics of the erythrocyte sedimentation rate" [7].

The anti-derivative \( PD_t \) is formed by equations (1) with real parameters \( T \) and \( E \) obtained by algorithms (1a) and (1b) of optimization due to the normalization of the known samples of the boundaries \( U_1 \) and \( U_2 \) of the adaptive range. However, derivatives from primitive characteristics classically create graphical analysis on iterative algorithms.

4. Graphical analysis

Graphical analysis organizes the derived characteristics of the current and of the slope of iteration-governmental algorithms differential relations:

\[
i_k = A \frac{U_{k+1} - U_k}{t_{k+1} - t_k}, \quad j_k = B \frac{j_{k+1} - j_k}{t_{k+1} - t_k}, \tag{1c}
\]

where \( k \) is the number of iterations, \( k = 1, n \); \( A \) and \( B \) are the coefficients of the correction current \( i_k \) and the slope of \( j_k \).

Algorithms (1c) approximate current \( i_k \) and \( j_k \) on the slope of the linear representation of the differential relations without taking into account the mathematical models being based on the experimental measurements and management.

Table 1 systematizes the characteristics of the current \( i_k \) and steepness \( j_k \), implemented algorithms (1c) difference relations with correction factors \( A = 1.25, B = 1.23 \). The deviation of the difference characteristics of the current \( i \) and the steepness \( j \) from the equivalents \( I, J \) estimate the relative errors \( \varepsilon_i \) and \( \varepsilon_j \).

Table 1. Assessment of differential and virtual characteristics.

| Parameter | Calculated values |
|-----------|-------------------|
| \( i, c \) | 1 2 3 4 5 6 7 8 9 10 11 12 13 |
| \( U/B \) | 1.42 2.33 2.92 3.30 3.55 3.71 3.81 3.88 3.92 3.95 3.97 3.98 3.99 |
| \( i, A \) | 1.14 0.74 0.475 0.31 0.20 0.125 0.088 0.050 0.038 0.025 0.013 0.009 - |
| \( j, A/c \) | 0.492 0.326 0.203 0.135 0.092 0.048 0.047 0.015 0.016 0.015 0.008 - - |
| \( I, A \) | 1.13 0.73 0.47 0.305 0.197 0.127 0.082 0.053 0.034 0.022 0.014 0.009 - - |
| \( J, A/c \) | 0.493 0.319 0.206 0.133 0.086 0.056 0.036 0.023 0.015 0.010 0.006 0.004 - - |
| \( \varepsilon_i,\% \) | -0.9 -1.4 -1.1 -1.6 -1.5 -1.6 -7.3 5.7 -11.8 -13.6 13.2 13.4 - - |
| \( \varepsilon_j,\% \) | 0.2 -2.2 1.5 -1.5 -7.0 14 -31 35 -6.7 -55 -21 - - |

Table 1 shows an increase in the steepness error \( \varepsilon_j \) by an order of magnitude relative to the current error \( \varepsilon_i \). The adequacy of the characteristics of the full-scale experiment is estimated by the reproducibility of the limit parameters \( T^\Delta \) and \( E^\Delta \) the iteration with respect to the equivalents of \( T \) and \( E \) by the relative error \( \varepsilon_T^\Delta \) and \( \varepsilon_E^\Delta \) (table 2).

Qualitative analysis shows (figure 1) overestimation of the amplitude of the graphical analysis of the current \( i_k \) and the steepness of \( j_k \) relative to the equivalent characteristics \( I \) and \( J \) due to the increased values of the iterative parameters \( T^\Delta \) and \( E^\Delta \) identification with the real \( T \) and \( E \)
equivalents. Quantitative analysis (table 2) proves the evaluation of graphical analysis of the parameter $\Delta \Theta$ with an error $\epsilon_\Theta$ of up to 1.5%, and for the parameter $T^\Delta$ with an error $\epsilon_T$ above 10% (figure 1).

**Table 2.** Assessment of parameters of differential and virtual characteristics.

| Parameter | Calculated values |
|-----------|-------------------|
| $t, \, c.$ | 1 2 3 4 5 6 7 8 9 10 11 12 13 |
| $U, B$    | 1.42 2.33 2.92 3.30 3.55 3.71 3.81 3.88 3.92 3.95 3.97 3.98 3.99 |
| $T^\Delta, c.$ | 2.32 2.27 2.34 2.30 2.17 2.72 1.87 3.33 3.38 1.67 1.65 - - |
| $E^\Delta, B$ | 4.06 4.01 4.03 4.01 3.98 4.04 3.97 4.05 4.01 3.99 3.99 - - |
| $E^*, B$   | 4.01 4.00 3.99 4.00 4.00 3.99 3.99 4.00 4.03 4.00 4.00 4.00 - - |
| $\epsilon_T^\%, \%$ | -1.18 -0.9 -2.2 -0.28 5.1 19 18 -46 -3.7 27 28 - - |
| $\epsilon_T^*, \%$ | 0.09 0.04 0.44 -0.13 -0.04 0.9 0.44 -0.44 0.9 0.9 0 -1.76 - |
| $\epsilon_E^\%, \%$ | -1.54 -0.24 -0.79 -0.30 0.38 -0.89 0.63 -1.17 -0.26 0.21 0.24 - - |
| $\epsilon_E^*, \%$ | -0.25 -0.01 0.19 -0.01 -0.03 0.05 0.08 -0.05 -0.68 0 -0.07 -0.04 - |

**Figure 1.** Pulse dynamic characteristics of tension (1, 2), current (3, 4) and steepness (5,6): 1, 3, 5 – virtual; 2, 4, 6 – differential.

Analytical algorithms for determining informative parameters in explicit form and their original method of differential calculus are valuable, but the complexity of the technical implementation minimizes the metrological efficiency due to the low reproducibility of the speed and acceleration characteristics. This is due to the experimental noise voltagem due to the influence of random perturbations from the temporal, temperature and parametric drift.

Binary modes of graphical analysis initialize the replacement of the rigid structure of highly specialized testers with a fixed calibration characteristic to the flexible architecture of the matrix association of computer analyzers with calibration due to the highly efficient replacement of the binary multiplicity by the $n$-dimensional dimension, an example is the methods of control by virtual characteristics.

5. **Patterns of virtual characteristics**

The calibration characteristics of the virtual [4-7] organizes the optimization algorithms are the limiting parameters derived for integral functions. Show virtual calibration for example, PDC current realized at derivative time PDC (1) voltage
\[ U' = C \frac{dU}{dt} = C \frac{dE(1 - e^{-t/T})}{dt} = I, \]

where \( C \) is the capacitance and \( I \) is the electrical current. After taking the derivative, we find the current

\[ I = C \frac{E}{T} e^{-t/T} = I_0 e^{-t/T}, \quad (2) \]

where \( I_0 \) is the initial (limit, maximum) current at the initial time \( t = 0 \). The physical meaning of the initial current \( I_0 \) does not follow from the limit \( \lim_{t \to 0} I = I_0 e^{-t/T} \) fits and patterns

\[ \lim_{t \to 0} I = I_0, \]

What corresponds to the maximum current limit, informative parameter of the virtual calibration characteristic (2) in the form of a pattern – current optimization

\[ \text{opt } I_\text{opt} = I_0. \quad (2a) \]

The physics of the \( I_0 \) parameter is not obvious from the model (2)

\[ I_0 = C \frac{E}{T} = \frac{CE}{CR} = \frac{E}{R}, \quad (2b) \]

since the ratio of the steady-state voltage \( E \) to the active resistance \( R \) is called current.

Informative parameters can serve not random variables: current \( I \) time and \( t \), but only the limit parameters of the virtual PDC: the initial current \( I_0 \) not (2a) and the time constant \( T \) – the time interval when the current \( e^{-t/T} \) times less than the current limit \( I_0 \) not. This rule follows from the limit

\[ \lim_{t \to T} I = I_0 e^{-T/T} = I_0 / e, \]

where \( e = 2.7(1828) \) is the base of the natural logarithm.

6. The calibration characteristics of the virtual

Analytical method [3] differs from the graphical analysis by registration of the velocity \( \dot{U} \) and acceleration \( \ddot{U} \) of the diagram \( U(t) \) for \( n \) response measurements (figure 1, graph 2). The algorithms for calculating the parameters are found by a mathematical model PDC \( U = U(E, T, t) \) differential equation of the first order

\[ T \ddot{U} + U = E. \quad (3) \]

Formula (3) allows determining only one of the required parameters depending on the value of the other.

For independent algorithms of calculation of informative parameters the second relation after differentiation on time in the form of the differential equation of the second order is found from model (3) \( T \dot{U} + \ddot{U} = 0 \). An algorithm for determining the time constant \( T \) is obtained from the linear expression

\[ T = \frac{-\dot{U}}{\ddot{U}}, \quad (3a) \]

as the ratio of velocity \( \dot{U} \) to acceleration \( \ddot{U} \) diagram \( U(t) \). Substituting the expression (3a) into the model (3) reveals the algorithm for determining the steady-state potential \( E \)

\[ E = U - \frac{\dot{U}^2}{\ddot{U}}. \quad (3b) \]
In practice, the algorithms (3a) and (3b) provide a graphical analysis of algorithms differential relations (1c) in the registration process through equal time intervals $t_i$ of the instantaneous values of $U_k(t_k)$ diagram $U(t)$, to calculate the increment $\dot{U}_k(t) = U_{k+1} - U_k$ in the interval $\Delta_k = t_{k+1} - t_k = t_0$ and calculating the second derivative $\ddot{U}_k(t) = \ddot{U}_{k+1} - \ddot{U}_k$ over time $\Delta_k$ and $\Delta_{k+1}$ on the interval $2t_0$.

Mathematical support of the analytical method is systematized in table 1. Table 2 shows the values with the calibration parameters $T^*$ and $E^*$ of the virtual characteristics.

The adequacy of the virtual characteristics of the current $I$ and the steepness $J$ proves the reproducibility of the limit parameters $T^*$ and $E^*$ optimization algorithms (3a) and (3b) with respect to the equivalents $T$ and $E$ on the relative error $\varepsilon_T^*$ and $\varepsilon_E^*$.

The qualitative analysis confirms the identity of the virtual characteristics of the current $I$ and the steepness $J$ to the equivalents of the current $I_\epsilon$ and the steepness $J_\epsilon$ of the full-scale experiment (figure 1) due to the identity of the parameters $T^*$ and $E^*$ virtual characteristics of the equivalents of $T$ and $E$ reference characteristics. Quantitative analysis (see table 2) consistent with the qualitative assessment of the virtual parameters $T^*$ and $E^*$ with $\varepsilon_T^*$ and $\varepsilon_E^*$ the relative error is not higher than 1%, which is one or two orders of magnitude lower than the graphical analysis of the difference relations $\varepsilon_T^*$ and $\varepsilon_E^*$ (figure 2).

The main advantage of the analytical method over graphical analysis is the automatic control of parameters due to mathematical support adequate to the physical and chemical process of control.

Consequently, it is proved that the increase in the order of metrological efficiency to the level of automatic control due to information technology calibration of virtual characteristics for the design of computer systems of automatic control.

The theoretical novelty of calibration is confirmed by the innovations of automatic control on virtual characteristics, made at the level of inventions and protected by patents of Russia. Select the method of determining the moisture content of wood [7], a method for determining the impedance components of a biological object [9] and a method for determining the dynamics of erythrocyte sedimentation rate [14].

Simple algorithms explicitly allocate a virtual calibration for the characteristics of the other power modes. To exclude random error approximant derived characteristics of informative integral limit parameters through a mathematical model that is due to the virtual dimension that reflects the substance and calibration name in the "virtual" characteristics.

Power modes are developed from successive iterative approximation to binomial decomposition to multiple modes by virtual characteristics to improve metrological efficiency, namely, methodological and dynamic error due to mathematical modeling of the actual characteristics of the experiment. Improving the speed and accuracy of automated interfaces microprocessor means demanded
linearization transformations of information that are possible with the implementation of the linear modes.

**Conclusion**

According to the concept of information integration of information processes, differentiated by the principles of microelectronics, mathematical support is developed according to the laws of redundancy from nonlinear models and methods of statistical analysis and iterative synthesis to the information technology of design of microprocessor energy saving and power supply, analytical control and biomedical monitoring with adequate experimental physics automatic methods of adaptive control with linear measurement modes and parameters of optimization of linear and virtual characteristics normalized by exemplary measures of the range boundaries. At the same time, the components of mathematical support has been developed including:

- methods of calibration from binary modes the integral characteristics of the prototypes to multiple modes their derivatives with respect to the virtual characteristics of innovation in the adaptive range program controlled standardized measures.
- binary modes initialize the replacement of the rigid structure of highly specialized testers with a fixed calibration characteristic to the flexible architecture of the matrix association of computer analyzers with calibration due to the highly efficient replacement of the binary multiplicity by the $n$-dimensional dimension, an example is the methods of control by virtual characteristics;
- calibration of the characteristics of virtual organizing optimization algorithms are the limiting parameters for derivative integral functions; algorithms are used to optimize virtual PDC a valid characteristic of a specific physical process; simple algorithms to explicitly allocate a virtual calibration for the characteristics of the other power modes.
- prove an order of magnitude increase in the metrological efficiency to the level of automatic calibration of the author's innovations protected by patents for inventions of the Russian Federation. Replace the calibration parameters of the statistical analysis on the virtual calibration with optimization algorithms are the limiting parameters for the normalized measures of the boundaries of the adaptive range organizes analysis and synthesis of the testers in the information technology design of automatic microprocessor-based systems.

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