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The Analysis of Electrode Roughness of Medical Electromagnetic Flowmeter on the Measurement of the Impact

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Abstract: Electromagnetic flowmeter is used in medical devices such as dialysis machine, or a liquid flow rate of oxygen is detected, high accuracy is required. The electrode and the insulation lining used for a period of time, because of erosion by the fluid is worn, they will produce a surface roughness. And the surface roughness will be larger with the increase of the use of time, the sensor pipe flow field will be affected. According to the weight function theory, the change of the flow field near the electrode will greatly affect the measurement signal of the electromagnetic flowmeter, this will make electromagnetic flowmeter measurement error. In this paper, through the simulation calculation for the roughness of the electrode change caused by the result of the measurement error. The conclusion is that in order to keep the accuracy of measurement, after a period of use the flowmeter, the electrode must be replaced. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Electromagnetic flowmeter, Surface roughness, Weighting function, Output signal, Induced electromotive force.

1. Introduction

Electromagnetic flowmeter is applied to the blood dialysis machine or liquid oxygen flow detection, has a high requirement on the accuracy of measurement. However, medium scour can make electrodes and insulating lining of the flowmeter frayed. This will cause the surface roughness of the electrodes and lining increases, as shown in Fig. 1.

Therefore, the flow field will be affected. According to the electromagnetic flowmeter weighting function theory [1]. The change of the flow field near the electrode will greatly affect the output signal, so the change of the surface roughness of the electrode had a great influence on electromagnetic flowmeter measurement. In this paper, through the simulation calculation for the roughness of the electrode change caused by the result of the measurement error, and calculation the measurement signal under different surface roughness. The results show that the surface roughness of the electrode will cause error to the output signal, and error will be larger with the increase of roughness.

2. The Calculation Method of Electromagnetic Flowmeter Measurement Signal

If the conductivity of the medium is uniform, the basic equations of the electromagnetic flowmeter is

$$\nabla^2 U = \nabla \cdot (V \times B), \quad (1)$$

where U is the induced voltage, V is the flow rate and B is the magnetic field intensity, solve the Eq. 1, the relationship of voltage and current velocity on the electrodes of the electromagnetic flowmeter can be obtained. Solve the (1) must be given boundary conditions. Applied to "long barreled flow meter" physical model [2], shown in Fig. 2.

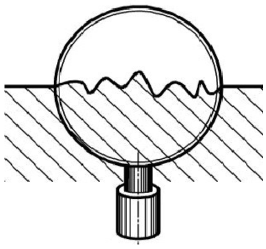

Fig. 1. Surface roughness.

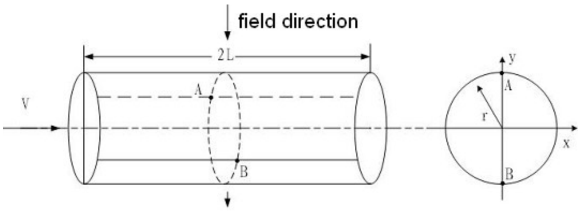

Fig. 2. The long barreled flowmeter model

There are six conditions:

1. Field direction, two electrode axes and the pipe are perpendicular to each other.
2. Measured fluid conductivity of the medium is uniform.
3. The direction of fluid flow and pipe direction are parallel, the flow state is axisymmetric distribution, and the flow rate was a function $V(r)$ of the radius vector r.
4. The flow rate at the pipe wall is zero, insulating lining on the inner wall.
5. The electromotive force of electrode A and B is U_{AB}.
6. All the physical quantities in the z axis are the same.

Introduction of auxiliary function G is solvable partial differential Eq.1, G is Green's function, and meet the Laplace's equation, $\nabla^2 G = 0$ and meet the boundary conditions by 4 and 5 prescribed[1], the boundary conditions are(2), (3) and (4),

$$\frac{\partial G}{\partial n} = +\frac{\pi RL}{s} \text{ on the electrode A} \qquad (2)$$

$$\frac{\partial G}{\partial n} = -\frac{\pi RL}{s} \text{ on the electrode B} \qquad (3)$$

$$\frac{\partial G}{\partial n} = 0 \text{ on the measurement pipe outside the electrode,} \qquad (4)$$

where R is the radius of pipe section and s is the electrode area. According to the condition 3 and (1), the electromotive force between electrode A and B can be obtained,

$$U_{AB} = \frac{1}{\pi RL}\int V(r)BWdV \qquad (5)$$

and

$$W = \nabla G , \qquad (6)$$

where W is the weight function, it is the three-dimensional function, W_x, W_y, W_z are the component of function W in the coordinate axes X, Y, Z. According to the above conditions, the weight functions only consider the Y axis component W_y, from (7) get (8),

$$W = \frac{\partial G}{\partial y} \qquad (7)$$

Calculated W analytic solution [1, 2] as

$$W = \frac{R^2(R^2 + x^2 - y^2)}{R^4 + 2R^2(x^2 - y^2) + (x^2 + y^2)^2} \qquad (8)$$

The distribution of weight function W in the electrode plane of the pipeline space, shown in Fig. 3 [1],

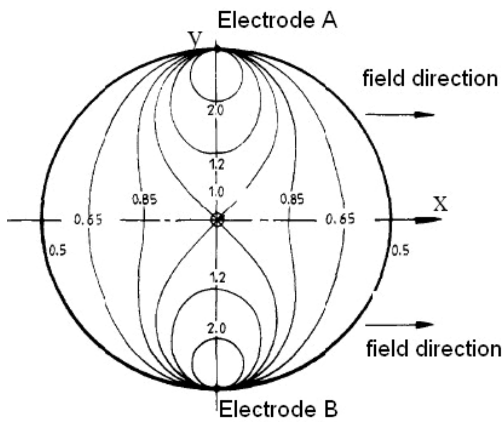

Fig. 3. The weighting function distribution of uniform magnetic field point electrode electromagnetic flowmeter.

Weight function is a dimensionless space function, any point of the weighting function shows that the contribution of this point of fluid cut the magnetic force line to produce induced electromotive force to the electrodes. According to the (5), (8), and velocity distribution of pipe flow field $V(r)$ is obtained by simulation, electromagnetic flowmeter measurement signals can be obtained:

$$E = 2BRk\int_0^R \int_{-\pi}^{\pi} W(r,\theta)V(r)rd\theta dr \quad (9)$$

Due to the electromotive force signal is obtained on electrode in the two-dimensional plane, without considering the whole pipeline on the direction of fluid's contribution to the electrode signal, therefore, with the dimensionless coefficient k. For the sake of simplicity, can assume that the magnetic field is uniform magnetic field everywhere, and $B = 1T$.

3. The Influence of Electrode Roughness of Electromagnetic Flowmeter Measurement Signals

Under the condition of electromagnetic flowmeter electrode is extremely smooth material, simulate the electromagnetic flowmeter pipe flow field. According to the characteristics of the medical electromagnetic flowmeter and set the meter pipe diameter of 10 mm, the electrode diameter of 1 mm, fluid medium is blood, average velocity is $2\ m/s$, The kinematic viscosity of the fluid is $3.0\times10^{-6}\ m^2/s$, according to the formula of pipeline fluid Reynolds number [2],

$$\text{Re} = \frac{\bar{v}D}{V}, \quad (10)$$

where $\bar{v}$ is the pipe average flow velocity of the fluid, D is the pipe diameter, V is the kinematic viscosity of the fluid. Re =100000, According to the Reynolds number, the pipe fluid motion state is turbulence. The pipe flow field velocity distribution contour is shown in Fig. 4.

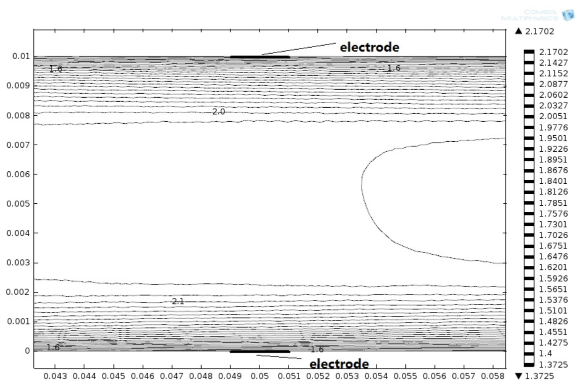

Fig. 4. Flow field distribution of the electromagnetic flowmeter with smooth electrode.

The electrode as point electrode, take two electrodes in the pipe cross section on flow velocity data, according to the (9), induced electromotive force can be obtained as $E = 0.022801\,k$.

Electromagnetic flowmeter to use after a period of time, medium scour can make electrodes of the flowmeter frayed, so the surface of the electrode surface will produce certain roughness. Set up roughness to the electrodes, and the roughness value is $Ra0.3\ \mu m$ .The flow field distribution near the electrode is shown in Fig. 5.

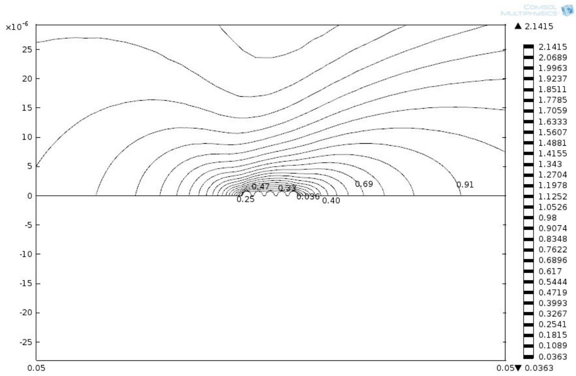

Fig. 5. $Ra0.3\ \mu m$ velocity contours near the electrodes.

Take two electrodes in the pipe cross section on flow velocity data, according to the (9), induced electromotive force can be obtained as $E = 0.022939\,k$. Compared with smooth electrode, measurement signal produced positive error.

Increasing the surface roughness of the electrode, set the value of surface roughness as $Ra0.6\ \mu m$. The flow field distribution near the electrode is shown in Fig. 6.

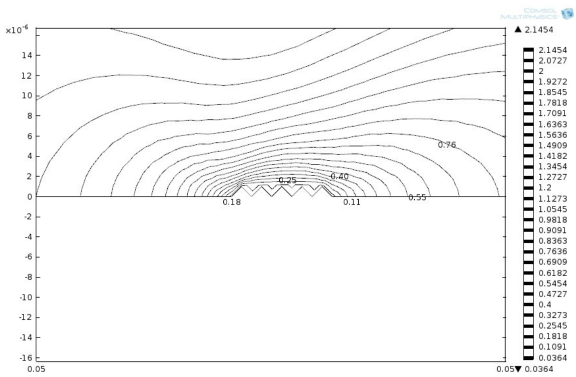

Fig. 6. $Ra0.6\ \mu m$ velocity contours near the electrodes.

Induced electromotive force can be obtained as $E = 0.023226\,k$. Obviously, with the increase of the electrode surface roughness, the positive error of induced electromotive force are continue to increase, respectively with the same method to simulate the surface roughness of the electrode are $Ra0.05\ \mu m$, Ra0.1 μm , Ra1.0 μm , Ra1.5 μm , Ra2.0 μm , average velocity is $2\ m/s$, flow field distribution is shown in Figs. 7-11.

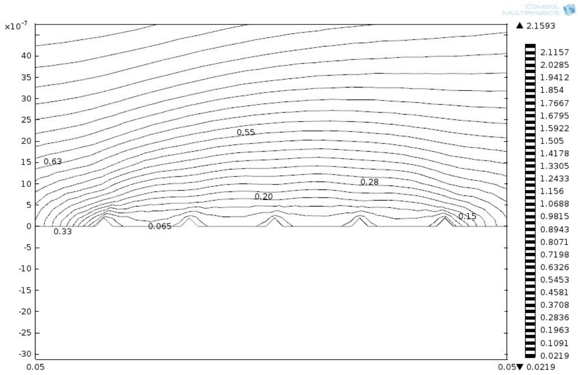

Fig. 7. $Ra0.05\,\mu m$ velocity contours near the electrodes.

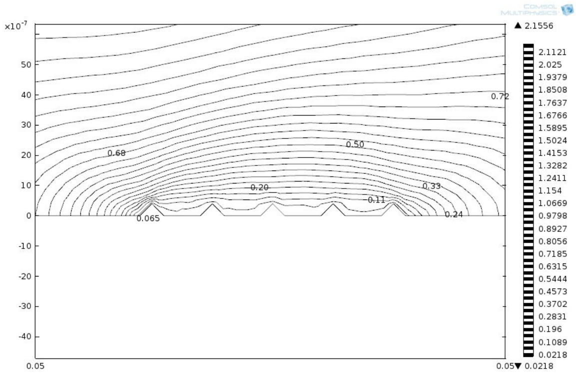

Fig. 8. $Ra0.1\,\mu m$ velocity contours near the electrodes.

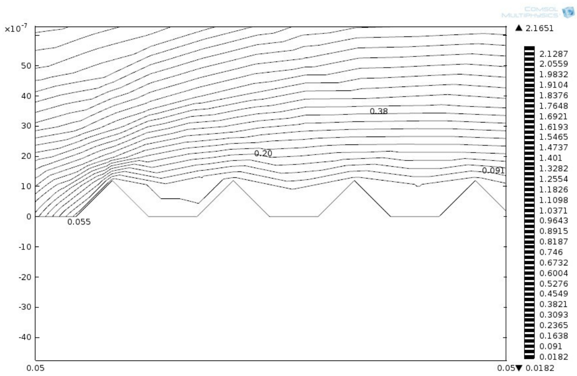

Fig. 9. $Ra1.0\,\mu m$ velocity contours near the electrodes.

Based on the electrode plane two-dimensional flow simulation data, calculated by the (9) can be obtained electromotive force data are $E = 0.022823\,k$, $E = 0.022846\,k$, $E = 0.023397\,k$, $E = 0.023494\,k$, $E = 0.023595\,k$. According to the above data, can be obtained the relationship between electrode roughness and induced electromotive force under the condition of the average flow velocity is $2\,m/s$ is shown in Fig. 12.

It can be seen that the increase of electrode roughness cause the increase of electrode induction electromotive force on both ends. Electrode roughness increases from $Ra0.3\,\mu m$ to $Ra0.6\,\mu m$, induced electromotive force incremental obviously faster, the reason is that the thickness of the pipe internal fluid viscous sublayer is between $0.3\,\mu m$ and $0.6\,\mu m$. In the case of the thickness of viscous sublayer and electrode roughness quite, so the influence of the flow field is more obvious in the case of the thickness of viscous sublayer and electrode roughness are similar.

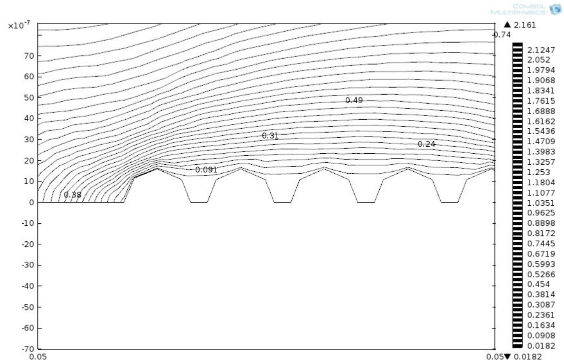

Fig. 10. $Ra1.5\,\mu m$ velocity contours near the electrodes.

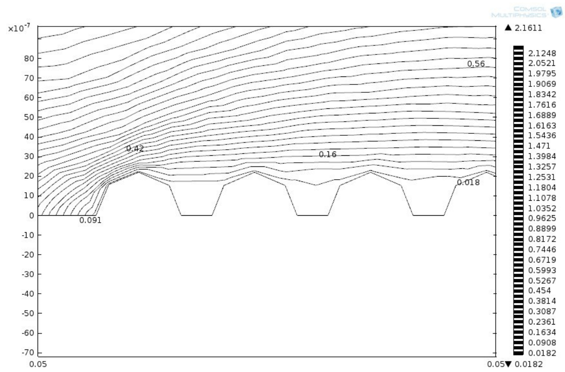

Fig. 11. $Ra2.0\,\mu m$ velocity contours near the electrodes.

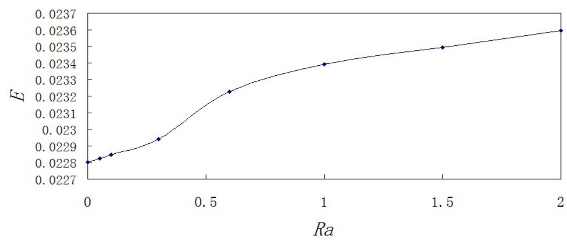

Fig. 12. Average flow velocity is $2\,m/s$, the relationship between electrode roughness and induction electromotive force.

Set up the average flow velocity of fluid is $3\,m/s$, the roughness of the electrodes respectively are 0, $Ra0.05\,\mu m$, Ra0.1 μm , $Ra0.3\,\mu m$, $Ra0.6\,\mu m$, $Ra1.0\,\mu m$, $Ra1.5\,\mu m$, $Ra2.0\,\mu m$. Based on the electrode plane two-dimensional flow simulation data, calculated by the (9) can be obtained electromotive force data are $E = 0.03479\,k$, $E = 0.034798\,k$, $E = 0.034842\,k$,

$E = 0.03565\,k$, $E = 0.036292\,k$, $E = 0.036537\,k$, $E = 0.036682\,k$, $E = 0.036756\,k$. According to the above data, can be obtained the relationship between electrode roughness and induced electromotive force under the condition of the average flow velocity is $3\,m/s$ is shown in Fig. 13:

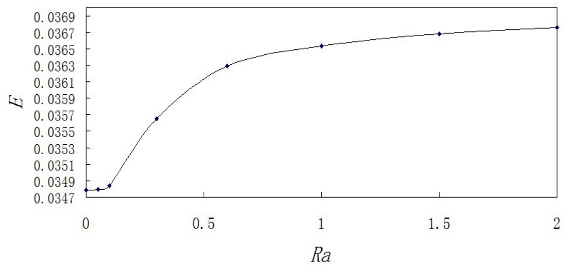

Fig. 13. Average flow velocity is $3\,m/s$, the relationship between electrode roughness and induction electromotive force.

It can be seen that similar to the average flow velocity is $2\,m/s$,In the case of average flow velocity is $3\,m/s$, with the increase of electrode roughness, induction electromotive force is also increased, measurement results show that the roughness of the electrode to generate positive error. On the electrode roughness for the range of Ra0.1 μm to Ra0.3 μm , induction electromotive force increases more quickly, this is due to average fluid velocity increases to $3\,m/s$, the thickness of viscous sublayer reduced to between $0.1\,\mu m$ and $0.3\,\mu m$.

4. Conclusions

The surface roughness of the electrode is scoured by the fluid will gradually increase, this will affect the flow field distribution near the electrodes. According to the weight function theory and the simulation results to get the following conclusion:

1. The roughness of the electrode change will change the distribution of flow field near the electrodes.

2. Weighting function values in the vicinity of the electrode is very large, so the Slight changes of flow field near the electrode will make the output signal is affected.

3. The increase of electrode roughness can make the signal increase on both ends of the electrodes and positive error occurred. The change of electrode roughness range near the viscous sublayer, the increment of error is the largest.

In summary, electromagnetic flowmeter accuracy deteriorates after a period of time resulting in a positive error is usually due to the surface electrode roughness increases. If the electrode roughness and thickness of the viscous sublayer of the fluid to be measured almost, then this error would be great .The accuracy requirement of medical electromagnetic flowmeter is very high, therefore, must be periodically check and replace the electrode can avoid the flowmeter is influenced by electrode roughness and produce error.

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