Theoretical Model of Electromagnetic Flowmeter, Verification and Sensitivity Increasing

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***Abstract*—The paper deals with the analytical correlation between the obtained polarization voltage and the dielectric fluid velocity through the circular cross section of the polarization transducer. The aim is verification of the analytical results by the comparison of the analytically calculated voltage between the electrodes and its numerically obtained value applying FEM (QuickField 5.6). As the result of the inverse problem solution (Response Surface Methodology, Design of Experiments and Flexible Tolerance Method) the optimal constructive parameters and the exciting magnetic field distribution are determined guarantying maximal outgoing signal and consequently increasing the device sensitivity.**

Keywords—electromagnetic flowmeter; polarization voltage; optimization; sensitivity

I. Introduction

The flowmeter is an instrument that measures linear, nonlinear, mass or volumetric flow rate of a liquid or a gas within a pipe or tube. Measuring the flow of liquids is a critical need in many industrial applications. In some operations, the ability to conduct accurate flow measurements is very important. There are cases in which inaccurate flow measurements or failure to take measurements can cause not only serious but even disastrous results.

With most liquid flow measurement instruments, the flow rate is determined indirectly by measuring the fluid's velocity [1], [2], or the change in kinetic energy [3]. Velocity depends on the pressure differential that is forcing the fluid through a pipe or conduit. Because the pipe's cross-sectional area is known and remains constant, the average velocity is an indication of the flow rate. Other factors that affect liquid flow rate are the liquid's viscosity and density, and the friction of the liquid in contact with the pipe walls.

In general, this specific equipment includes the following groups: differential pressure, positive displacement, velocity, and mass meters. The group of the velocity instruments operates linearly with respect to the volume flow rate. Because of this simple relationship, their range ability is larger. Their additional advantage is that they have minimum sensitivity to viscosity changes when are used at Reynolds numbers above 10000 (turbulent flow). Most velocity-type meter housings are equipped with flanges or fittings to permit them to be connected directly into pipelines. The velocity flowmeters include the devices based on the electromagnetic field theory – electromagnetic and magnetoelectric flowmeters. The obvious advantages of these instruments are due to their contactless transducing and electrical output signals, which discloses great possibilities for automatic control and management.

The present paper deals with some electromagnetic flowmeter theoretical problems, verification of the obtained analytical results numerically, by applying Finite Element Method and finally - optimal design guarantying maximal outgoing voltage of the device (i.e. maximal sensitivity) or guarantying that the changes in temperature, density, viscosity, concentration and electrical conductivity of the medium do not affect the output signal. The operation principle of the electromagnetic flowmeter is based on Faraday's law, which states that a voltage is induced when a conductor moves through an exciting magnetic field. For this purpose a magnetic field is established transverse to a flow pipe. This field polarized moving dielectric fluid and a potential difference appears between suitable detecting electrodes. This potential difference is linearly proportional to the volumetric flow rate through the pipe.

II. Theoretical Model

A. Construction of the device

Some rough idea for an electromagnetic transducer is shown in Fig.1.

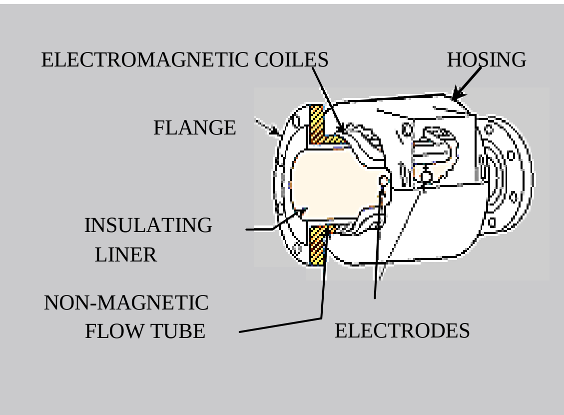

Fig.1.The major components of an electromagnetic flowmeter are electrodes and coils

B. Analytical analysis

A schematic view of the device cross section is presented in Fig. 2.

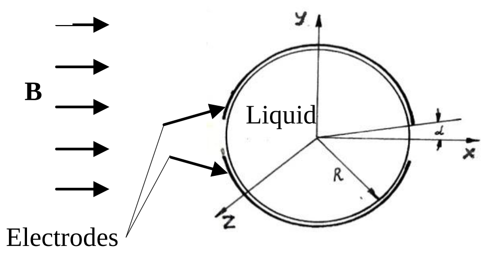

Fig. 2. Cross section of polarization transducer

Accepted idealizations in analytical investigation are:

- The length of the tube is vastly greater than any cross sectional dimension;
- The two electrodes are conductive, nonmagnetic. The tube is of dielectric material and consequently on the walls electric charges are not stored;
- The liquid is nonmagnetic.

Additionally the following assumptions are made:

- The forward motion of the fluid is uniform;
- The processes are stationary;
- The exciting magnetic field **B** is homogeneous;
- The currents of conductivity are neglected;
- The physical characteristics of the medium ε , μ and γ are considered constants.

The governing equation of polarization transducer is solved in cylindrical coordinates with respect to the scalar electric potential

$$\nabla^2\varphi = \frac{\varepsilon - \varepsilon_0}{\varepsilon} div(\mathbf{v}\times\mathbf{B}) \qquad (1)$$

After a number of transformations [4], a final equation is obtained relating the polarization voltage U between electrodes and the middle velocity v_m of the fluid

$$U = \frac{\pi}{4\ln 4/\alpha}\frac{\varepsilon_r - 1}{\varepsilon_r} B v_m d \cos\alpha . \qquad (2)$$

III. NUMERICAL EXAMPLE

A. Analytical solution

Equation (2) is solved by the use of admissible value of the liquid velocity $v_m = 0{,}5\,\mathrm{m/s}$, amplitude of the applied magnetic field $\mathrm{B} = 0{,}5\,\mathrm{T}$ and the following values of the other parameters: $d = 0.05\,\mathrm{m}$ (diameter of the tube); $\alpha = 10^0$ or $(0.1745\,\mathrm{rad})$ - angle between the two electrodes; relative dielectric permittivity $\varepsilon_r = 4$. As a result the value of the polarization potential is found $U = 2{,}315\,\mathrm{mV}$.

B. Numerical solution applying FEM

The same field analysis in solving the forward problem was carryied out using finite element method (FEM) and applying QuickField 5.6 software package [5]. The following boundary conditions are imposed:

- $\frac{\partial\varphi}{\partial n} = 0$ along the symmetry line *Oy*;
- φ= 0 - Dirichlet boundary conditions along the axis of electrical antisymmetry *Ox*;
- The given values of the potentials on the boundaries of electrodes: $\varphi_1 = 0$ and $\varphi = \varphi_2 = 2{,}315\,\mathrm{mV}$. So in advance the polarization voltage is assumed to be $U = 2{,}315\,\mathrm{mV}$.

Now, the problem – object of the analytical solution is simulated and solved in the reverse order: the input quantity is polarization voltage between the electrodes and as output value the middle velocity of the fluid is determined. The comparison between the analytical and the numerical solution for velocity shows satisfactory agreement within the limits of approximately 10%.

IV. INVERSE PROBLEM SOLUTION

As the result of the inverse problem solution (Response Surface Methodology, Design of Experiments and Flexible Tolerance Method) the optimal constructive parameters and the exciting magnetic field distribution are determined guarantying maximal outgoing signal and consequently increasing the device sensitivity.

V. CONCLUSION

The theoretical model of a polarization transducer is described and the analytical dependence between the dielectric fluid velocity and the polarization voltage of the device is obtained. The analytical results are verified by the comparison of the analytically calculated and numerically found values applying FEM. As an inverse problem solution, the optimal constructive parameters and the exciting magnetic field distribution are determined guarantying maximal outgoing signal and consequently increasing the device sensitivity.

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