NEW GENERATION OF MAGNETIC FLOWMETERS FOR LIQUID METAL

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Abstract: A magnetic flowmeter is described in which the inductor is an electromagnet inducing a pulsed low-frequency magnetic field in the pipe channel. Due to an alternating magnetic field applied, the effect of external noise caused by the power-line frequency is fully excluded, the effect of thermo-electromotive force is significantly reduced, and the effect of eddy currents is practically excluded, etc.

Keywords: magnetic flowmeters, inductor, liquid metals, nuclear power plants.

1. INTRODUCTION

Liquid metals (sodium, potassium, lithium, lead-bismuth and sodium-potassium eutectics) are used as heat-transport media at nuclear power installations. In this case a demand arises for heat-transport medium flowmeters which are capable of functioning under the near-extreme conditions. High temperature (up to 400 – 500 °C), complex radiation environment, as well as extremely high reliability requirements limit the scope for choosing instrument designs.

The conventionally designed electromagnetic flowmeter for liquid metals comprises a pipe made of stainless steel, two measuring electrodes welded onto the outer surface of the pipe wall, an inductor inducing a magnetic field within the working volume of the channel, and a measuring device. In the well-known designs, the inductor which is a constant magnet induces in the pipe channel a magnetic field directed at right angle to the plane passing through the line which connects the electrodes and the axis of the pipe [1], [2]. When measuring liquid metals having electronic conductance, electrode polarization phenomenon does not exist, therefore a magnetic field induced by the constant magnet can be used in electromagnetic flowmeters.

When the liquid metal passes through the channel, an electric field which generates circulating currents in the measured medium and in the pipe wall contacting the measured medium is established in the liquid metal traversing the magnetic field. Owing to the currents passing in the pipe wall, potential difference is set up between the electrodes, which is taken to be a measure of the volume flow rate of the liquid metal. The potential difference e is calculated by the equation

$$e = BDv = 4BQ_0 / \pi D ,$$

where B is magnetic induction, D is a channel diameter, v and Q_0 are respectively a mean velocity and a volume flow rate of the liquid metal.

The instruments in question do not have trouble connected with noise and restrictions caused by electrode polarization. However, use of molten metals with high temperature and high electric conductance, as well as lack of inner lining leads to flowmeter indications being significantly affected by temperature variation in the measured medium.

Due to the magnetic system being heated, the induction of the magnetic field and, therefore, the induced electromotive force e are decreased.

The corresponding reduction factor k_t can be expressed by the formula

$$k_t = 1 - \beta_M (t_M - t_0),$$

where β_M is a demagnetization factor the value of which is approximately $(2.6\text{-}2.8)10^{-4}/^0\text{C}$ for magnets [1], t_M is a mean temperature of the magnet, t_0 is an initial temperature of the magnet, which usually equals 20^0C. The temperature of the magnet in the operating mode of the flowmeter can reach $200\ ^0\text{C}$ and over.

For certain types of magnetic system, experiments with an electromagnetic flowmeter show that with the temperature of the measured medium being $300\ ^0\text{C}$ and the mean temperature of the magnet being $54\ ^0\text{C}$ the factor $k_t = 0{,}99$, and with increase in these temperatures respectively up to $400\ ^0\text{C}$ and $75\ ^0$ the factor k_t decreases down to 0.985.

For controlling the influence of the temperature on the sensibility of the flowmeter with constant magnets, measures should be taken to provide better cooling of the magnetic system, and the magnetic system itself must be heat treated as it is manufactured with the aim of stabilizing its magnetic characteristics.

Besides, the flowmeter with a constant magnet is sensitive to the thermo-electromotive force arising in different components of the instrument design. If the material of the pipe and that of the electrodes are different, and if temperature difference exists between the electrodes as well, then parasitic thermo-electromotive force arises. To reduce it to an acceptable minimum, the electrodes and the pipe are made of the same material. Moreover, the pipe units with the pairs of electrodes which induce at a temperature difference of $20\ ^0\text{C}$ the thermo-electromotive force exceeding a certain minimum, e.g. in the order of 5 µV, are rejected.

For the flowmeter with constant magnets, the arrangement of the electrodes is of significant importance. A vertical arrangement on a horizontal pipe is the most unfavourable. At a high temperature of molten metal, strong air convection currents occur giving rise to temperature difference of the electrodes and, therefore, perceptible thermo-electromotive force.

Thus, for example thermo-electromotive force amounted to 0.2 µV on a pipe of 25 mm in diameter at a metal temperature of 300 ^{0}C. [1]. Therefore, for flowmeters with constant magnets, it is advisable to arrange the electrodes in a horizontal plane, and preferably on a vertical pipeline.

Although electromagnetic flowmeters with constant magnets acquired general use due to their simple design, for the above reasons they do not comply with modern requirements for instruments of the nuclear industry.

Their main disadvantages are as follows:
- low stability of the magnetic field in time ,
- high temperature dependence of metrological characteristics,
- low noise immunity,
- no possibility of controlling the operation of the instrument in use.

It is necessary to revise the design of the magnetic flowmeter , for the purpose of its modernisation.

The public corporation "NIITeplopribor" has developed new type electromagnetic flowmeters for measuring liquid metal flow rate.

2. ELECTROMAGNETIC FLOWMETER

The experience in applying an alternating magnetic field and signal processing algorithms in electromagnetic flowmeters of general industrial type for measuring flow rate of liquids with ionic electro-conductivity has been used in designing the instruments. High stability of flow rate measurement and negligible temperature dependence of metrological characteristics have been attained by applying an alternating magnetic field set up by the electromagnet and a special algorithm for signal processing.

Like in many flowmeters of general industrial type, a low-frequency pulsed bipolar magnetic field set up by the inductor which is an electromagnet has been applied.

The processing of a signal from the electrodes is performed as follows: during the transient process of switching the magnetic field of differing polarity the signal does not change, the signal from the electrodes is isolated only at the points of time when the magnetic field becomes settled. Besides, the summation of signals measured in the presence of a positive and a negative pulse of the magnetic field makes it possible to eliminate thermo-electromotive force and other parasitic signals the origin of which is not bound up with the magnetic exciting field set up by the inductor in the channel of the instrument. As the magnetic field polarity changes, Foucault currents occur in different structural components of the flowmeter. The period of transient process is not informative and it is excluded from the measurement process.

Fig. 1 shows a construction diagram of the proposed electromagnetic flowmeter for liquid metal.
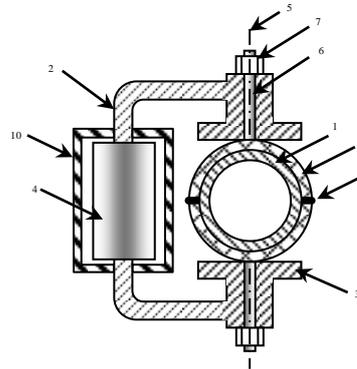

Fig. 1

The electromagnetic flowmeter comprises pipe 1 made of stainless steel without electrical insulating coating and an inductor consisting of C-shaped magnetic conductor 2 with pole tips 3 and of induction coil 4. For attaching the inductor to the pipe at the poles, there are holes along their axis, the axes of the holes coinciding with those of pole tips 5. The inductor is attached to the pipe with posts 6 inserted into the above-mentioned holes of the poles. The posts are welded to pipe 1 at the points where the generatrix of the pipe intersects the axis of poles 5. On the opposite side the posts are screwed up with nuts 7. Two electrodes 8 are welded onto the outer surface of the pipe in the line perpendicular to that jointing the centres of the poles. The housing divides the flowmeter construction into two zones, a high-temperature one where the pipe with liquid metal is found and a low-temperature one where the induction coil and the central part of the magnetic conductor are found. Besides, the pipe section located close to the housing is wrapped in a heat-resisting insulation tape of asbestos or basalt fabric. Due to such a design, enhanced reliability of the instrument and protection of the induction coil from heat radiation of the pipe with liquid metal [3] are provided. Fig. 2 shows a photo of the instrument with a 40 mm diameter channel.

Fig.2

A new design is proposed for fastening the inductor to the pipe. In all well-known flowmeters with constant magnets the inductor is connected to the pipe at the pipe periphery, which increases the overall dimensions, shunts a part of the signal and partially distorts the induced electric field in the pipe channel. In the new instrument the fastening elements connecting the inductor to the pipe are located at those points on the surface of the central part of the pipe, in which the electric potential of the induced magnetic field is always equal to zero, regardless of velocity of the liquid metal flow streaming along the channel. In this case the fastening element does not lead to shunting a flowmeter signal, does not disturb the distribution of currents in the pipe walls and does not change their value.

The inductor is an electromagnet establishing a bipolar pulsed alternating low-frequency magnetic field in the pipe channel.

Using an alternating magnetic field inductor made it possible to solve the problem of in-service operation diagnostics of the flowmeter and control of its metrological characteristics.

The test results of a 100 mm diameter flowmeter tested on a liquid metal flow-measuring stand are cited in Fig. 3. The symbols ○ and ◊ designate the obtained dependences of respectively the reduced error and the relative error on the measured flow, which are obtained by experiment on the liquid metal stand.

The measurement results processed by the method of least-squares made it possible to obtain the dependence of indications of the flowmeter Q_f on indications of the flow-measuring stand Q_e, which is described as follows:

$$Q_f = 1.0054 Q_e - Q_0, Q_0 = 0,0159 m^3 / h .$$

The metrological and technical characteristics of the flowmeter are as follows.

The measured medium is a liquid metal heat-transfer material with a specific electrical resistance of no more than $0.2 \cdot 10^{-6}$ Ω·m (sodium). The temperature of the measured medium ranges 350 °C to 525 °C. The pressure of the measured medium is no greater than 1.0 MPa.

The ambient temperature around the primary transducer ranges 20 °C to 90 °C at a relative humidity of 45 % to 80 %. The air temperature in the location of the electronic transducer ranges 5 °C to 40 °C at a relative humidity as high as 80 %.

The flowmeters are developed for the modifications the nominal diameter and the flow rate measurement ranges of which are cited in Table 1.

Table 1

Modification	Nominal Diameter, mm	Volume Flow Rate, m³/h	
		Q_{min}	Q_{max}
IRMU-1-25	25	0.03	3
IRMU-1-40	40	0.12	12
IRMU-1-80	80	1.3	130
IRMU-1-100	100	1.5	150

The limits of the admissible basic error of the flowmeter are no greater than ±2 % of the upper limit of measurements.

The mass of the component parts of the flowmeter is no more than:
  – 11 kg for the primary transducer,
  – 8 kg for the electronic transducer.

The mean lifetime of the flowmeter is no less than 15 years. The mean-time-between-failures is no less than 100,000 h, the faultness probability of the flowmeter over 8,000 h which corresponds to the above MTBF is no less than:
  – 0.99 for the primary transducer;
  – 0.96 for the electronic transducer.

The flowmeter has:
  – DC analogue output signal of 4 mA to 20 mA;
  – digital indication of the measured flow rate on the display board within the measurement range of (0 …100) %;
  – RS485 code interface.

REFERENCES

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