Practical Application of Simulation of Electromagnetic Flowmeters

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Abstract: The simulation model of an electromagnetic flowmeter and its application for metrological characteristics devices analysis is considered.

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1. Introduction

Technical possibilities of flowmeters simulation methods are formed by theoretical and experimental knowledge level about flow measurement method, and also by technology progress and by the circuit construction of the device. Now there were possible an application of simulation methods in metrology for research of majority of the electromagnetic flowmeters used in Russia.

Here should be considered physical bases of an electromagnetic flowmeter simulation modeling. Usually conversion coefficient of the primary flow transducer is represented by following formula:

$$K_{\text{v}} = \frac{U}{Iv}, \tag{1}$$

where U - pressure between the electrodes, caused by liquid flow movement; I - a current of magnetic field excitation, created in turn of the inductor coil ; v - average velocity of liquid flow proceeding on the flowmeter channel.

According to (1) conversion coefficient K_{v} is presented as the relation of converter output value U/I to its input value, i.e. velocity v. The right part of (1) contains only the current parameters arising on an input and an output of the primary flowmeter converter. It is not represent some constructive content of the converter.

Using methods of the similarity and dimensional theory, we will express conversion coefficient K_{v} through some generalized design data of the device. On the basis of the dimensional analysis the considered coefficient can be described by means of certain hypothetical mutual inductance M , which reflect the communication between the inductor with the measured liquid flow and the characteristic linear size which we will accept equal to the channel diameter D:

$$K_{\text{v}} = \frac{M}{D}. \tag{2}$$

Representation of conversion coefficient K_{v} by expression (2) is done by means of only two design data of the device. Here the characteristic coefficient M acts as the basic "generalized" parameter of the primary converter design, determining function of flow velocity conversion in an electric signal. Obviously, the mutual inductance reflects an inductor design, its arrangement in a pipe relative to electrodes and magnetic field allocation in a channel operating zone because of the flowmeter output signal depends on these parameters.

Further we will pay attention that M depends not only on an inductor design and its allocation on a pipe, but also from some conditions of flow kinematics. For example, some flowmeters are sensitive to reorganisation of some flow profile which appears between laminar and turbulent currents, and also some of them could be sensitive to change of flow structure asymmetry and influence of allocation heterogeneity in the structure channel of the measured media (pulp), etc.

These factors change K_v, therefore, mutual inductance between inductor and measured flow in a channel operational zone is changing too. Thus, communication between inductor and a channel operational zone depends on some service conditions of a flowmeter too. Obviously, value M has influence by design data of the device, as, for example, the electrode size or the form of the flowmeter channel or an insulating cover quality of the pipe internal surface, etc.

From the above follows that mutual inductance between inductor and liquid flow sensitivity is a major factor which determines the flowmeter constructive decision, signal information capability towards the measured flow and service condition sensitivity. Comparing the expression (1) with (2) it is easy to count up value M for any flowmeter. Majority of industry producing flowmeters has value M situated in limits from 10^{-6} to 10^{-7} Gn. With other things being equal inductor connection with a liquid flow proportionally increases with channel diameter enlargement.

Expression of conversion coefficient with using mutual inductance between inductor and a liquid flow suggests a method of flowmeter simulation modeling.

Basic element of simulation model can be the induction coil placed in the flowmeter channel and connected by a magnetic flow with its inductor. This correlation is characterized by a certain own coefficient M_k. It is possible to provide M_k with various values, including values are equal or multiple M by revising an induction coil design and coils allocation with its position in the channel. Otherwise, simulation of mutual inductance connection between inductor and device channel by means of the induction coil is able to reproduce flowmeter conversional coefficient K_v by dry method, i.e. without a liquid flow. This model is able to be means of metrological analyses of the device if the obvious unequivocal functional communication between design model elements and the original unit and also flowmeter service conditions will be reached.

In this paper we will consider these dependences.

2. Simulation Model

If exists mutual inductance connection between inductor and the flowmeter channel there should be the magnetic flow providing this connection. The magnetic flow in the channel is created exclusively by a current proceeding on coils of the inductor coil as the liquid has low electroconductivity, it is possible to neglect of magnetic field which created by currents in the measured media. We will designate this flow - Φ_0. It does not depend on flowmeter service conditions, it is identical both at the empty channel, and at liquid flow on it, it does not depend on distribution of speed on channel section, etc. Obviously, not all magnetic flow Φ_0 forms researched mutual inductance connection between inductor and a liquid which are moving on the channel, it is formed only that part of magnetic flow which can be described by formula:

$$\Phi = MI = \frac{D}{v}\int_{\tau}[\mathbf{B}\times\mathbf{W}]\mathbf{v}d\tau, \tag{3}$$

where $\mathbf{B}$ - magnetic field induction; $\mathbf{W}$ - volume weight function; $\mathbf{v}$ - flow velocity vector; τ - volume of a channel active zone of the. The magnetic flow Φ is a flow component Φ_0. The magnetic flow Φ depends on flow kinematics in the, as considered above mutual inductance communication M of inductor with a liquid, but simultaneously it cannot exceed Φ_0.

Obviously, if the flow Φ is closer to Φ_0, and the less it depends on service conditions, then the flowmeter design and the device metrological characteristics is especially optimum.

Expression (3) allows revealing flow dependence Φ and mutual inductance M on flowmeter design data and other conditions as an external magnetic field and velocity distribution in the channel. Function $\mathbf{W}$ reflects the weight brought by a flow stream with a velocity vector $\mathbf{v}$ on

value Φ. As it is well known, function $\mathbf{W}$ is determined only by channel diameter; extent of the isolated section; allocation and sizes of electrodes. It does not depend neither from velocity, nor on an external magnetic field. Detailed analytical research of volume weight function is resulted in [1]. We will notice that if the flowmeter channel is not entirely filled by a liquid, or there is a non-uniform allocation of measured media structure on operational volumes (for example, at pulp flow measurement) then these factors are reflected in weight function $\mathbf{W}$.
It is analytically possible to set and determine a required magnetic flow Φ as function of the velocity profil in the channel. The flow velocity allocation can be modeled by expression [2]:

$$v_z = (1 - r/R)^{1/n} + \frac{mr}{R}(1 - r/R)^{1/k} \exp(-a\vartheta)\sin\vartheta, \qquad (4)$$

where v_z - component of the velocity, directed along a channel axis; r, ϑ - cylindrical co-ordinates with the centre on a channel axis; R - channel radius; n, m, a - the flow mode coefficients. The first member of the right part – axisymmetric component of a velocity profile, and the second member - spectrum of spatial harmonics.
Thus, the problem of flowmeter simulation modeling lies in the fact that to mark out magnetic flow Φ and to transform it to the electric pressure equal U with using induction coil and electronics elements. Then reproducing pressure $U = f(v)$ on an input of the flowmeter measuring device by dry method, it is possible to construct the metrological characteristic depending on the set constructive sizes of the channel and service conditions.
It is possible to reduce the necessary information on a magnetic field by using known characteristic which describes magnetic field in some closed volume through normal induction component to a surface closing this volume.
Then it is possible to express a required magnetic stream through allocation of magnetic field B_n on an internal surface of the channel and superficial weight function W_n as follows [3]:

$$\Phi = D\int_S B_n W_n dS, \quad M = \frac{D}{I}\int_S B_n W_n dS, \qquad (5)$$

where S - channel surface. 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 $\mathbf{W}$ [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.
If it is possible to carry out all above mentioned, basic possibility of modeling inductor mutual inductance connection M with a channel operational zone by means of the induction coil placed in a flowmeter pipe appears. Using such model it is possible to do researches of its metrological characteristics. Changing design induction coil data and its position in the flowmeter channel, it is possible to model various designs of the device; structure of the measured media flow and even its composition. Differently, such simulation model gives possibility of comprehensive investigation of flowmeter metrological characteristics without application liquid flow-measuring plant. The considered modeling principles are applied in the POTOK-T plant which served for graduation and calibration of electromagnetic flowmeters.

3. Potok-T plant

Plant includes: a set of a magnetic field converters (induction coils) type "Sensor"; interfaced the block; the interface plate with analogue-digital and digit-analogue converters; the software; the personal COMPUTER of IBM PC type; magazines of electric resistance; a calipers and micrometers sets.

Fig. 1 Potok-T plant

Plant has following characteristics:

- diameter of flowmeter conventional pass.................. 25 - 4000 mm
- top measurement limit on the volume flow................... 0,01 - 350000 m3/h
- simulated operational media - water by temperature.... 10 - 180 °C
- basic error:
  - by the volume flow and volume .... ± 0,2 %
  - by warmth quantity .... ±0,5 %
- intertesting interval... 2 years
- full service life, not less than ....15 years
- overall dimensions:
  - sensors ....from (170*46*10) to (435*280*10) mm
  - interfacing block .... (135*50*125) mm
- weight:
  - sensors ....0,2 - 2,8 kg
  - interfacing block, no more.............................0,8 kg

Plant takes places on a desktop. It is protected by patents of Russia.

Regular Sensor controls of POTOK-T plant are the plane induction coils made in the printing way. They model an idealized device design and service conditions, namely: the flowmeter channel has diameter which is equal to conventional diameter, electrodes are "dot", length of the isolated is site 3 - 4 sizes of conditional diameter of a flowmeter, a flow of an electrowire liquid is about 10^{-4} Sm/m, axisymmetric, extremely turbulent, etc.

It is desirable to create an individual design for the each flowmeter sensor, but practically it is impossible by economic reasons. Therefore deviations between some design parametres of a flowmeter or flow kinematic structure and setting in the sensor design are taking into account by means of correction coefficients. These coefficients are defined by calculation and by means of comparative tests liquid and dry method of a representative devices series.

The flowmeters test technique with using POTOK-T plant is expounded in recommendations [4]. Design variants limitation for Sensors and application of correction coefficient, certainly, reduce accuracy of devices calibration with using of POTOK-T plant. In addition to that necessity of the organization and carrying out of comparative tests for these coefficient determination increases labor input; cost and terms of simulation method adoption. Direct dependence of device checking accuracy by a simulation method from a technological level; flowmeter manufacture quality and stability of its constructive decision exists. Each firm-developer and the flowmeters manufacturer periodically improve flowmeters. They change their circuit and constructive decisions; the element base; applied materials and the software. It leads to change of correction coefficients and to necessity of their specification by devices repeated comparative tests. Nevertheless, the quantity of flowmeters types and updatings for which the POTOK-T plant is applicable continues to increase. The volume of comparative tests, naturally, also grows quickly.
Time rupture between the manufacture start of any modernized devices series and possibility of its checking by the simulation method increases. Everyone are interested in application of the simulation checking method, including the flowmeters manufacturer. However, much to our regret, in this area practically is absent direct business tie between devices developers and plants developers, therefore the full qualitative control over a set of correction coefficients is becoming more and more inconvenient.
Other approach to the problem decision of the simulating method application for flowmeters checking is necessary. This approach have to allow to spend the majority of researches without using of correction coefficients and to carry out calculation of the coefficients without the organization of special comparative tests for devices series by liquid and dry methods.
In (1) conversion coefficient of the primary converter it is received from the supposition that input parametre of a flowmeter is average velocity of measured media flow in the channel. In this case it is expedient to accept as input parameter of the device the flow volume of measured media Q. Then the conversion coefficient of the primary converter becomes

$$K_q = U / IQ = 4M / \pi D^3 \qquad (6)$$

and it is possible to present this conversion coefficient by folowing expression

$$K_{iy} = \alpha I / U\,, \qquad (7)$$

where α – output signal of the measuring device. If a flowmeter is correctly calibrated and also a output signal is presented in flow measure units then the following ratio is observed

$$\alpha - Q \leq \Delta Q\,, \qquad (8)$$

where Δ_q - standardize absolute error of flow measurement. In this case product of the primary converter conversion coefficient and the measuring device conversion coefficient is equal to one within a maximum permissible error. Obviously, high rigour of flowmeter simulation modeling is necessary for graduation and primary checking of again made flowmeter or after repair of the flowmeter primary converter as it is required to install functional connection of the set flow volume with design elements and device service conditions according necessary accuracy. In this case, applying of the POTOK-T plant is impossible to do without the correction coefficients determined by comparative tests. Because of they allow to approach idealized flowmeter model to model of the investigated device.Let's notice that almost all flowmeters which are let out by the industry are graduated by means of flow-measuring plants. Therefore 90 - 95 % of cases of the POTOK-T plant application to electromagnetic flowmeters are intended only for secondary devices checking in their operation conditions of. It is other situation for secondary flowmeter calibration. When the device graduated it is unimportant what method: simulation or liquid means that some dependence of instrument readings on the flow volume is established within maximum permissible error, i.e. The primary goal of simulation modeling which arises at primary calibration of the devices with using POTOK-T plant is already solved. Considered functional connection between the flow volume; all flowmeter design elements and stream kinematics is settled. The same situation arises in case of repair or replacement of the flowmeter electronic block. Now a calibration object is only the state control of this functional communication. This problem can be reserved without device modeling in its strict understanding. It is enough to make a set of the parameters defining the flowmeter calibration characteristic and to supervise and verify among themselves periodically. Thus it is necessary to observe following conditions. The first is the set of parameters should be sufficient for definition of the device metrological characteristic. The second is these parameters should be accessible to measurements without liquid flow passing through the channel. The third is these parameters have to be preliminary measured at correctly functioning device, i.e. it is desirable to do direct after its calibration or before the operation start. On occasion, probably, these parameters can be measured at the device which is in operation and before the intertesting interval termination. The fourth, all these parameters should be brought in the passport or in an electronic device database for compare with at the subsequent checkings out.

The new recommendation [5] normalizing procedure of flowmeters secondary checking by the above mentioned method by means of POTOK-T plant is developed. According to this recommendation two key parameters with which are supervised the flowmeter calibration characteristic are the primary converter calibration factors and the measuring device.

The calibration factor of primary converter K_F is calculated by results of measurement mutual inductance communication M between inductor and a measured media flow, and also measurements of diameter of the channel and distances between electrodes. These measurements are carried out by means of POTOK-T plan. As it is not required to know absolute value *of M*, and it is enough to measure its relative value, there is no necessity to apply the correction coefficient determined by comparative tests of this type devices series. The calibration factor of measuring device K_M is the inverse value of measuring device conversion coefficient. The device is presented (4). The Measurement technique, naturally, should be identical both directly after flowmeter calibration and its subsequent verifications. Thus, the simulation model founded on these parameters appears sufficient in the case if it unequivocally characterizes established earlier, for example, with a проливной method gives real calibration of the device characteristic, and therefore it supervises also settled earlier mutual inductance connection inductor with a liquid flow. Differently, with using the calibration factors it is rather simply to do secondary calibration of the flowmeter by dry method. Necessity for the correction factors determinated by means of comparative tests disappears. Accuracy of flowmeter calibration and possibility of obviously unfit rejection of device improve. The technique and procedure of measurements of these calibrated flowmeter parameters by dry method and test reports registration is expounded in recommendations [5].

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