Electromagnetic Flowmeters With the Governing Boundary Conditions on The Channel Wall

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Abstract: Electromagnetic flowmeters at which electric potential distribution to channel surfaces is controlled with using the foreign current brought to measuring electrodes are considered.

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1. Introduction

Liquid metals (sodium, potassium, lithium, eutectic of plumbum and bismuth, sodium and potassium) are used as heat-transfer in nuclear power plants. In the process some requirement for heat-transfer flowmeters is appeared. This flowmeters have to be able to operate in close to the extreme condition. A high temperature (to 400 - 500°C), complicated radiating conditions and also extremely high reliability requirements essentially limit choice of devices constructional design.

Application of flow measurement electromagnetic method solves this problem. The electromagnetic flowmeter contains a not magnetic steel pipe. Two electrodes and inductor composed induction coil and magnetic conductor with polar tips are welded-in to the pipe outwall.

Inductor is rigidly attached to a flowmeter pipe. The inductor attaching points to a pipe are located on a vertical symmetry line of the pipe which is magnetic and electric neutral lines too. Such inductor fastening provides absence of shunting by magnetic conductor of electric signal induced between electrodes. The inductor coil is removed from a pipe which is a source of thermal radiation.

High accuracy of flow measurement; good operational characteristics and device reliability was reached due to application of a pulse low-frequency magnetic excitation field; microprocessors and program methods of signals processing. Influence of external mains frequency interfering signal; insignificant influence of own induction and capacitive hindrances are eliminated. Influence of vortical currents is almost eliminated.

As the devise channel has no insulating cover, the metal pipe serves as the electric shunt of a signal. The currents causing a voltage drop on flow transducer internal resistance passes on pipe sidewall. This voltage drop is estimated as the factor k_t which is defined from expression [1] proceed:

$$k_t = \frac{2D_1/D_2}{1+(D_1/D_2)^2+(\sigma_2/\sigma)\left[1-(D_1/D_2)^2\right]}, \qquad (1)$$

where D_1, D_2 - diameters of a pipe (internal and external); σ, σ_t - conductivity of a liquid and a pipe material. The value of k_t is less to one: $k_t \le 1$. The value is closer to one, the difference between D_1 and D_2 is less, i.e. the pipe wall is thinner the relation σ_t/σ is less.

The formula (1) is fair if there is no additional transitive electric resistance between the fused metal and the pipe sidewall. Actually it often arises and usually is called as contact resistance. This resistance essentially complicates flowmeter operation according two reasons: it reduces a measured potential difference and causes an additional error of measurement owing to the inconstancy. Potential difference reduction occurs because the shunting current proceeding on a metal pipe reduces voltage on internal resistance of the converter (that considers factor k_t and also on transitive contact resistance R_k.

The k_k factor considering previously mentioned phenomenon is possible to present factor together with k_t under the formula

$$k_t = \frac{2D_1 / D_2}{1 + (D_1 / D_2)^2 + (2R_k \sigma_t / D_1 + \sigma_2 / \sigma)\left[1 - (D_1 / D_2)^2\right]}. \quad (2)$$

Considerable contact resistance R_k arises on the one hand, because of insufficient cleanliness of an pipe internal surface and formation on it oxide films and from another hand - owing to not enough wetting of a pipe surface by a liquid.

An essential lack of flowmeters is sensitivity to shunting action of the channel wall.

The special scheme of measurement can provide to a flowmeter tolerance to resistance of a channel sidewall. The scheme of measurements is constructed such way that electric field distribution in channel sidewall which is identical to electric field in an interface of liquid metal [2] is always provided by means of the foreign current passed through electrodes and a wall of a pipe.

As electric potentials in a sidewall and an interface are identical, the measurement mode practically corresponds to a mode of flowmeter measurement with a channel electroinsulating cover. Differently the conditions providing absence normal components of a current between the measured media and a sidewall of the channel are created and supported artificially by means of a foreign current. The foreign current proceeding through electrodes and a pipe sidewall is the flow measure.

2. Measuring Systems

Let's consider measuring systems with using which the influence of channel sidewall shunting action is practically eliminated. Feature of these schemes is that the foreign current changing distribution of electric potential on border between a wall of the channel and an interface of the measured media through electrodes and a channel wall is passed. The measured media is the liquid metal heat-transfer.

Let's consider two types of the measuring schemes providing controlling by conditions on border between the measured media and a channel sidewall. They possess following characteristic specific properties.

The first type of schemes is sensitive to changes of pipe sidewall electric resistance but is tolerant to change media electroconductivity and to contact resistance. Polarity of a current coincides with polarity of the induced by flow movement signal.

The second type of schemes is sensitive to change the measured media electroconductivity and to contact resistance, but is tolerant to changes of pipe sidewall electric resistance. Polarity of a foreign current is opposite to polarity of the induced by stream movement signal.

The flowmeter block diagramme is resulted on fig. 1. Here the electric field distribution in the channel wall which is identical to electric field in an interface of liquid metal in case of not electroconductive sidewall is provided by means of a foreign current.

This flow transducer is presented in the form of the equivalent scheme consisting of EMF source E; internal resistance r and the shunting resistance R equal to resistance of a channel sidewall. The scheme of measurements contains two contours of a feedback - negative on voltage and positive on a current. The role of last consists in transformation of a output signal α in a current I having such size at which voltage on resistance R is installed practically equal to source size E .

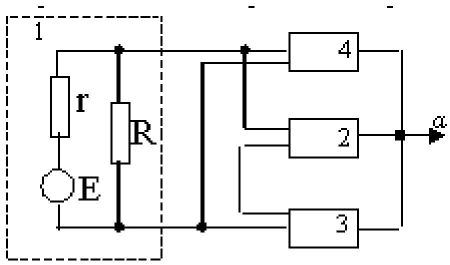

Fig. 1 The flowmeter block diagram with two feedback converters:
1 - the primary converter; 2 - the comparator; 3 - the negative feedback converter ; 4 - the positive feedback converter .

This condition is provided in the event if the ratio of transformation factors of the negative and positive feedback is equal to shunting resistance of a pipe sidewall R, i.e.

$$K_u / K_I = R, \tag{3}$$

where $K_u = U/\alpha$ - converter 3 transformation factor; $K_I = I/\alpha$ - converter 4 transformation factor. During the realization of a condition (3) electric potentials in a sidewall and an interface become identical and the measurement mode practically corresponds to a flowmeter with a channel electroinsulating cover. The foreign current proceeding through a pipe sidewall is the flow measure. Connection of output co-ordinate α with the measured size E can be presented in the form of the well-known formula

$$\alpha = E \frac{K}{1 + K\beta}, \tag{4}$$

where $K = K_H \dfrac{RR_{in}}{rR + RR_{in} + rR_{in}}$, $\beta = K_u$.

The received equation shows that the system is stable and as a whole operates as the system covered by a negative feedback with factor β and the output co-ordinate does not depend on value of internal resistance r.

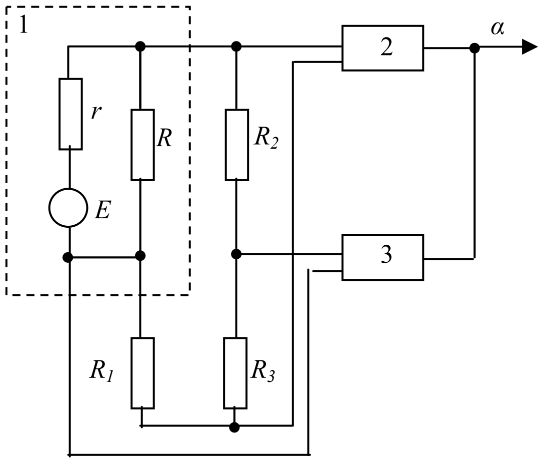

Fig. 2. The bridge scheme of a flowmeter: 1 - the primary converter;
2 - the comparator; 3 - the feedback converter.

Other schemes of a flowmeter with the same metrological characteristics are known also. For example it is the bridge scheme (fig. 2). This scheme contains only one contour of a feedback with the converter of output co-ordinate in an electric current. Simultaneously a condition of independence of the bridge scheme signal from change of source EMF E internal resistance r is a ratio

$$R_1 R_3 / R_2 = R \qquad (5)$$

If the flowmeter magnetic field is created by means of an electromagnet then the foreign current can be supported to be constant and a feedback is realized by respective alteration of electromagnet excitation current. The exciting current value which is convenient for regulation is set up by a choice of exciting coil parameters.

Resistance R in service depends on temperature of the heat-transfer which can be supervised by corresponding measuring apparatuses and can be considered at factor k_t calculation .

If wall resistance R for any reasons changes than conditions (3) and (5) are broken. Such situations are possible at long operation of the device when sticking of deposits and oxides to its internal surface and washing away from the sidewall metal of any components change its electric resistance. It leads to an error of value k_t definition.

It is possible to construct the flowmeter scheme which is tolerant to changes of pipe sidewall resistance [3] on the same principle of passing a foreign current through electrodes. For this purpose foreign current is passed through electrodes and a pipe sidewall. This foreign current value is able to provide zero potential difference between measuring electrodes. The foreign current also is accepted as flow measure. Such scheme is typical measuring system with a negative feedback on a current (fig. 3) in which voltage U between electrodes is described by formula:

$$U = \frac{ER}{r+R}\left(1 - \frac{Ir}{E}\right). \qquad (6)$$

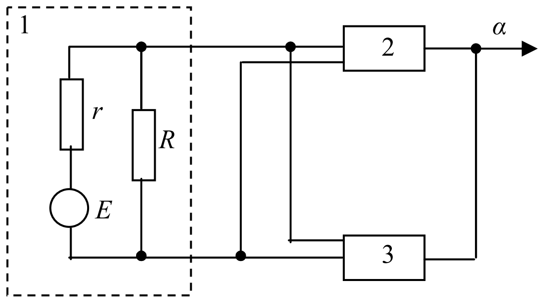

Fig. 3. The scheme of a flowmeter with zero potential in a channel wall:
1 - the primary converter; 2 - the comparator; 3 - the feedback converter.

From (6) follows that if the foreign current I equals $I = E / r$ then a potential difference between electrodes $U = 0$. Electric potentials in any place inside a sidewall become identical and do not depend on resistance R of a sidewall.

In this case the current I brings the information only about EMF E and heat-transfer resistance r and does not depend on sidewall resistance and its changes. However, this scheme is sensitive to change of electric resistance of the measured media. This resistance depends on heat-transfer temperature which can be supervised by corresponding measuring apparatuses and can be considered at factor calculation k_t.

Other measuring flowmeters schemes possessing similar metrological characteristics can be constructed by means of boundary conditions controlling by a foreign current.
For example, It can be realized with application of the current generator which periodically creates monotonously accruing and decreasing foreign current through a channel wall. The moment of achievement of the value providing this or that mode of electric field formation in the channel is fixed by indication system. One of such schemes (fig. 4) contains the alternating current generator 3 with using which alternating current (for example, the sinusoidal or sawtooth form) is periodically passed through a flowmeter.
The comparator 2 fixes the moments of balance of the measurement scheme when the electronic key 4 opens and generator output voltage is supplied on the voltage indicator. The flow measure is generator output voltage. Normalizing resistance R_0 installs an operating mode: if $R_0 = R$ than flowmeter operates in a mode corresponding to schemes fig. 1 and fig. 2 if $R_0 = 0$ - fig. 3.
Replacement of the primary converter with equivalent schemes having the concentrated parameters (as it is made above) is rather relative as it is system with the distributed parameters.
So, if there are cylindrical pipeline and a homogeneous magnetic field then channel leaks of a foreign current in the measured media and from the measured media to a pipe sidewall are possible on some sites of an internal cannel surface. It, certainly, reduces accuracy of indemnification of shunting effect by the considered methods and schemes.

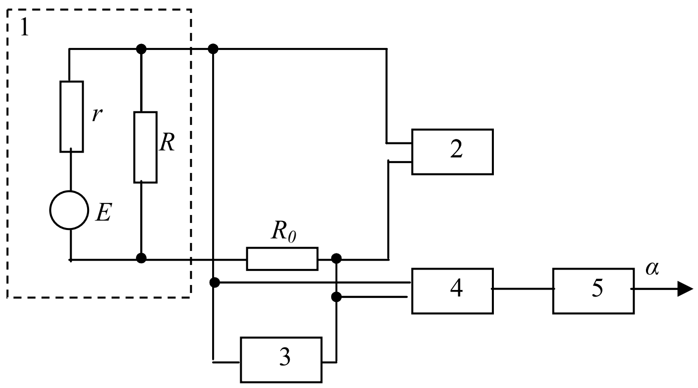

Fig. 4. The flowmeter scheme with the current generator: 1 - the primary converter; 2 - the comparator; 3 - the current generator; 4 - the electronic key; 5 - the indicator.

Controlling of boundary conditions on a channel sidewall can be applied for flowmeters with ionic liquids for example: pulps and suspensions where the raised deterioration of electroinsulating coverings of the electromagnetic flowmeters traditional designs channel [4] is observed. The exception of an insulating cover of the channel can raise reliability. The electromagnetic flowmeter possessing raised reliability is represented on fig. 5. It contains magnetic field induction 6; the site of the pipeline 1 made from not magnetic steel; the additional electrode 3 contacting to measuring media 7 and isolated from the metal pipeline 1 by electroinsulating plug 2 with flanging 11 surrounding a contact surface of an additional electrode. The generator of a current 9 which is operated by the comparator 8 is connected to electrodes 4 and 5. The input of the comparator 8 is connected to an additional electrode 3 and to an electrode 4. When the liquid is moving on pipeline the electric field is caused in the liquid and in the pipe sidewall by interaction between flow liquid and inductor magnetic field. Intensity of electric field is proportional to an induction of a magnetic field and flow velocity. Under electric field in a liquid and pipeline sidewalls circulating currents proceed. Because the measured media electroconductivity is considerably lower than pipeline sidewalls electroconductivity the sidewall make strong shunting impact on the signal induced in a liquid. The part of this signal is found out in the form of a potential difference ΔU between an additional electrode 3 and an electrode 4. The value ΔU is proportional to an induction of a magnetic field; measured media flow velocity and measured media electroconductivity. The potential difference value ΔU is rising with increasing of flanging diameter of the isolating plug round an additional electrode contact surface. For normal and stable operation of a flowmeter it is quite enough to have flanging with the diameter size which is equal more than three diameters of an additional electrode contact surface. The comparator 8 strengthens a potential difference ΔU perceived by it and will transform it to the current of the generator 9 passed through electrodes 4 and 5 and pipeline sidewall. This current is a current of a negative feedback of a flowmeter. In process of current increase through electrodes 4 and 5 shunting influence by pipeline sidewalls of the intensity of electric field induced in a liquid decreases; circulating currents between a liquid and pipeline walls decrease; the potential difference ΔU between electrodes 3 and 4 thus decreases. At achievement of the minimum exchange by circulating currents between a liquid and pipeline sidewalls there comes balance of system with a feedback which the considered flowmeter is. The flow measure is current of a feedback generated by the generator 9.

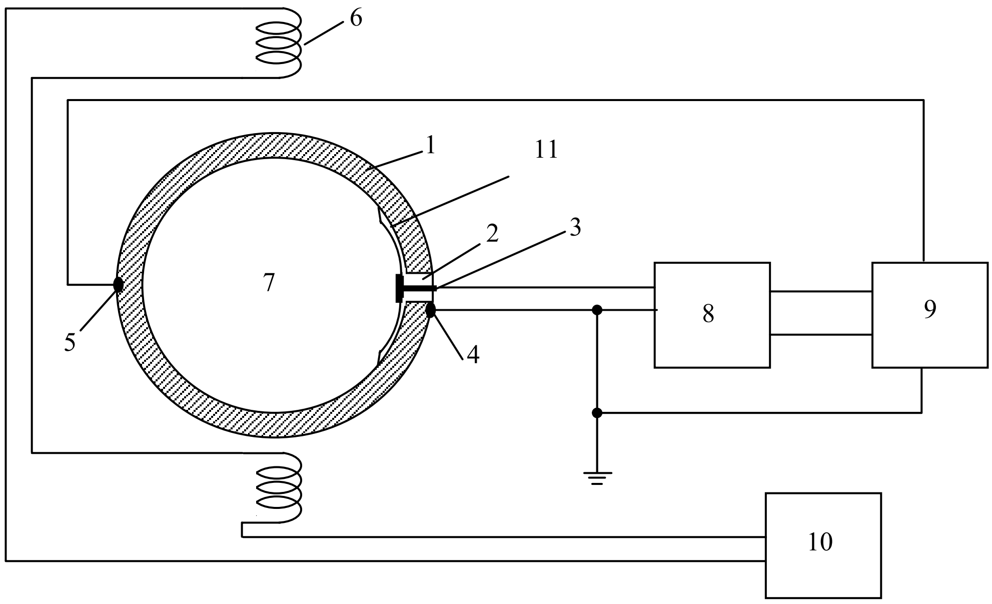

Fig. 5 Flowmeter for ionic liquids.

The considered electromagnetic flowmeters with operated boundary conditions can find application at measurement of liquid metals, pulps, cement mortars and other media.

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