Physical Bases of Simulation of the Electromagnetic Flowmeters

I.D.Velt, S.I.Kuznetsov, N.V.Terekhina,
State Research Center "Niiteplopribor", Russia
Tel: +7-495-6165762, FAX: +7-495-615-78-00, E-mail: datchik@online.ru

Abstract: The research problem of electromagnetic flowmeters metrological characteristics dependence on a velocity profile by a simulation method is considered. The simulating method of research of dependence of metrological characteristics of electromagnetic flowmeters on a velocity profile is considered.

Keywords: Electromagnetic Flowmeter, Simulation Method, Velocity Profile

1. Introduction

Problem of electroconductive medium flow rate measurement with complicated changed kinematic structure of the flow is supremely important both for the accounting (in municipal services, for the environmental problems solution etc.), and for the technological subjects (in chemical industry, an iron and steel industry, in microelectronics manufacture, etc.). Development and upgrading of electropower and heat power plants and solution of the ecological problem and environmental protection demands more and more exact and well-tried measurement instrument of flow quantity of the water and heat-transfer based of water in penstock.

The signal raised on electromagnetic flowmeter electrodes is defined by flow velocity profile on canal cross-section, averaged with the so-called volume weight function which depends on geometry of the flowmeter channel. This characteristic is not typical for other flow transducer in which the measured value is local flow velocity more often.

In the device channel there are no structure elements which could block the flow or distort the flow diagram. Indications of electromagnetic flowmeters practically do not depend on change of physical characteristics of the measured media - density, viscosity, electroconductivity and they depend on flow velocity profile in the channel very little.

Therefore, when there is a problem of accuracy and reliability increase of flow measurements, first of all the problem solution is connected with an electromagnetic method of measurement.

Measurement conditions in small (20 - 80 mm) and big diameters pipes lead to the fact that the kinematic flow structure in flowmeter operational volume is various.

Flowmeters of small diameter almost always can be installed far enough from pipeline armature. For this reason the flow profile in pipes of small diameter it is possible to consider axisymmetric reliably . However the transition requirement to a dynamic range 1:1000 inevitably leads to reorganisation of the velocity profile inside admissible flow range.

Flows in pipes of the big diameter are turbulent always. Here flowmeters often are required to be insalled near to pipeline armature. The velocity profile is essentially asymmetric. Such flows are typical for the main, derivational, distributive and technological pipelines which are delivering water from pump stations to the operating power system or taking away from it.

As a rule, flows proceed at temperature from 5 - 35^{o}C, however in systems of a heat supply the temperature of the heat-transfer liquid can reach 150 - 180^{o}C. Cold water can contain insignificant quantity of sand, silt, seaweed and even small fish. As a rule, filters are install on suction pipe of the pump for decrease in quantity of impurity. The floe velocity does not exceed 1,5 - 3,5 km/s, and, the bigger diameter of the pipeline, the rated flow velocity lower.

Pipelines of small and average diameters (400 - 1200 mm) are usually produced of steel, and the big diameters pipelines are produced from ferroconcrete. They are built underground on depth 2 - 3 m from its surface. Access for installation of flowmeters is usually possible in the place most inconvenient for measurements: near bending pipeline from the pump or supply unit to any unit, a sediment bowl, a tank or inside of the well where the lock valve, a disk shutter, the return valve or by-pass a tee is located. As it is known, flow velocity distribution often has essentially asymmetric diagram. Besides, access to the pipeline is in these parts limited or close adjoins the unit as it usually directly lies concrete basis or close to aggregate. Outside, on a horizontal and rectilinear site of the pipeline where velocity diagram is axisymmetric, flowmeter installation is complicated by reason of performance of special civil and erection works for pipeline opening, and also for the arrangement of device service.

Electromagnetic flowmeters allow to measure the flow at the difficult flow structures created by non-uniform distribution of phase structure at measurement coal, sand pulps and suspensions; by the change of flow distribution on channel section close located pipeline armature etc. For research of electromagnetic flowmeters in such conditions special metrological maintenance is necessary. The flow-measuring plant reproducing necessary flow structure, are extremely difficult and expensive. Calibration of electromagnetic flowmeters at difficult flow structures can be realized by method of simulation modelling.

2. Basic Equations

The signal of electromagnetic flowmeter U is functional of magnetic field distributions and liquid velocity. In view of smallness of magnetohydrodynamic interactions the flow distribution is determined only by hydrodynamics and for a considered problem is set.

Obvious dependence of U-signal on the specified distributions looks like

$$U = \int_{\tau} d\tau \mathbf{v} \left[\frac{\partial g}{\partial \mathbf{r}} \mathbf{B} \right], \tag{1}$$

where $g(\mathbf{r})$ - volume weight function which in cylindrical co-ordinates becomes:

$$g(z,\rho,\theta) = \int_0^{\infty} dk \cos kz \sum_{\substack{m=0 \\ n=2m+1}}^{\infty} (-1)^m \frac{\mathrm{I}_n(k\rho)}{\mathrm{I}_n'(kr)} \sin n\theta . \tag{2}$$

Here $\mathrm{I}_n(k\rho)$ - the modified Bessel function, $\mathrm{I}_n'(kr) = \frac{d\,\mathrm{I}_n(kr)}{dr}$.

We supposed that electrodes are in points with co-ordinates $\rho = r,\ z = 0,\ \theta = \pm\pi/2$.

From (1) follows that volume weight function characterizes the contribution to a flowmeter signal of the potentials induced by liquid flow in an inductor magnetic field in various points of the channel.

Integral on k in (2) it is possible to present as the sum of deductions of subintegral expression on the poles, being in the zero $\mathrm{I}_n'(kr)$. Having limited to deductions in zero with the minimum values $|k|$, we receive the approached expression for $g(z,\rho,\theta)$:

$$g(z,\rho,\theta) = \frac{\sin\theta e^{-|z|/r}\left(1-\rho^2/r^2\, e^{2|z|/r}\right)}{1+2\rho^2 r^{-2}\cos 2\theta e^{-2|z|/r}+\rho^4/r^4\, e^{4|z|/r}} . \tag{3}$$

Having considered that scalar magnetic potential A ($\mathbf{B} = \operatorname{grad} A$) satisfies to the equation of Puasson, the most general expression for scalar magnetic potential in the flowmeter channel we will write down

$$A(z,\rho,\theta) = \int_{-\infty}^{+\infty} dk \left[e^{ikz} \sum_{n=0}^{\infty} \left[a_n(k)\cos n\theta + b_n(k)\sin n\theta \right] \frac{\mathrm{I}_n(k\rho)}{\mathrm{I}_n'(kr)} \right]. \tag{4}$$

We use the circumstance that the signal of an electromagnetic flowmeter is characterized by that component of a magnetic field which is defined only by factors $a_n(k)$. Therefore to express a signal through a normal component of a magnetic field to a internal surface of the pipe $S(z,\theta)$, it is enough to receive a parity

$$a_n = f_n(H_n(z,\theta)), \tag{5}$$

where f_n - functional from $H_n(z,\theta)$.

Let's notice that normal to a plane the $S(z,\theta)$ magnetic field component is equal

$$B(z,\theta) = \left.\frac{\partial A}{\partial \rho}\right|_{\rho=r} = \int_{-\infty}^{+\infty} dk \left[e^{ikz} \sum_{n=0}^{\infty} \left[a_n(k)\cos n\theta + b_n(k)\sin n\theta \right] \right]. \tag{6}$$

And, factors α_n we will define through $H_n(z_S,\theta_S)$ as follows:

$$a_n = \frac{1}{4\pi^2}\int_{-\infty}^{\infty} dz e^{-ikz} \int_0^{2\pi} d\theta \cos n\theta H_n(z,\theta),\ b_n = \frac{1}{4\pi^2}\int_{-\infty}^{\infty} dz e^{-ikz} \int_0^{2\pi} d\theta \sin n\theta H_n(z,\theta). \tag{7}$$

Substituting turned out expression in (1), for a flowmeter signal U we find out

$$U = \int_{S(z,\theta)} dSB_n(z,\theta)G(z,\theta), \tag{8}$$

where superficial weight function for a internal surface of the pipe $S(z,\theta)$, is equal

$$G_n(\tilde{z},\tilde{\theta}) = \int d\tau\, \vec{v} \left[\frac{\partial g}{\partial \vec{r}} \times \frac{\partial g'}{\partial \vec{r}} \right], \tag{9}$$

where $d\tau = \rho\, d\rho d\theta\, dz$, $g' = g(z-\tilde{z},\rho,\theta-\tilde{\theta})$.

Superficial weight function $G_n(\tilde{z},\tilde{\theta})$ by the formula (9) is presented analytically depending on design data of the channel and flow structure.

It is known that volume weight function decreases on distance r away electrodes. Therefore superficial weight function is also considerably distinct from zero only if the distance is less than r from electrodes. So the greatest influence on superficial weight function is rendered by distortions of a velocity profile near to electrodes.

Expression (9) shows that distortion of a velocity profile can sharply change a picture of superficial weight function level lines. As an example we will consider axisymmetric current. Two most typical modes are developed turbulent; realized at Reynolds's great numbers, and laminar, responded to Reynolds's small hydraulic numbers.

At a turbulent mode it is possible to consider distribution of velocity homogeneous, such that $\mathbf{v} = v_0\mathbf{e}_z$, and $v_0 = \text{const}$.

For a flat flow velocity profile it is had

$$G^T(z,\theta) = \frac{v_0}{2\pi^2}\int_{-\infty}^{+\infty} \cos kz dk \sum_{\substack{p=1 \\ n=2p-1}}^{\infty} (-1)^{p-1} n \cos n\theta \left[\frac{I_n(kr)}{rI_n'(kr)} \right]^2 . \tag{10}$$

For the qualitative analysis of weight function we will take advantage of asymptotic representations of Bessel's function:

$$\mathrm{I}_n(x) \cong \exp[s/n - \operatorname{arcth}(n/s)]\frac{D(s)}{\sqrt{2\pi s}}, \tag{11}$$

where $s = \sqrt{n^2 + x^2}$, and $D(s)$ –Debye series:

$$D(s) = 1 + \frac{1}{8}\left(\frac{1}{s} - \frac{5n^2}{3s^3}\right) + \frac{1}{8^2}\frac{3}{s^3}\left(\frac{3}{2} - \frac{77n^2}{9s^2} + \frac{385n^4}{54s^4}\right) + \dots \qquad (12)$$

Expressions (11), (12) qualitatively truly describe $I_n(x)$ at all x and n, and, hence, superficial function G^T is approximately equal

$$G^T = \frac{v_0}{r}\frac{\cos\theta \,\mathrm{ch}(z/r)}{\cos 2\theta + \mathrm{ch}(2z/r)}. \qquad (13)$$

Function G^T decreases exponentially at big z and have the singularities at $z = 0,\ \theta = \pm\pi/2$. Superficial weight function $G^T(z,\theta)$ is represented on fig.1 and its lines of levels is represented on fig.2.

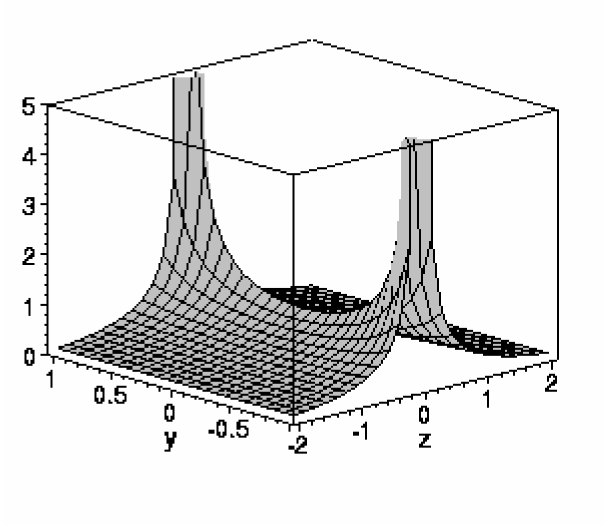

Fig. 1 Superficial weight function *for a turbulent flow*

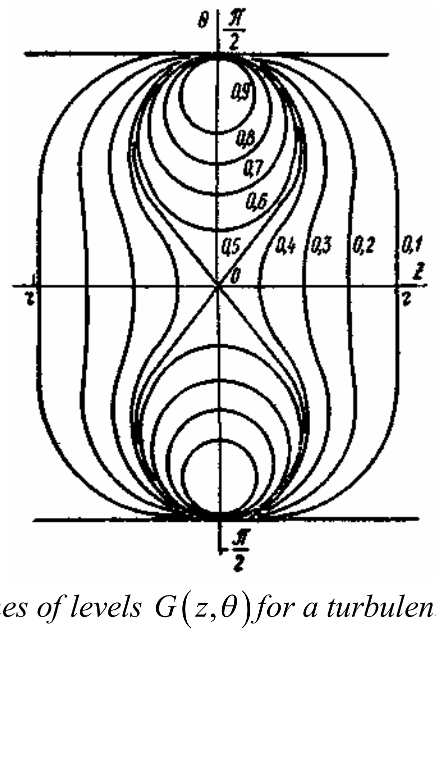

Fig. 2 Lines of levels $G(z,\theta)$ *for a turbulent flow*

For laminar mode $v_z = v_0\left[1-(\rho/r)^2\right]$ for superficial weight function it is possible to present expression in a kind

$$G^L(z,\theta)=\int_{-\infty}^{+\infty}\frac{v_0}{2\pi^2}\cos kz\,dk\sum(-1)^{p-1}n\cos n\theta\left[\frac{I_n(kr)}{rI'_n(kr)}\right]^2\left\{1+\frac{n^2}{k^2r^2}-\left(\frac{rI'_n(kr)}{I_n(kr)}\right)^2\right\}. \qquad (14)$$

Using асимптотическими formulas (11-12), we will receive, that for a laminar profile

$$G^L=\frac{v_0}{r}\operatorname{arctg}\frac{\cos\theta}{\operatorname{sh}(z/r)}. \qquad (15)$$

Superficial weight function $G^L(z,\theta)$ is represented on fig.3 and its lines of levels is represented on fig.4.

So, the analysis of behavior of superficial weight function shows that, basically, for any function $v_z(r,\theta)$ it is possible to receive superficial weight function corresponding to it, and, this function will always decrease at $|z|\to\infty$ and to increase to the maximum size at approach to electrodes.

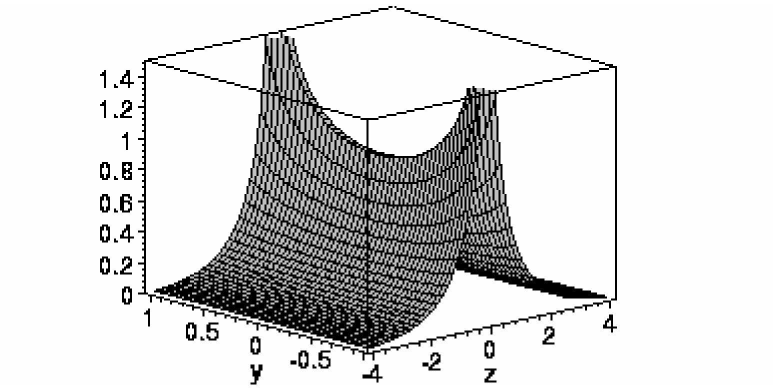

Fig. 3 Superficial weight function *for a laminar flow*

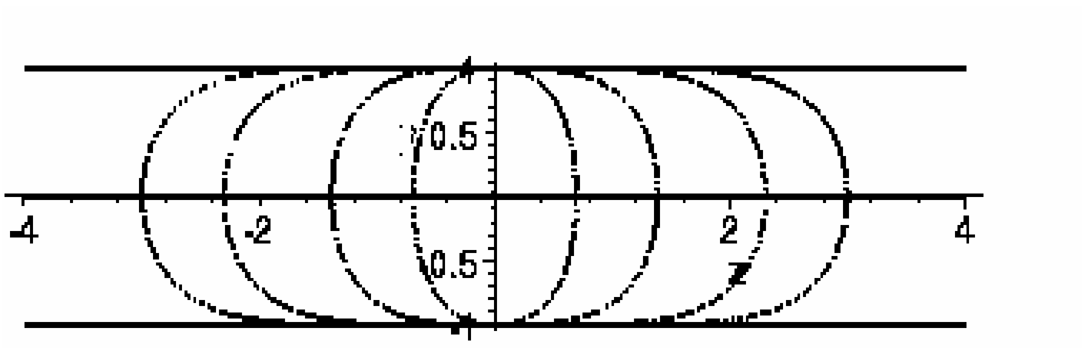

Fig. 2 Lines of levels $G^L(z,\theta)$*for a laminar flow*

L.A.Salami's researches [1] of flow in channels of the big diameter have shown that real flow profiles are described, for example, by the type equations

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

where r,θ - cylindrical co-ordinates; R - internal radius of the channel; *n, m, a* - the factors characterizing a flow mode.

The first term of an equation in the right part characterize axisymmetrics a component of a velocity profile, and the second term is a spectrum of spatial harmonics. And, the spatial harmonics defined by the second term of the right part of equation fade quickly. Therefore real flow modes can be essentially limited.

3. Conclusion

As physical basis of simulation model we can take the induction coil which had on an internal channel surface of the flowmeter dismantled from the pipeline. If turns of the induction coil are distributed on lines of superficial weight function than integrated voltage induced in the coil by a magnetic field of a flowmeter, will be proportional to voltage U arising between electrodes at flow movement of a liquid with corresponding distribution of flow velocity and structure.
Hereby, the simulation model with the magnetic field converter in the form of the induction coil executed on superficial weight function allows to model devices of a various design and at various hydrodynamic modes and flow structures.
As superficial weight function depends on geometry of the channel; kinematic flow structure; distribution of phase structure of the measured media in the channel; level of filling with a channel liquid at nonpressure flow. Therefore it is possible to research metrological characteristics of devices with changing of each of listed above factors separately or all of them together by simulation method. For this purpose it is enough to apply the coil executed with regard to the superficial weight function which reflects any reseach factor or their set.

References

[1] Salami L. A. , Trans. Inst. Measurement and Control, July-Sept.1984,V.6.,№ 4.,197-201.