LAPLACE MODEL OF TRANSFORMATION FOR OPTIMIZATION OF MEASURING SIGNAL IN NON-UNIFORM FLOW OF LIQUID

Genadijs Moskvins, Evelina Spakovica, Artjoms Moskvins, Anastasija Sahtarina
Latvia University of Agriculture
logicor@llu.lv

Abstract. In the article the main results of theoretic analysis and experimental researches of new possibilities for development of intelligent sensors and measuring instruments for the use in the communal service system of commercial accounting of energy resources in separate apartments are submitted. The determining of the moment of automatic correction of an error as the function of deviation of errors is reflected. The principal electric scheme and algorithm for correction of errors are submitted. The main results of elaboration of intelligent system for commercial accounting and saving of energy resources in apartments of consumers', also the theoretical substantiations and practically useful conclusions are reflected. On the basis of analysis and synthesis, experimental, analytical, mathematical, physical and metrological models a new type of intelligent methods of measuring and an automatic method for correction of errors by using operating microcomputers was elaborated. A mathematical model of automatic correction of errors by using of the Laplace p-transformations method is submitted.

Introduction

For development of intelligent measuring instruments and electronic sensors (PMT) of binary type are preferable, where two stable states of electronic key exist. In the conditions of non-uniform flows of liquids such choice is decisive from the point of view of simplicity, information flow conciseness in the channel of data corresponding, signal energy capacity, interface problem simplification and quick calculation of error correction coefficients. Intelligent measuring instruments and electronic sensors (PMT) of binary type are preferable at a full informational adequacy to signals of analogous types (according to Kotelnikov's theorem) [1 – 4].

Further on the principles of synthesis of intelligent discrete mathematical correction model by using the theory of discrete mathematics and Laplace p-transformations a new type of intelligent measuring devices "Logicor" and the method "Logitest" for automatic correction of errors by using micro-computers was elaborated.

Methods and materials

The intelligent expert system "Logicor" includes devices for measurement of consumption of cold and hot water, thermal and electric energy, also gas in the automated technological processes, in separate apartments, in housing and the communal service system. The high technology methods and devices "Logicor" contain programs "Logitest" for metrological certification and estimation of accuracy, including the algorithms of error correction, the communication interfaces of the electric devices and radio systems, special interface for automatic data accumulation and their accuracy analysis, Fig. 1. The basic results are formed in a complete agreement of the existing notions, data, level of knowledge about the investigation process and objects with the trend being towards the convergence of development an intelligent technology to estimate the error factors and measure the accuracy of flowmeters. The analytical research was focused on elaboration of mathematical models of digital correction of intelligent measuring systems in non-uniform flow of liquids [1; 3; 4]. The assessment of the results was carried out using the weighing method [1; 2].

The intelligent measuring system "Logicor" allows providing preliminary mathematical, physical and metrological modeling of the process of measurement on a place of measurement in real apartment conditions. It guarantees more exact both, authentic results of measurements and allows providing faultless accounting of the consumed energy resources. Besides, optimized applied programs, algorithms, "know-how", processors, effective radio-frequency devices, the full set of components for the system of intellectual measurements of the quantity of cold and hot water, heat, gas and quantity of the consumed electricity are provided [1; 2; 5 – 8]. The main problem of the traditional methodological approach in the elaboration of intelligent sensors very often in the measuring process does not provide sufficiently complete knowledge about all the inner processes in the object under exploration because the functional structure of the synthesized device is oriented only towards the realization of in advance programmed functions.

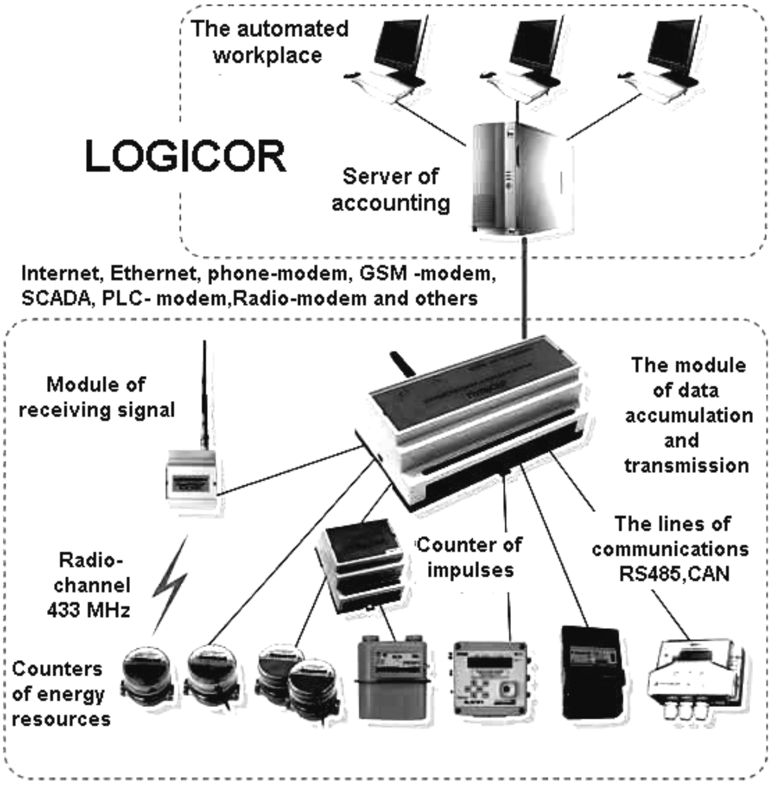

Fig. 1. **Intelligent expert system "Logicor" for commercial accounting of energy resources**

Results and discussion

In the article the elaboration of models for automatic correction of error on the basis of the intelligent primary measuring transducer (PMT), binary signal and statistic methods of measurement computer results processing are discussed, Fig. 1 – 2.

The results of the scientific work contain the researches of development problems of automatic measuring, dosing, accounting and saving of energy resources in separate apartments and houses on the basis of analysis and synthesis, experimental, analytical, mathematical, physical and metrological models by means of elaboration of intelligent methods of measuring and error correction.

The following indices are offered as the main criteria of statistical control preciseness of intelligent measuring systems:

- preciseness coefficient K_{nd} of nominal dose:

$$K_{nd} = \frac{\Delta_{sda}}{X_{nd}},$$

where $\Delta_{sda} = (X_f - X_{nd})$ – absolute error of separate dose;
X_f – actually measured volume of separate dose;
X_{nd} – nominal volume of separate dose;

- preciseness coefficient K_{kd} of measuring medium total quantity:

$$K_{kd} = \frac{\Delta_{ska}}{X_{kd}},$$

where $\Delta_{ska} = (X_f - X_{kd})$ – absolute error of total volume;
Δ_{ska} – actually measured total volume;
X_{kd} – nominal volume;

- preciseness coefficient relatively to admitted metrological norm of separate nominal dose K^d_{mn} and for total nominal amount K^k_{mn}:

$$K^{d}_{mn} = \frac{\Delta_{sd}}{\Delta_{dp}} \text{ and } K^{k}_{mn} = \frac{\Delta_{sk}}{\Delta_{kp}} 100\,\% ,$$

where Δ_{dp} and Δ_{kp} – metrological norm for separate nominal dose and for the total volume;

- preciseness coefficient relatively to admitted random deviation of separate dose K_{ds} and nominal volume K_{ks}:

$$K_{ds} = \frac{\sigma_d}{\sigma_{dp}} \text{ and } K_{ks} = \frac{\sigma_k}{\sigma_{kp}} ,$$

where σ_d and σ_k – actual standard deviation for separate dose and for total volume;
σ_{dp} and σ_{kp} – their metrological norm of standard deviations;

- variation coefficient

$$K_v = \frac{\sigma_{d,k}}{X_c} ,$$

where $\sigma_{d,k}$ – preciseness parameter (standard deviation), X_c – average value.

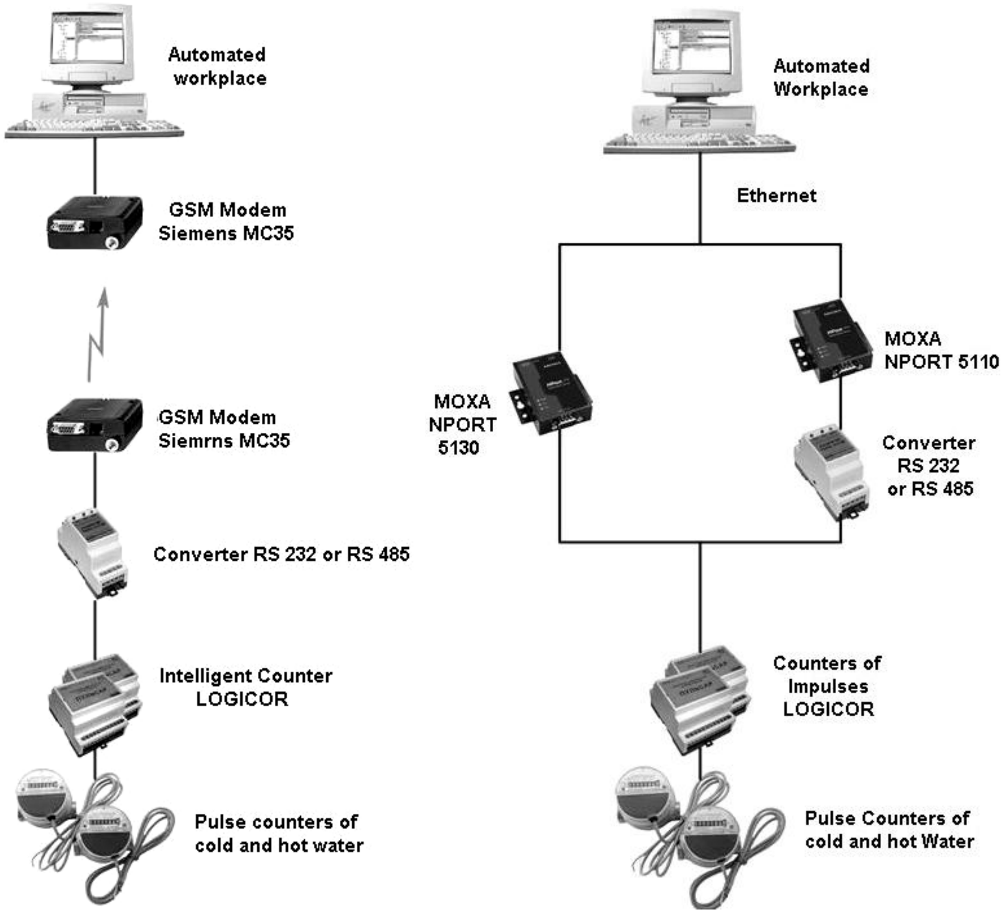

Fig. 2. **Elaboration of intelligent system "Logicor" for commercial accounting of cold and hot water**

In the process of flowmeter exploitation in real conditions due to mechanical wear of PMT, changes of technological, constructional, physical-chemical properties of liquids, changes of condition of measuring and other known and unknown reasons, deviation of nominal error level are possible when the error exceeds an admitted standard metrological norm.

Therefore, in this case it is offered to use the metrological calibration of PMT by the method of utmost error. Such metrological approaches are used, if an error of measuring should not exceed the upper and low limits of the metrological norm [1; 2; 5 – 8].

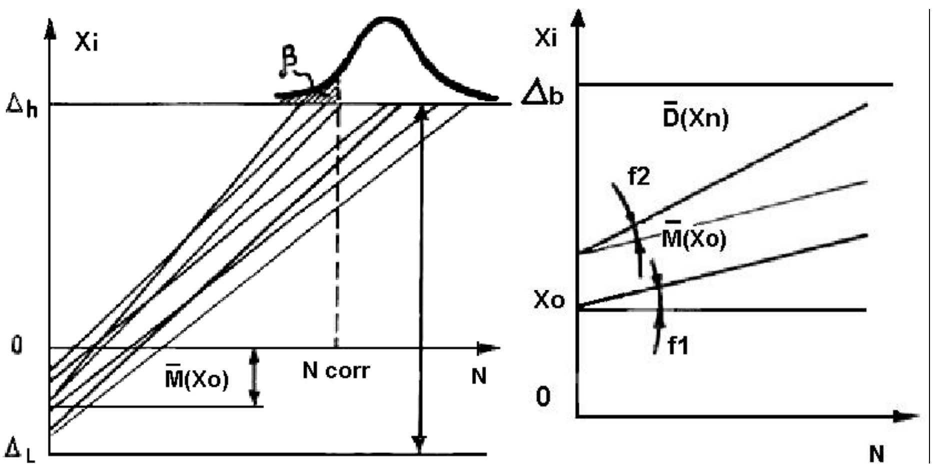

Fig. 3. **Determining of the moment of correction of an error, where deviation function of PMT errors is $V = \mathrm{tg}\varphi_1$, $W = \mathrm{tg}\varphi_2$**

The following estimations are offered as the main metrological characteristics of the intelligent measuring system "Logicor":

σ_d – magnitudes of random error deviation;
$M(x_0)$ – average error magnitude of flowmeter ;
σ_{xo}^2 – dispersion of error of flowmeter optimal dose;
$M(V)$ – magnitude of average speed of deviation of error from a metrological norm of optimal dose;
σ_v^2 – dispersion of speed of deviation of error from a metrological norm;

On the basis of the experimental researches the corresponding nomograms were elaborated, which allow to define the optimal moments for automatic error correction of flowmeters. For example, Fig.4 shows linear (Fig. 4a) and nonlinear (Fig. 4b), $M(X_n) = M(X_o)N^b$, $K_1<5$, $K_1 = \Delta/K_\sigma\sigma_t$ typical characteristic of flowmeter for initial setting of PMT optimal separate dose.

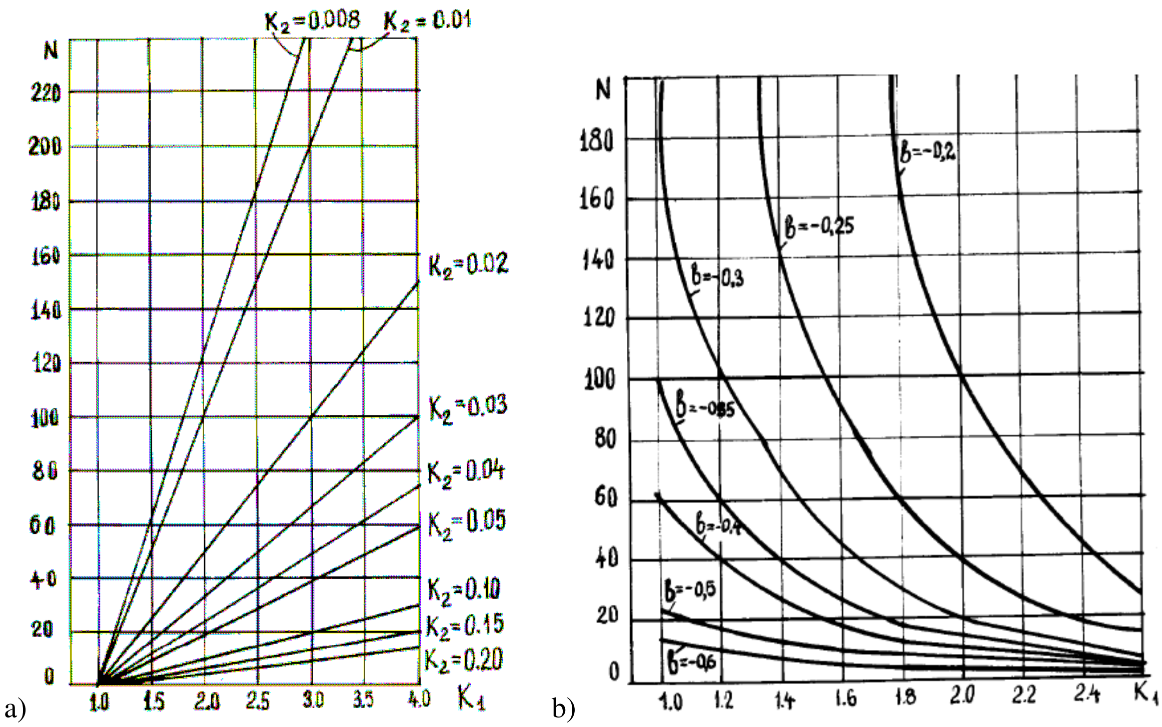

Fig. 4. **Nomograms for determining an optimal time moment for automatic correction of error in case, if deviation of PMT error is linear (a) and nonlinear (b), $M(X_n)=M(X_o)N^b$, $K_1 < 5$, $K_1= \Delta/K_\sigma\ \sigma_t$**

In Fig. 5 nomograms for determining an optimal time moment for automatic correction of error are shown, in case if deviation of PMT error is nonlinear (lg$T$, P_1, $P_2 < 1200$; $P_1 < 700$, $P_2 < 0.1$). That allows by means of the offered algorithms (Fig. 6b) to carry out automatic metrological accuracy control of intelligent means of measurement in real conditions. The conception of researches experimentally is fully proved. That allows already using patented methods and devices "Logicor" in praxis. The results allow us to make conclusions that the hypothesis about the possibility of development of the existing measuring systems by means of the offered intelligent methods and devices "Logicor" completely proved to be true [3; 4; 9 – 19]. The carried out experimental tests of the elaborated methods for accuracy control of flowmeters, metrological and analytical models, as well as of error correction algorithms proved the accepted scientific theses and adequateness to the physical models of the processes.

The main advantages of the offered intelligent measuring systems are accuracy which can be very simply achieved in real conditions by means of use of error correction algorithms, simplicity and reliability of the primary measuring transducer (PMT), possibilities of statistic analysis, control and preciseness regulation in on-line mode using microcomputer that is an integral part of the measuring system (Fig. 6a).

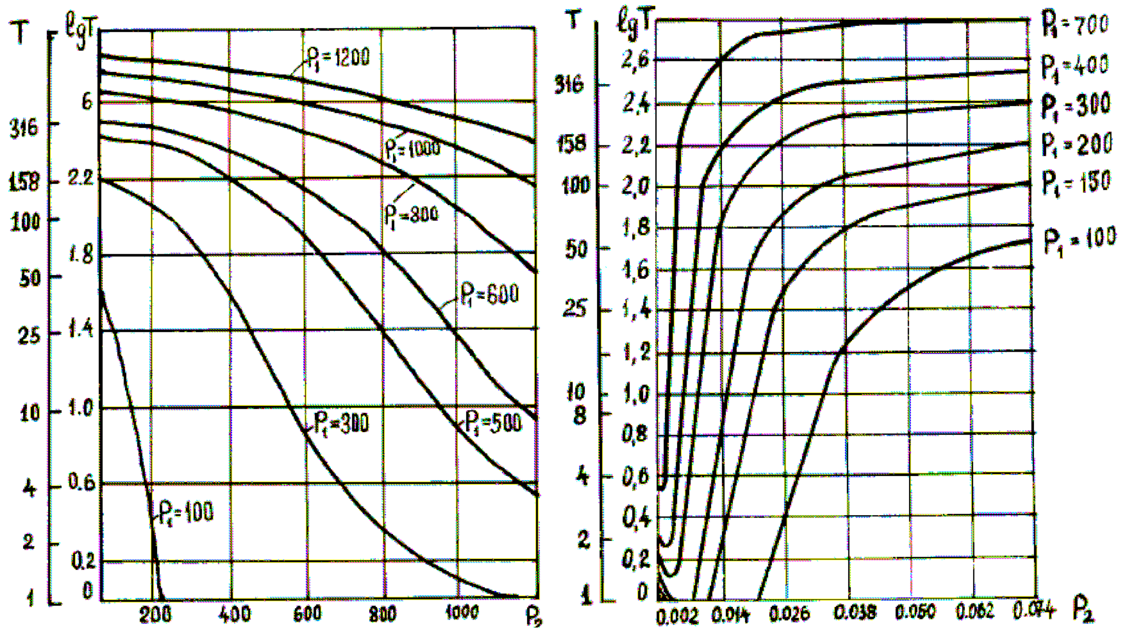

Fig. 5. **Nomograms for determining an optimal time moment for automatic correction of error in case if deviation of PMT error is nonlinear, lg*T*, P_1, P_2 < 1200; P_1 < 700, P_2 < 0.1**

Automatic detection of correction factor in a uniform flow of liquid usually represents not complex challenge. The solution is reduced to definition of optimum "weight factor of a neural network" by means of iterative algorithm [2], Fig. 6b. But calculation of signal of correction in a non-uniform flow of liquid demands of preliminary theoretical analysis of mathematical model [1; 3 – 5; 7; 8].

Taking into account stochastic character of parameters that have influence on an error of measuring, it is offered to include the following criteria of an assessment of error:

- magnitude of systematic (Mc) and random (S) error;
- changes function of these magnitudes in time and space;
- degree of possible correlation of separate error components;
- magnitude of generalized coefficient of correction $K_{corr} = f\,(P_m, P_t, T_k, P_t / T_k)$, where P_t, T_k and P_t / T_k – correspondingly temporal and space/temporal actual discrete metrical assessments of intelligent measuring system, but P_m – metrical parameters of PMT (Fig. 7a).

In the process of mathematical modeling an optimal discrete signal of the intelligent measuring device "Logicor" is calculated and the principles of calculation of the correction signal for the uniform and non-uniform flows according to the basic scheme are calculated.

From the initial formula and tables of Laplace p-transformation the signal $X(s)$ for the outcoming signal is calculated and its original $X(t)$ detected, that allows to calculate the correction signal at any time t.

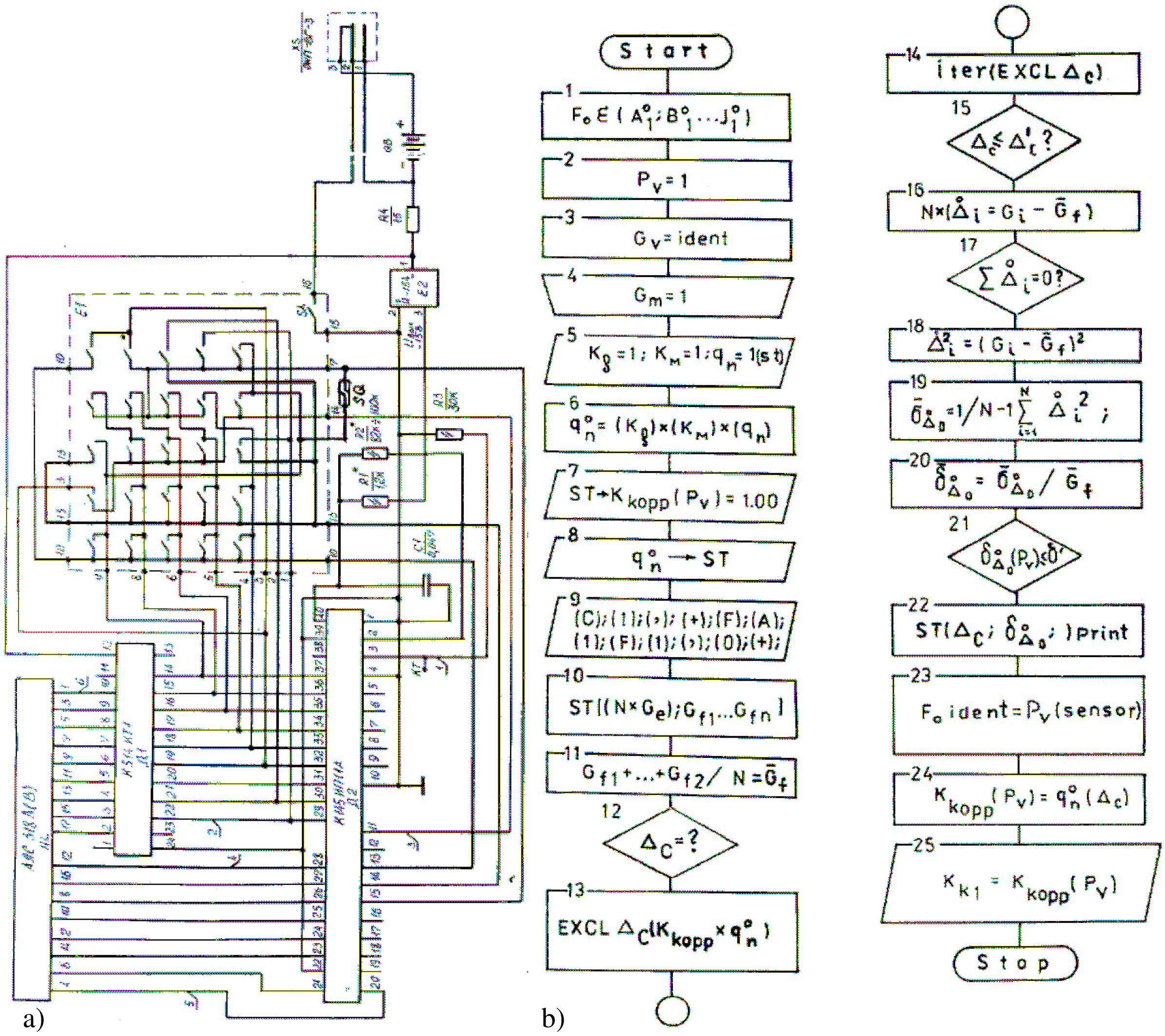

Fig. 6. **Principal scheme of device (a) and algorithm for correction of errors (b)**

At non-uniform, nonformed flow a discrete electronic key switches off not periodically, but at the time moments $t = T_1, T_2, T_3 \ldots T_n$, switches on at time moments $T = T_0 + h_0, T_1 + h \ldots T_n + h_0$.

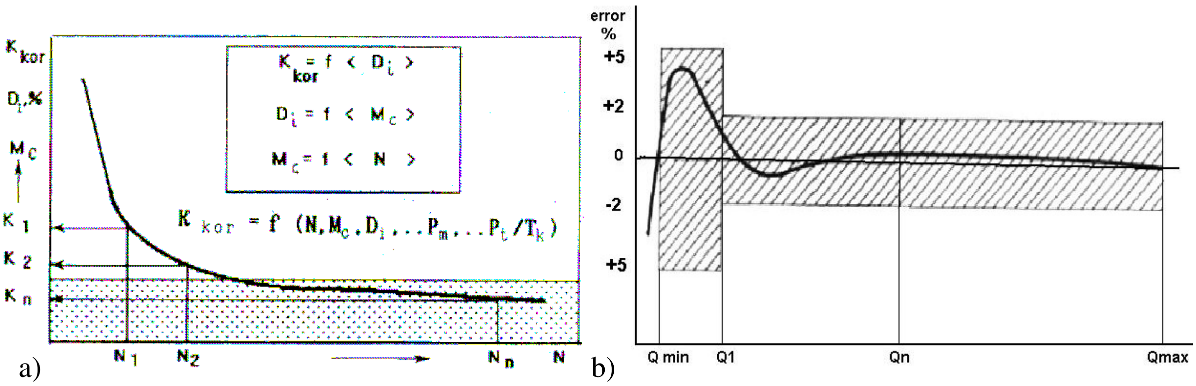

Fig. 7. **Generalized model of process of measurement (a) and a characteristic curve (b) of an error (Δ, %) of a flowmeter with a critical point Q_1 of the consumption, $\Delta = f(Q)$, $m^3 \cdot s^{-1}$**

Using the test signal 1n(t) and having carried out the transformation of Laplace, the equations are got for the outcoming signal for a non-uninformed flow. The original of the signal is found using the tables of Laplace *p*-transformations. Further Laplace transformation equations are given and on the concrete example the methods for discrete correction signal calculation using two electronic keys are shown [12; 13]. For this purpose we will present a system of synthesis of signals in the form of two electric keys receiving a signal from the primary measuring transducer (PMT). The first signal we will accept as the basic signal and the second signal as additional (correction). As a result work of the electronic key and transformation of a signal will occur not periodically, but in some stochastic intervals of time.

For calculation of the correction signal according to [3; 4] and the scheme shown in Fig. 8 let us assume that a key is switched on in the time moments:

$$t = T_1, T_2, T_3, T_4, \dots T_n \tag{1}$$

and is disconnected in the time moments:

$$t = T_0 + h_0, T_1 + h_1, T_2 + h_2, \dots T_n + h_n. \tag{2}$$

From the Laplace tables of transformation it is possible to define the reaction of the system:

$$\begin{aligned} 1_n(t) &= \sum_{n=0}^{\infty} [1(t - T_n) - 1(t - T_n - h_n)] = \\ &= \sum_{n=0}^{\infty} \Delta h_n 1(t - T_0) = \end{aligned} ; \tag{3}$$

$$= \begin{cases} 1, \text{if } T_n < t < h_n \\ 0, \text{if } \ "t" \text{ is defined differently} \end{cases} . \tag{4}$$

We can write the equation for an entrance signal:

$$g_n(t) = g(t) 1_n(t). \tag{5}$$

Using the Laplace transformation, we receive the equation:

$$\begin{gathered} G_n(s) = \frac{1}{2\pi j} \oint_r G_u 1_n(s - u) du \\ G(s) = L\{g(t)\} \\ 1_n(s) = L\{1_n(t)\} = L\left\{ \sum_{n=0}^{\infty} \Delta h_n 1(t - T_n) \right\} \end{gathered} . \tag{6, 7, 8}$$

We can be convinced that:

$$L\{1_n(t)\} = \sum_{n=0}^{\infty} [e^{-sTn} - e^{-s(Tn+hn)}] \frac{1}{s}. \tag{9}$$

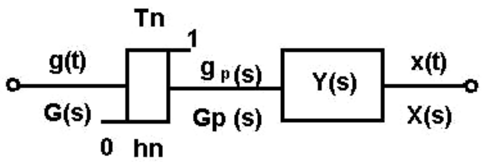

Fig. 8. **Generalized scheme for calculation of correction signal**

Having placed this formula in the equation (6), we receive:

$$G_n(s) = \sum_{n=0}^{\infty} \oint_r G(u) \frac{e^{-Tn(s-u)} - e^{-(Tn+hn)(s-u)}}{s - u} du. \tag{10}$$

Considering unequal intervals of time:

$$\overset{Tn+hn}{\underset{Tn}{P}}\{G(s)\} = L\{g(t)[1(t-T_n)-(t-T_n-h_n)]\} = \\ = L\{g(t)\Delta h_n 1(t-T_n)\}. \tag{11}$$

Then the equation will be correct:

$$G_n(s) = \sum_{n=0}^{\infty} \overset{Tn+hn}{\underset{Tn}{P}}\{G(s)\} = \sum_{n=0}^{\infty} \overset{\infty}{\underset{Tn+hn}{P}}\{G(s)\} - \sum_{n=0}^{\infty} \overset{\infty}{\underset{Tn}{P}}\{G(s)\}. \tag{12}$$

Laplace transformation for a target signal can be defined by formula:

$$X(s) = Y(s)\,G_n(s). \tag{13}$$

The original of the tested signal can be defined using the tables of *p*-transformations.

In case of non-uniform flow of liquid the actual discrete correction signal can be calculated by the Laplace transformation method using two electric keys:

$$X(s) = \frac{1}{1-e^{-k}sT_1} X_0(s), \tag{14}$$

where k – whole positive number;
$X_0(s)$ – function, which corresponds to the Laplace's transformation of a signal X_0, equal $X(t)$ in an interval $0 < t < kT_1$ also it is equal to zero out of this interval of time.

Let us assume that two periods T_1 and T_2 of an electronic key are connected by a ratio:

$$\frac{T_1}{T_2} = \frac{b}{q}, \tag{15}$$

where b, q – whole positive numbers.

At $k=1$ using the Laplace's transformation it is possible to find the equation:

$$X(s) = \frac{X_0(s)}{1-e^{-sT_1}} = \frac{X_0(s)[1+\sum_{i=1}^{q-1} e^{-(i\frac{b}{q})sT_2}]}{[1-e^{-bsT_2}]}. \tag{16}$$

Similarly it is possible to find:

$$X(s) = \frac{X_0(s)}{\left[1-e^{-sT_1}\right]^r} = \frac{X_0(s)\left[1+\sum_{i=1}^{q-1} e^{-\left(i\frac{b}{q}\right)sT_2}\right]^r}{\left[1-e^{-bsT_2}\right]^r} \tag{17}$$

where r – whole positive number.

At the end the equations are found, which allow defining the Laplace's transformations for the periodic function T_1 with a ratio:

$$T_2 = (\frac{q}{b})T_1 \tag{18}$$

As a result of the analytical research the equations for the dynamic intelligent measuring system "Logicor" with two electronic keys for non-uniform flow of liquid are defined.

Conclusions

1. In the article an original method of digital physical modeling of optimal dose by using iteration algorithm of correction is offered as well as the main results of the researches of a new method for statistic control of intelligent measuring means and assessing their preciseness taking into account the stochastic character of signals coming to the primary measuring transducer is reflected.

2. The researches show that traditional flowmeters of cold and hot water in separate premises are unsuitable for commercial calculations as make measurements in the critical zone of an error of the device exceeding the admissible accuracy standard norm (Fig. 7b).
3. On the basis of mathematical modeling of the measuring process with use of the Laplace transformation and experimental research results, analytical equations are given, that are useful for calculation of the correction signal for a uniform and non-uniform character of flow and allow assessing the reserves of preciseness rise of the intelligent measuring device in real conditions.
4. The accuracy of intelligent measuring systems in real conditions can be raised:
   - by specification and stabilization of technically technological characteristics and parameters;
   - by optimization of the parameters of influence on errors and by automatic calculation of correction coefficients;
   - by constructive and technological optimization of the measuring system;
   - by making the measuring system more simple and by limiting the amount of the actors that have influence on measuring preciseness.

References

1. Moskvins, Genādijs. Intelektualizētās automātiskās mērīšanas, dozēšanas un uzskaites sistēmas : Zin. darbu kopsav. Dr. hab. inž. zin. grāda iegūšanai / Genādijs Moskvins ; LLU. Jelgava, 1996 (LLU). 91 lpp: diagr., zīm., sh., tab.; 20 cm. Bibliogr.: 71.-78.lpp. (111 nos.). Kopsav. angļu, kr.;
2. Moskvin G., Back Propagation and Transformation Methods in Artificial Intelligence Systems. Proceedings of the 4-th International Scientific and Practical Conference, June 26-28, 2003, Rezekne, pp. 367 – 376;
3. Кузин Л.Т. Расчет и проектирование дискретных систем управления. Машгиз, 1962, 684 с.
4. Черных И. В. Моделирование электротехнических устройств в MATLAB, Simulink и SimPowerSystems, 2008 г., М.: ДМК Пресс; СПб.: 288 с.
5. Moskvins G. Intelektuālās sistēmas un tehnoloģijas: mācību līdzeklis studiju priekšmetam "Intelektuālās sistēmas un tehnoloģijas", Jelgava : LLU, 2008. 136 lpp : il., ģīm., diagr ; 24 cm. Bibliogr. : 130.-136. lpp. (115 nos.). ISBN 9789984784625;
6. Moskvins G., Intelligent technologies in agriculture - ISBN 978-9934-8158-8-1, RTU, Rīga, 2011, 10 lpp;.
7. Moskvin G.A. Artificial Intelligence Measuring, Automatic Control and Expert Systems in Agriculture: in 3-rd IFAC/CIGR Workshop on Artificial Intelligence in Agriculture, Makuhari, Japan, April 24-26,1998, Preprints, p.176-181;
8. Moskvin G., Spakovica E., Moskvin A.. Development of Intelligent Technologies and Systems in Agriculture. 7th International Scientific Conference «Engineering for Rural Development» LLU, TF, 29.-30.05.2008, Jelgava, p. 208-215;
9. Moskvin G. United States Patent 5,016,569.
10. Moskvin G. United States Patent 4,989,445.
11. Moskvin G. United States Patent 5,012,762.
12. Moskvin G. United States Patent 5,161,483.
13. Moskvin G. Europaisches Patent Nr.0372089.
14. Moskvin G. Europatent 0471076.
15. Moskvin G. Patent of New Zealand Nr. 228982.
16. Moskvin G. Patent of India Nr.175562.
17. Moskvin G. Patent of Bulgaria Nr.50482.
18. Moskvin G. Magyar Patent Nr.205530.
19. Москвин Г.А. Интеллектуальные квартирные счетчики «Логикор». Каталог XV международного Салона изобретений и инновационных технологий «Архимед». 20-23 марта 2012 г., Москва, ЭкоЦентр Сокольники.