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INVERSE FIELD PROBLEM IN A MAGNETOELECTRIC FLOWMETER

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ABSTRACT

The presented paper deals with determination of design parameters of a system, which creates uniform electric field transverse to a pipe through which flows dielectric fluid. The main purpose is development of a magnetoelectric flowmeter for measuring the volumetric flow rate of moving dielectric fluid. Different variants of the electrode locations, their dimensions and potentials have been investigated in order to obtain uniform electric field inside the pipe. Field analysis in solving a forward problem was carrying out using finite element method and applying QuickField 5.6 software package The inverse problem is solved using Response Surface Methodology and Design of Experiments.

Index Terms - magnetoelectric flowmeter, finite element method, uniform electric field, inverse problem,

1. INTRODUCTION

Many industrial applications require a measurement of flow [1], [2]. Such a measurement is the quantification of bulk fluid movement. It can be measured in several different ways. There are great variety of methods and devices for measuring of the parameters of moving fluids and especially the volumetric flow rate. But in some particular cases it is difficult to find suitable measuring device, because of diversity of physical, chemical or any other properties of the fluids, wide working modes and opposite requirements. The devices based on the electromagnetic field theory – electromagnetic and magnetoelectric flowmeters have obvious advantages due to the contactless transducer and electrical output signal, which gives great possibilities for automatic control and management.

In the present paper, the field of a magnetoelectric flowmeter for measuring the volumetric flow rate of moving dielectric fluid is studied. The principle of operation of the electromagnetic flowmeter is based on Faraday's law of induction, which states that a voltage is induced when a conductor moves through a magnetic field. In such a device a uniform magnetic induction is established transverse to a flow pipe. The conductive liquid serves as the conductor and flow of the metered fluid generates a potential difference at suitable detecting electrodes. This potential difference is linearly proportional to volumetric flow rate through the pipe.

When the investigated fluid is dielectric a flowmeter can be designed based on the fact that a moving, polarized dielectric generates an effective magnetic moment. It is the basis for creating of the magnetoelectric flowmeter [3]. In this case a uniform electric field is established transverse to a pipe through which a dielectric fluid flows and a magnetic induction is generated which is linearly proportional to the volumetric flow rate through the pipe.

2. STUDIED FLOWMETER

As it was already mentioned the main purpose of the presented investigation is development of a system for measuring the volumetric flow rate of moving dielectric fluid field. That is way we have at first to design a device, which creates uniform electric field transverse to a pipe through which flows the dielectric fluid.

The principal geometry of the investigated system is shown in Fig. 1. This system has to create uniform electric field transverse to a pipe 1 through which flows a dielectric fluid 11.

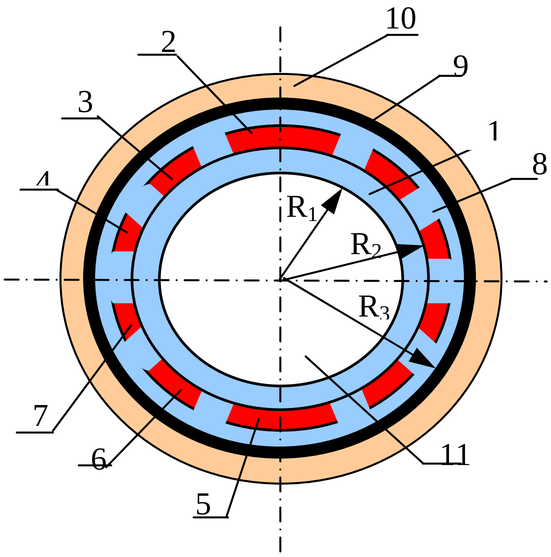

Figure 1 Principal geometry of the investigated system.

Elements of the system shown in Fig.1 are:
1 - pipe ;
2,3,4 - electrodes with potential V1, V2,V3;
5,6,7 - electrodes with potential -V1, -V2,-V3;
8 - dielectric ring
9 - earthing ring
10 - magnetic pipe
11- fluid

3. DETERMNATION OF THE DESIGN PARAMETERS

The specific purpose –uniform electric field transverse to a pipe through which flows dielectric fluid, determines the design parameters, the change of which has significant influence on the electric field distribution inside the pipe.

In previous investigation [4] was considered variant of system with only two electrodes with potential V and –V, shown in Fig.2, but it creates not enough uniform electric field and needs improvement.

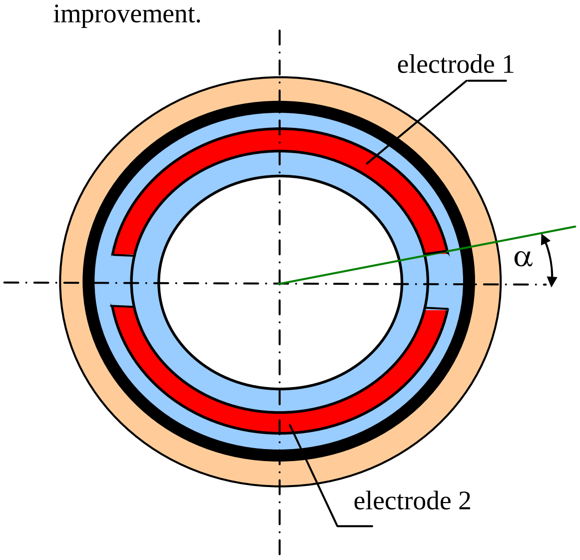

Figure 2 Initial system with only two electrodes: electrode 1 with potential V and electrode 2 with potential –V.

In this system only two parameters – the geometric angle α and potential of electrodes V were varied in order to obtain uniform electric field inside the pipe. The values of the parameters are limited according to some constructive boundaries.

$8^0 \le \alpha \le 23^0$;

$50V \le V \le 300V$

In Fig. 3 is given electric field distribution obtained with the initial system. Only a quarter of the system has been analysed due to the geometrical and electrical symmetry of the investigated region. The problem was solved as plane–parallel one, using finite element method and applying QuickField software package [5].

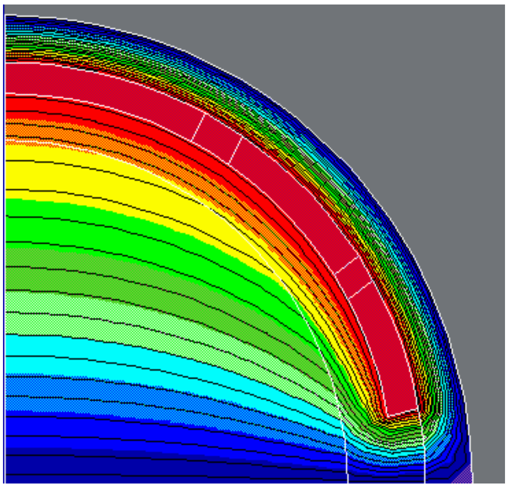
Figure 3 The electric field distribution obtained with the initial system

The next step in investigation was determination of another design of the system, which can produce really uniform electric field, transverse to a pipe with dielectric fluid.

During the investigation two main variants were considered, which are shown in Fig.4 and Fig.5 respectively. Again due the geometrical and electrical symmetry of the investigated region the only a half or even a quarter of the system have been studied.

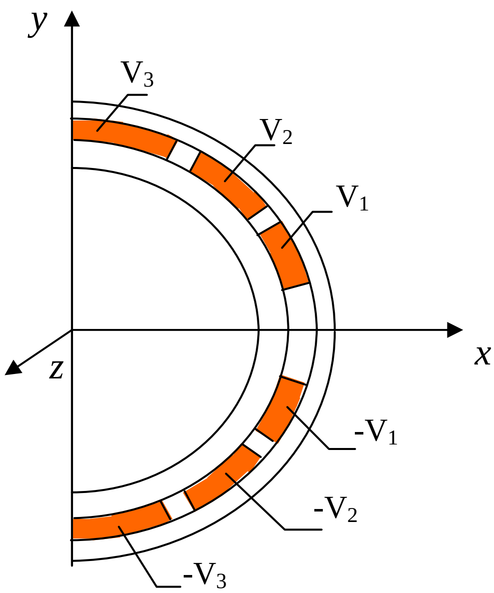

Figure 4 System with electrodes containing parts with different potentials: electrode 1 with potentials V_1, V_2 and V_3 and the geometrically opposite electrode 2 with potentials $-V_1$, $-V_2$ and $-V_3$.

The system proposed in Fig.4 allows a good possibility for changing the electric field distribution - we can supply different parts of each electrode with different voltages. In this case we can vary three design parameters: values V_1, V_2 and V_3. Thus it is possible to obtain rather different field distribution from the initial one.

In Fig.5 another possibility for changing the electric field inside the pipe is shown. In this case the electrodes contain again three parts, but with fixed different values of the potentials V_1, V_2 and V_3. In this case we can vary five design parameters: angels α_1, α_2, α_3, α_4 and α_5.

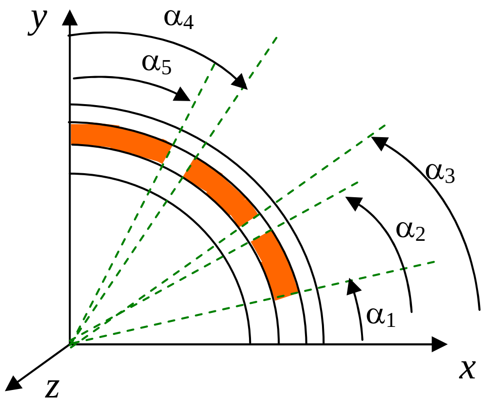

Figure 5. System with five design parameters: angles α_1, α_2, α_3, α_4 and α_5. The potentials of the three parts of electrodes have fixed values V_1, V_2 and V_3.

After analyzing and comparing the possibilities for changing the electric field distribution in the investigated systems the design, shown in Fig.5 was chosen as most suitable for the purpose of investigations. Thus the sought design parameters formed vector $\vec{h} = (\alpha_1,..\alpha_5)$

4. FORWARD PROBLEM FORMULATION

The aim of forward problem formulation is to constitute mathematical model of the electric field inside the pipe with dielectric fluid, which depends significantly on chosen design parameters – in considered problem on angles α_1, α_2, α_3, α_4 and α_5.

In Fig. 6 is given the region of investigation with posed boundary conditions. As it was already mentioned the field problem has been solved using finite element method and it was considered in plane *xOy* as plane-parallel one. The investigated region includes domains:

Ω_4- dielectric fluid,

Ω5- pipe,

Ω_1, Ω_2 and Ω_3 –electrodes with different constant values of the potential.

The boundaries are:

OA- axis of geometrical symmetry,

OB - axis of electrical antisymmetry,

AB - boundary of the earthing ring.

The electric field is modelled by Laplace equation:

$$\nabla^2 V = 0 \qquad (1)$$

where V is scalar electric potential.

The boundary conditions are posed:

$\frac{\partial V}{\partial n} = 0$ along the symmetry line OA;

V = 0 - Dirichlet boundary conditions along the axe of electrical antisymmetry OB and outer boundary of the earthing ring AB

$V = V_1$, $V = V_2$; and $V = V_3$ on the boundaries of electrodes Ω_1, Ω_2 and Ω_3

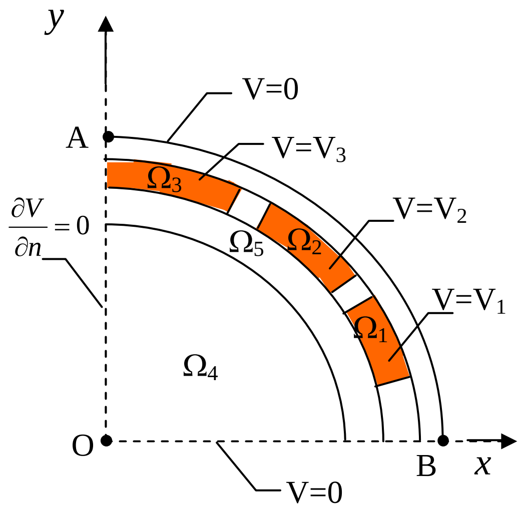

Figure 6. Region of field investigation with boundary conditions

5. FEM ANALYSIS

Numerical simulation of the electric field was carried out using QuickField software package. The problem was solved for different combinations of values of the design parameters $\vec{h} = (\alpha_1,..\alpha_5)$, according to the plan of numerical FEM experiments. This plan is based on the design of experiments theory and was used by our group in many previous investigations [6].

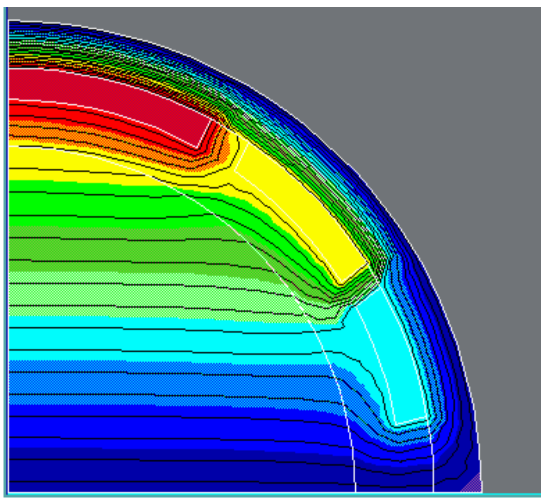

Figure 7 The uniform electric field distribution obtained with the optimised system

In Fig. 7 is shown the uniform electric field, obtained by the proposed optimized system.

6. INVERSE PROBLEM SOLUTION

Using the data, collected in numerical experiments in the forward step, the electric field models $\hat{T}^j$ at j=1,.10 control points has been approximated as expressions of the following type:

$$\hat{T}^j = b_0^j + \sum_{k=1}^{p} b_k^j h_k + \sum_{k=1}^{p} b_{kk}^j h_k^2 + \sum_{\substack{k=1 \\ r=k+1}}^{p} b_{kr}^j h_k h_r \qquad (2)$$

In (2), $p=5$ is number of design variables h_k, k=1÷ p. The design variables are used in normalized units. Coefficients b_0^j, b_k^j, b_{kk}^j and $b_{k,r}^j$ can be found using the method of least squares.

The inverse problem has been solved as optimisation one. Vector $\vec{h}$ determines seeking design parameters. The optimisation criterion used was the quadratic sum of the differences between the computed $\hat{T}^j(\vec{h})$ and desired $T_{desired}$ constant field in control points.

$$F_{\min}(\vec{h}) = \left\{ \sum_{j=1}^{p} \left(\hat{T}^j - T_{desired} \right)^2 \right\}_{\min} \qquad (3)$$

Table 1 presents design parameters for the obtained optimal variant of electric field distribution. In this case fixed potentials of electrodes are:

V1 =10V
V1 =7.5V
V1 =3.5V

Table 1

Values of the design parameters for optimal variant

Design Parameters	Values
α_1	28.83^0
α_2	34.46^0
α_3	32.74^0
α_4	28.9^0
α_5	10.33^0

7. CONCLUSIONS

Inverse problem in a system used for measuring the volumetric flow rate of moving dielectric fluid was solved. Different design variants of the system have been studied, changing electrode locations, their dimensions and potentials. As a result uniform electric field transverse to a pipe with dielectric fluid was obtained.

Field analysis in solving a forward problem was carrying out using finite element method and applying QuickField 5.6 software package. The inverse problem is solved using Response Surface Methodology and Design of Experiments.

8. ACKNOWLEDGEMENT

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