SIMULATION OF THE ELECTROMAGNETIC FLOWMETERS

Yu. Mikhailova /Presenter, and I. D. Welt

State Research Center "Niiteplopribor", Moscow, Russia, agydel@gmail.com

Abstract: The electromagnetic flowmeters allow the discharge measurement under intricate flow structures in form of: inexact channel filling with measured medium; nonuniform allocation of a phase composition under coal, sand pulp and suspension measurements; change of velocity allocation by channel section with the close locating fixings of tubing; and etc. There is necessary the specialized metrological equipment under the circumstances for electromagnetic flowmeter checking. It is possible to make the calibration of electromagnetic flowmeters under intricate flow shapes by means of simulation method.

Keywords: electromagnetic flowmeter, simulation method, weight function.

1. INTRODUCTION

In research and development of electromagnetic flowmeters a large number of technical problems arise, and it is desirable to solve them by experiment as the test results will permit the structural optimization of the instrument design to be simplified and precipitated. We shall divide all the technical problems which should be preferably solved by experiment into three groups:

● Problems of choosing structural components of the primary transducer, a channel design, its shape of the extent of the isolated section, dimensions and a design of the electrodes; an inductor design, a characteristic of magnetic field distribution, and other components of the instrument.

● Problems of the relationship between signal and fluid flow structure. For example, the effect of velocity distribution over the cross-section of the channel, which is caused by a change in the Reynolds number, the effect of different flow asymmetries caused by the pipeline fittings situated close to the instrument (bend, gate valve, check valve) etc. The effect of heterogeneous phase distribution of the measured medium in the net section of the channel, etc.

● Problems of flowmeter indications affected by interference of mechanical and electromagnetic nature, e.g. pulses of the flow velocity, a signal of electrode polarization, thermal EMF, mains frequency noise, single pulses, etc.

These problems can be experimentally solved only in case there are appropriate metrological means which make it possible to study in detail the influence functions of the factors, each taken separately, which determine the metrological characteristic of the instrument.

It is impossible to study flowmeters within a wide scope of changes in influencing factors on the existing liquid flow-measuring installations for the following reasons.

Suppose that we have a standard liquid flow-measuring installation of a rather high precision. The measured medium in that installation is pure tap water within a narrow temperature range, over the measuring section of the installation an axisymmetric kinematical fluid flow pattern is provided using appropriate devices, velocity pulsations are smoothed out, etc.

We do not know, however, a large number of other factors determining the flow pattern immediately in the measuring cross-section of the flowmeter channel.

Namely: the character and distribution of the axial and the tangential flow velocities over the cross-section of the channel, the contact angles on different parts of the channel surface, especially hydrophobic coatings (e.g. of fluoroplastic type) and the condition of the boundary layer on those parts, the level and polarity of EMF polarization, thermal EMF, amplitudes, phases of the harmonic spectrum of mains frequency noise, and many other things. We do not know all those factors in a quantitative sense, although, in principle, they can affect the result of flow rate measurement performed by the electromagnetic method. We do not know their variations in time either.

Due to its principle of operation, the liquid flow-measuring installation does not allow changing the measurement conditions, namely changing the density of the measured medium for investigating the dependence of instrument indications on the Reynolds number, changing the asymmetry of the flow pattern, and introducing interferences of mechanical and electromagnetic origin.

Consequently it is difficult to investigate flowmeters on a large scale with the aim of determining the influence functions of their characteristics such as changes in the flow pattern and interferences of different origin and level.

It is extremely difficult to test flowmeters on a flow-measuring installation with the aim of revealing the dependence of their characteristics on design modifications.

For example, our interest is the influence function of the dependence of the calibration characteristic of the instrument on the inaccurate electrode mounting. For this purpose, it is necessary to make two, if not more, prototype instruments the electrodes of which are mounted at different distances.

Elementary calculations can show that the displacement of the electrodes cause slight changes in signals. Therefore, the obtained differences between the indications of those instruments on the liquid flow-measuring installation do not signify at all that they are only caused by a change in the magnitude of the electrode displacement.

It is said above that the liquid measuring installation has a series of unaccountable factors which can be different when testing even the same instrument at a different time.

Variations in signals of the same level are also possible due to inaccurate manufacturing of the other components of the instrument design, which must be strictly identical in all instruments according to the experiment statement.

Consequently, testing instruments on the liquid flow-measuring installation with the aim of determining the dependence of their characteristics on a change in design values requires, on the one hand, labour-intensive work on manufacturing many prototype instruments and, on the other hand, does not allow the required measurement accuracy to be attained, in spite of the fact that the liquid flow-measuring installation itself even has an indefinitely small error of flow rate measurement.

Due to its principle of operation, the liquid flow-measuring installation is conservative, it is not designed for performing versatile investigations of flowmeters, it is extremely low-informative, the only informative parameter of the liquid flow-measuring installation, which is represented in a numerical expression, is the amount of water flow rate passed through the instrument channel and measured by appropriate means.

Perhaps, that is the reason why most instrument developers do not conduct large-scale investigations of electromagnetic flowmeters, no pertinent publications are available, and modifications of the instrument design are made by intuition, to the best of one's understanding of process physics.

The instrument simulation method is convenient for conducting large-scale investigations of electromagnetic flowmeters. It is, as it were, specially designed for conducting instrument tests within the widest range of variation in measurement conditions.

Using a simulation model one can normalize and simulate, and in most cases very easily, practically all the factors of interest which determine the flowmeter design, the flow pattern and interferences of different nature.

When developing modern electromagnetic flowmeters a problem is usually specified to increase the measurement accuracy with simultaneous reduction in the overall dimensions of the instrument and its power consumption.

In this problem there is an apparent contradiction or incompatibility of one requirement with the other.

The reduction in dimensions and power consumption leads to the level of the informative signal component decreased and the valid signal-to-noise ratio inevitably reduced, and consequently to the measurement accuracy diminished. This contradiction is solved by using microprocessor technology and sophisticating the digital signal processing programme. Thus, the signal processing algorithm acquires greater importance as it makes possible to isolate the informative signal component from a complex set of noise arising during the instrument operation. However, the quality of the algorithm and that of its record in the memory of the instrument under investigation cannot always be controlled during check and acceptance testing.

As a rule, most of the electromagnetic interference met with during the instrument operation is not present on standard liquid flow-measuring installations as special measures are taken on those installations to ensure high protection from the penetration of interference of different nature (due to

absence of EMI sources which usually exist under industrial conditions, as well as use of shielding, earthing, etc.). The measured medium is pure tap water within a narrow temperature range of $(20\pm5^0 C)$. Using appropriate devices the kinematic fluid flow pattern in the channel is kept axisymmetric; velocity pulsations are smoothed out, etc.

The real operational conditions naturally differ in physical properties, working temperature of the measured medium, flow pattern, composition and level of interference from these commonly accepted and standardized modes.

It is possible to conduct the investigation of the flowmeter under near operational conditions using the simulation method. Electromagnetic flowmeter simulation is a powerful rational method for investigating, checking and calibrating instruments, and its technical capabilities are significantly wider that those of liquid flow-measuring installations.

The simulation ensures the following advantages:

— unlimited range of simulated flow rates;

— investigation of instruments with channel diameters ranging from small values (in the order of several mm) to unrestrictedly large ones (up to 2,000 mm and over);

— high accuracy of investigation and calibration facilities (the limits of error does not exceed $0.10 - 0.20$ %);

— possibility to investigate instruments under test conditions maximally approximating to real operational conditions:

— simulating a fluid flow within a wide range of physical properties (viscosity, density, temperature, etc.);

— simulating heterogeneity of the measured medium composition: dispersivity, multiphaseness;

— simulating flows with a differing kinematic structure, at any Reynolds numbers, at axially asymmetrical velocity distributions, as well as with different levels and frequency spectrum of pulsations;

— simulating magnetohydrodynamic processes which arise when measuring liquid metal flow rate;

— simulating interference of different nature: heat noise, EMI of the industrial network, radio frequency interference, single pulses, mechanical vibrations, hydraulic shocks, etc.

— possibility to calibrate instruments both in the field and under conditions of the calibration laboratory;

— high capacity of the metrological means, full automation of investigation result processing, record-keeping and archive maintenance;

— portability of the complex of simulation check means (small overall dimensions, low weight and low power consumption).

In addition, it is significantly simpler to conduct the investigation of electromagnetic flowmeters using simulation than under natural conditions.

It should be noted that at present time not all possibilities of the simulation method are realized.

If a problem is formulated to investigate metrological characteristics of the flowmeter without fluid flow passing through the instrument channel, then the electromagnetic flowmeter model must simulate a signal identical in physical parameters to the signal of the simulated instrument, but without fluid flow moving, i.e. a different principle of conversion must be used in the model.

An indispensable condition is the accuracy of characteristic conversion of the model and the original, which must be high enough to satisfy the problems stated.

2. SIMULATION METHOD

In order to make an analogy between the electromagnetic flowmeter and its simulated model, it is necessary to determine their common features from the point of view of the general theory of converters. Such an approach makes it possible to select, as a simulation model, a converter based on a different principle of conversion, but having the same common functional features.

Let us consider the primary transducer (PT) of the electromagnetic flowmeter as a system which converts energy of the fluid flow and that of the inductor power supply into electric energy released through the electrodes and arriving at the input of the measuring device.

PT of the electromagnetic flowmeter can be regarded from the point of view of the theory of converters as a system which converts energy of the fluid flow and that of the electromagnet power supply into electric energy released at the output. Therefore, PT is a six-pole. However, it can also be considered as a quadripole having an internal energy source.

Let us take as output parameters of the equivalent quadripole the parameters which characterize energy of the inductor power supply. That will make it possible to draw a certain analogy between PT and its simulated model.

The equivalent quadripole is active, irreversible, externally supplied, i.e. PT in question does not comprise independent energy sources, and its activity is due to energy of the fluid flow which creates a signal on the electrodes only when energy for establishing the magnetic field is delivered from the outside. It is described by the matrix

$$\begin{vmatrix} U_1 \\ U_2 \end{vmatrix} = \begin{vmatrix} z_{11} & 0 \\ z_{21} & z_{22} \end{vmatrix} \bullet \begin{vmatrix} I_1 \\ I_2 \end{vmatrix} , \qquad (1)$$

where U_1 is the supply voltage of the inductor; U_2 is the voltage between the electrodes; I_1 is the supply current of the inductor; I_2 is the current passing through the electrodes and the input circuit of the measuring device.

Using the matrix simulation method it is possible to build a great number of different equivalent circuits of PT composed of elements of electrical engineering and electronics, which can be regarded as its simulated models. According to the rules of the matrix simulation, a circuit with a nonsymmetrical matrix must comprise an amplifier. Some of the model circuits are cited in the paper [3].

An amplifier can be excluded with provision made for a corresponding balancing circuit and its manual tuning. Several alternative block diagrams of the simulated models complying with the above requirements are also cited in the paper [3].

For analyzing the characteristics of the simulated model the most convenient equivalent circuit of PT is one with a gyrator (Fig. 1). An ideal gyrator [4] is a purely theoretical element of the electric circuit, which is described by the equations

$$U_1' = -pI_2' ; \quad U_2' = pI_1'$$

where U_1', I_1' are the input voltages and currents of the gyrator; U_2', I_2' are the output voltages and currents of the gyrator; p is the gyrator resistance.

For the circuit shown in Fig.1

$$U_2 = I_1 \left(p + R \right). \qquad (2)$$

Given that $|p|=R$ we have $Z_{21}=2R$, $Z_{12}=0$ i.e. the static characteristic of PT is presented in terms of the resistance Z_{21}. In other words, only the parameter Z_{21} is a function of velocity or fluid flow rate.
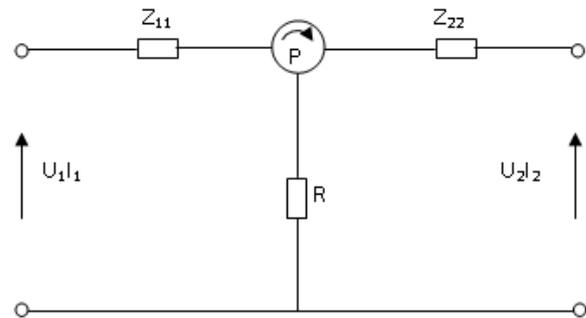

Fig.1 – Equivalent circuit of the primary transducer

The value R can be represented as the static characteristic of PT:

$$R=U_2/2I_1. \qquad (3)$$

Let us express the parameters of the model in terms of the parameters of the flowmeter.

As is well known [1], the informative component of the signal produced between the electrodes of the flowmeter is described by the expression:

$$U = \int_{\tau} \left[\vec{B} \times \vec{W} \right] \vec{v} d\tau , \qquad (4)$$

where U is the voltage between the electrodes which arises when the fluid flow moves along the channel of the flowmeter, W is the volume weight function, τ is the volume of the active channel zone, B is the magnetic field induction, v is the flow velocity.

The function W is only determined by the channel diameter, the extent of the isolated section, the location and the dimensions of the electrodes. It does not depend on either the velocity or the external magnetic field.

The representation of U in the form of (4) is convenient when investigating and demarcating the signal dependence on design values and external conditions: external magnetic field and velocity distribution.

The signal U can also be expressed in terms of the magnetic field distribution B_n on the internal surface of the channel, and the surface weight function W_n as follows, [2].

$$U = v_s \int_{S} \left[B_n \times W_n \right] dS , \qquad (5)$$

where v_s is the mean velocity of the flow, S is the surface of the channel

Introducing the notion of a "surface weight function" made it possible to describe the flowmeter signal with a significantly smaller scope of the required information on the magnetic field in the working zone of the channel and, thus, not only open a real possibility of investigating electromagnetic flowmeters by a non-liquid method, but also significantly simplify calculations of the instrument. The surface weight function W_n depends on the kinematic flow pattern (i.e. the velocity distribution in the channel) and on all the factors determining the volume weight function W, [2].The voltage U_2 induced by the fluid flow can be calculated from equations (4) or (5).

Expression (3) is represented in terms of the parameters (U_2, I_1) depending on the energy delivered to the flowmeter, which makes it difficult to analyze the dependence of the static characteristic on the flowmeter design. Let us try to express the static characteristic of the flowmeter in terms of the design values of the flowmeter.

For this purpose we shall introduce characteristic quantities: a characteristic linear dimension – the channel radius r_0 and a characteristic magnetic flux Φ_o which will be taken to be equal to:

$$\Phi_0 = r_0 \int_S (B_n W_n) ds , \qquad (6)$$

The characteristic magnetic flux Φ_o is different from the real magnetic flux threading the surface S of the flowmeter channel in that it takes into account the surface weight function according to expression (6).

The surface weight function W_n is determined by the familiar conditions of signal shaping, namely the geometrical parameters of the channel, the dimensions and location of the electrodes, the extent of the insulating coating of the channel, the velocity distribution of the flow, inhomogeneous distribution of electric conductivity of the measured medium in the working volume of the channel, the filling level of the channel with free water, etc.

Concept introduction «superficial weight function W_n» has allowed not only to describe magnetic flow Φ by essentially smaller volume of the necessary information about a magnetic field in a channel operational zone, but also to open real possibility of creation concerning a simple induction coil design with distribution of coils on a cylindrical surface or a plane dissecting channel operational volume. It is necessary to notice that superficial weight function W_n depends on kinematic flow structure, i.e. velocity distribution in the channel, and from all factors determining volume weight function W [3]. Differently, various allocations of coils to surfaces or induction coil plane correspond to a channel various design and velocity distribution of a measured liquid in its cross-section. It is necessary to create such induction coil design with which help it is possible to mark out required magnetic flow Φ from the general magnetic field, to apprehend and transform it to an electric signal.Thereby, not only the real possibility of research of electromagnetic flowmeters by the simulation method is opening, but also the device calculations are simplifying considerably.

For a flat flow velocity profile it is had

$$G^T\left(z,\theta\right) = \frac{v_0}{2\pi^2}\int_{-\infty}^{+\infty} \cos kz\, dk \sum_{\substack{p=1 \\ n=2p-1}}^{\infty} (-1)^{p-1} n \cos n\theta \left[\frac{I_n(kr)}{rI_n'(kr)}\right]^2 .$$

Superficial weight function $G^T\left(z,\theta\right)$ for a flat flow velocity profile is represented on fig.2 and its lines of levels is represented on fig.3.
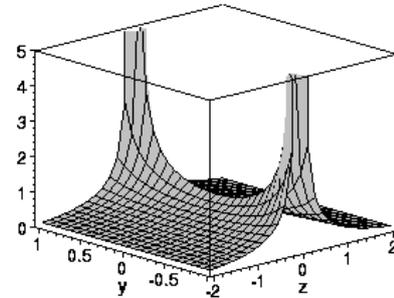

Fig. 2 Superficial weight function *for a turbulent flow*

For laminar mode $v_z = v_0\left[1-(\rho/r)^2\right]$ superficial weight function $G^L\left(z,\theta\right)$ is represented on fig.4 and its lines of levels is represented on fig.5.
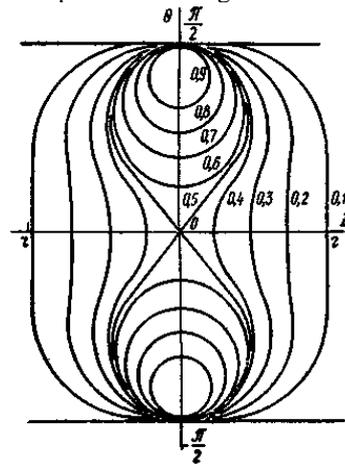

Fig. 3 Lines of levels $G\left(z,\theta\right)$ for a turbulent flow

Therefore, if the real magnetic flux penetrating through the surface S is invariable for the given instrument instance, then the characteristic flow Φ_o depends on many factors which determine the conditions of flow rate measurement and assumes different values as these conditions change.
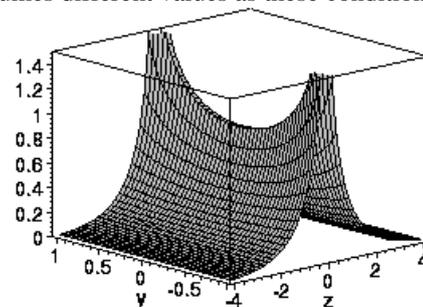

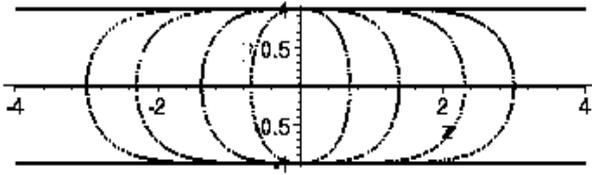Fig. 4 Superficial weight function *for a laminar flow*

Fig. 5 Lines of levels $G^L z, \theta$ for a laminar flow

Further comparing expressions (3), (5), (6) one can obtain an expression for the static characteristic of PT which has the dimensions of electric resistance and is represented in terms of the flow velocity and the design values of the flowmeter.

$$R = v_s M_0 / D, \qquad (7)$$

where $M_o = \Phi_o / I_1$ is the characteristic factor of mutual inductance between the active zone of the channel and the inductor, D is the channel radius.

The representation of the static characteristic of PT in the form of expression (7) is convenient in that it is performed in terms of its characteristic design values.

Thus, the mutual inductance factor is a principal "generalized" parameter of the static characteristic of PT and is determined by:

– an inductor design (it forms a magnetic field in the working zone of the channel);
– a channel design of the flowmeter, geometry and location of the electrodes (i.e. the elements forming the weight function);
– flow velocity distribution and inhomogeneous distribution of electric conductivity in the active volume of the channel.

Further we consider the conversion factor of PT (K_ϕ). It can be represented as the ratio of an output value of the primary transducer to its input value.

As an output value we shall take the ratio of a signal between the electrodes U to the excitation current I of the inductor and as an output value the velocity of the fluid flow passing through the channel.

For the purposes of simulation it is convenient to represent the factor K_ϕ in terms of the characteristic mutual inductance M_0 between the inductor and the working zone of the instrument in the form of

$$K_\phi = \frac{U}{v_s I} = \frac{M_0}{D}. \qquad (8)$$

In most industrially produced flowmeters of different companies and modifications, the value M_0 is within the range of $10^{-6} \ldots 10^{-8}$ H, in this case we should emphasize that its magnitude depends not only on the instrument design (e.g. it increases proportionally with the diameter), but also on the measurement conditions: distribution of flow velocity and electric conductivity in the working volume of the channel. Under familiar conditions of the distribution of magnetic field inductance, the value M_0 can be invariant to several versions of flow velocity profile, e.g. to a laminar and a turbulent flow.

The surface weight function depends on choosing a surface, in this case it is not necessary to use the surface of the pipeline channel as the surface S, one can take the surface passing through the channel axis and the line connecting the electrodes.

Thus, the primary task of PT simulation is to develop a method for simulating mutual inductance between the active zone of the channel and the inductor of the instrument under investigation. This problem is solved by different methods and means. The character itself of the "generalized" criterion M_0 suggests the possibility of creating a simulated model of the active channel zone in the form of an induction coil the turns of which are bonded with the excitation coils of the inductor by the magnetic flux. In this case, if the turns of the induction coil are distributed according to the law of the surface weight function and situated respectively on the surface of the channel or on the plane passing through the channel axis and the line connecting the electrodes, then such a coil together with the instrument inductor constitutes a simulated model of PT. With the help of it, the effect of mutual inductance between the inductor winding and the active zone of the channel can be simulated without passing a fluid flow through the flowmeter.

At least two simulation variants of the electromagnetic PT are possible, the above examined induction coil being used in both variants. It can be built as a cylindrical or flat printed coil. A flat design of the coil, however, has a number of advantages as compared with a cylindrical one:

● it is simpler for calculations of its parameters since it is not subject to flexural strain;
● it has smaller dimensions, which simplifies its manufacture and placement in the flowmeter channel.

At the same time, using a flat induction coil it is possible to simulate flows only symmetric about the plane in the instrument channel, in which the induction coil at issue is situated. The said coil is a simulator of the active channel zone. The displacement of the coil relative to the operating position towards one or another side is strictly equivalent to the displacement of the flowmeter channel relative to the inductor. By the way, the inaccuracy of the induction coil being installed in the channel of the flowmeter is a main source of uncertainty in instrument calibration by the simulation method. Using the induction coil at issue, it is possible for example, to measure the factors M_0 of the simulated flowmeter, which correspond to different measurement conditions. Depending on how the turns of the induction coil are distributed, to which surface weight function they correspond, the given coil simulates the corresponding measurement conditions. For example, in turbulent conditions when the velocity distribution can be regarded as homogeneous, the surface weight function is approximately equal to

$$W_n^t = \frac{v_s}{r} \frac{cos\theta \, ch \, z/r}{cos 2\theta + ch 2 \, z/r}, \qquad (9)$$

where θ, r, z is a cylindrical coordinate system in which the axis z is directed along the axis of the channel, r is the channel radius, θ is the angle of rotation about the axis, reckoned in a counter-clockwise direction.

For a laminar regime $v_z = v_s [1 - (\rho/r)^2]$, where ρ is the distance to the axis z.

In this case, the expression for the surface weight function mapping the laminar flow takes the form

$$W_n^{\varLambda} = \frac{v_s}{r} arctg \frac{cos\theta}{sh\, z/r} \quad . \qquad (10)$$

The investigations of flow conditions in large diameter channels have shown that real flow profiles are described, for example, by equations of the type

$$v = \left(1 - r/R\right)^{1/n} + m\left(r/R\right)\left(1 - r/R\right)^{1/k} \exp\left(-a\theta\right)\sin\theta,$$

where r, θ are cylindrical coordinates with the centre on the axis of the channel; R is the inner radius of the channel; n, m, a are the factors characterizing the flow regime.

The first term of the right part characterizes the axisymmetric component of the velocity profile, and the second term the spatial harmonic spectrum, spatial harmonics defined by the second term in the right part of the equation being quickly attenuated.

Therefore, real flow conditions can be significantly limited. The behaviour analysis of the surface weight function shows that, in principle, for any function $v_z\left(\mathbb{C}, \theta\right)$ it is possible to obtain its related surface weight function [5].

Using the apparatus of surface weight functions for different kinematic flow patterns made it possible to create magnetic field converters as a set of printed induction coils simulating the corresponding velocity distributions in the channel.

With the help of standard measuring means the factor of mutual inductance M_x is measured between two coils one of which is an inductor coil and the other a coil-simulator of the channel. In this case the magnitude of M_0 is found from the formula

$$M_0 = M_x k \quad , \qquad (11)$$

where $\quad k = \dfrac{2r_0 \int\limits_{S} W_n ds}{N} , \qquad N = \sum\limits_{i=1}^{n} \int\limits_{F_i} i dF_i ,$

k is the design value of the induction coil-simulator, N is the total area of the turns; n is the number of turns; dF_i is an element of the surface between the i-th and the $(i+1)$-th turns.

3. METHOD POSSIBILITIES

On the basis of the measured vales M_0 further simulation of signals corresponding to flow rate measurement modes makes no difficulty. The simulation of a signal equivalent to that excited between the electrodes by the fluid flow is realized via the electrical resistance R according to expression (7), included into the inductor power-supply circuit. When calculating on the basis of formula (7), the resistance R usually turns out to be extremely small (low-ohmic) and amounts to several mohms; as is well known, it is difficult to work with such resistances, therefore, in practice resistor dividers composed of significantly higher ohmic resistances are used [6].

The coil-simulator can also be used as a magnetic field converter. As this takes place, the inductor draws the current corresponding to the operating mode of the flowmeter.

In this case, the signal induced by the magnetic field in the coil-simulator is equal to

$$U_k = \frac{d\Phi_0}{kdt} = \frac{M_0 dI_1}{kdt} = \frac{r_0}{kdt} d\left[\int\limits_S (B_n W_n) ds\right] \quad , (12)$$

In order to obtain a signal simulating the voltage U between the electrodes of PT, it is necessary to integrate the signal U_κ (e.g. using an electronic integrating device), i.e. obtain:

$$U = \frac{1}{T} \int\limits_0^{t_{mod}} U_k dt;$$

where t_{mod} is the signal simulation time.

However, only the informative component of the PT signal, without electromagnetic interference of different nature accompanying the informative signal component with the instrument in use, is simulated by the examined methods.

Characteristics of electromagnetic interference and their sources substantially depend on operational conditions of instruments, physical properties of the measured current and components used in the instrument. Since electromagnetic flowmeters are quite widely used (in industry, agriculture, in scientific investigations, etc.), operational conditions and, therefore, different situations of measurement modes are extremely various. As a rule, a low-frequency pulsed bipolar magnetic field is used in electromagnetic flowmeters.

Potential difference on the electrodes is related to the inductor supply current and electromagnetic interference of different origin by the following dependence [7]:

$$U = (v_s M_o/D)I_1 + M_s dI_1/dt + U_{cm}(t) + \mu, \qquad (13)$$

where $U_{cm}(t)$ is exterior sources of signal (interference); μ is interference in the channel of the signal transduction path.

The level of the informative signal component $(v_s M_o/D)I_1$ ranges 10 μV to 5 mV.

The component $M_s dI_1/dt$ characterizes a signal of "quadrature" interference the effect of which is easily eliminated by the signal processing algorithm.

The component $(v_s M_o/D)I_1$ is informative, i.e. proportional to the mean velocity of the flow. However, it also comprises elements of the interference signal caused by velocity pulsations and heterogeneities of the phase components of the measured medium.

Let us consider them in more detail. All interferences can be divided into two groups: we shall place into the first group interference arising in the presence of a magnetic excitation field (mainly multiplicative noise), i.e. that bound up with the inductor supply current – this is interference caused by flow velocity fluctuations and dispersivity of the measured medium. We shall place into the second group interference from exterior sources (mainly additive noise).

The first group of interference is determined by the expression

$$U_n = \int\limits_\tau d\tau \vec{G} div\left[\vec{v}_\phi\left(t\right) \vec{B}\right] +$$

$$+ \int\limits_\tau d\tau \left(\partial \ln \sigma(t)/\partial \vec{r}\right)\left[\vec{v}\vec{B}\right] + \qquad (14)$$

$$+ \int\limits_\tau d\tau \left(\partial \ln \sigma(t)/\partial \vec{r}\right)\left[\vec{G} d\vec{B}/dt\right],$$

where τ is the working volume of the channel; $\vec{G}$ is Green's function; $\vec{v}_{\phi}(t)$ is the flow velocity fluctuation; $\sigma(t)$ is the electric conductivity of the measured medium; $\vec{r}$ is a radius-vector.

The first term of equation (14) characterizes a signal caused by flow turbulence, and the second and the third terms of the right part of the equation characterize interferences caused by medium dispersivity: respectively common-mode interference and quadrature interference. The frequency spectrum of pulsations caused by flow turbulence is within (3 – 300) Hz and obeys a law similar to 1/f. The amplitude does not exceed (5—10)% of the informative signal component. The frequency spectrum of the noise signal caused by heterogeneities in the measured medium is determined by the size and number of particles of a solid phase and gas bubbles in the flow, as well as by the velocity of particle motion. According to the experimental data, this signal ranges $(10—5 \cdot 10^{-3})$ Hz. The amplitude can reach 10 – 23 % of the informative signal component.

Multiplicative interference also arises because of:
– magnetic field fluctuation;
– amplitude fluctuations in the power-supply circuit.

Signals which are not bound up with the magnetic field belong to the second group, in particular a polarization signal caused by electrochemical reactions such as:
– the establishment of equilibrium between ions of the metal electrode grid and similar ions in the fluid (the voltage of ion balance of a metal electrode);
– redox reactions during the charge exchange of ions of the measured medium;
– the establishment of equilibrium in the oxide film of electrode metal;
– the formation of gas bubbles of hydrogen or oxygen on the electrodes, etc.

The potential difference of electrode polarization can reach (100-200) mV rising above in particular cases.

Since the polarization process is accompanied to a greater or lesser extent by ion movement, its frequency spectrum is extremely low and falls inside the limits of $(10^{-3}—10)$ Hz.

Exterior interference is also due to heat noise in the fluid and the input cascades of the measuring device, thermal EMF of the electrodes, industrial noise including noise of a 50 Hz industrial network and its derivatives (2nd, 3rd, 4th, 5th harmonics), single pulses, etc.

The process of constructing an algorithm for valid signal (flow rate) estimation based on a series of noisy observations comprises two stages:
– simulating a physical situation of noisy signal measurement;
– the synthesis proper of estimation algorithms oriented to a specific character of noisy environment, presence of possible uncertainties, incorrectness of measurement data (error conditions, outliers, etc.).

It should be noted that the simultaneous presence of all kinds of interference is hardly probable. Usually the composition of interferences and their level substantially depend on the operational conditions of the construction and the standard size of an instrument.

The State Scientific Centre "NIITeplopribor" has developed the Potok-T installation for simulation check of electromagnetic flowmeters, volume meter and heat meters. The desk-top and special maintenance-free installation makes it possible to check instruments with a nominal diameter of 25 – 4,000 mm and flow rates of 0 – 350,000 m³/h. The installation consists of a set of magnetic field converters, a PC, an interface card comprising an analog-to-digital converter, and a matching unit. The limits of admissible error of the installation is no more than 0.17 %, which allows checking instruments of a Class 0.5 when using a special State Standard Procedure of a Class 0.2 as well. At present the Potok-T installation is designed for checking flowmeters and heat meters with diameters of 25…600 mm, as well as instruments with channel diameters up to 4,000 mm with electromagnetic transducers of local flow velocity.

The installation has the following characteristics:
Nominal diameter of the flowmeter :   25 – 4000 mm
Upper limit of volume flow rate measurement:
  0.01 – 350000 m³/h
Simulated working medium – water, at a temperature of
10 – 180 °C
Basic error: in volumetric flow rate and volume: ±0.2 %
in quantity of heat: ±0.5 %
Calibration interval: 2 years
Total service life, no less than 15 years
Overall dimensions: sensors from (170×46×10) to (435×280×10) mm; matching unit (135×50×125) mm
Weight: sensors 0.2 – 2.8 kg, matching unit, no more than 0.8 kg
The installation is of desktop design, covered by Russian Federation patents.

REFERENCES
1. Bevir M.K. Theory of Induced Voltage Electromagnetic Flow measurement. -IEE Trans. Magn., 1970, 6, № 2.
2. Welt I. D., Mikhailova Yu. V. et al. On Non-liquid Method of Experimental Investigation of Electromagnetic Flowmeters. – Magnetic Hydrodynamics, 1976, № 3.
3. Welt I. D., Mikhailova Yu. V. Metrology, № 11, 1998.
4. Milyakh A. N., Shidlovsky A. K. "Reciprocity Principle and Reversibility of Phenomena in Electrical Engineering", "Naukova Dumka" Publishing House, Kiev, 1967.
5. Welt I. D., Mikhailova Yu. V. Electromagnetic Flowmeter Simulation with Complex Flow Patters, Measurement Technology, № 7, 2005, p. 33.
6. Welt I. D. Calibrator for Investigation of Electromagnetic Flowmeters by Simulation Method. Measurement Technology № 12, 2004.
7. Welt I. D., Gusak P. P., Zheltonozhsky I. L., Poznyak A. S., Vasilevsky Yu. A. Digital Simulation of Measurement Modes of Electromagnetic Flowmeter. Collected Volume of Proceedings. Moscow, NIITeplopribor, 1990.