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Stability of Electromagnetic Flowmeter

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Abstract

Stability of electromagnetic flowmeter was examined with respect to earthing technique. Addition of auxiliary electrode which is attached near the main electrodes improved the stability of zero base noise against the fluctuation in exciting current of electromagnet. At the same time, zero base noise was markedly decreased by the addition of the auxiliary electrode. It was concluded that the shortening of the electrode pipe is effective to adapt the instrument for the fluid with larger electrical resistivity than tap water.

I. Introduction

Electromagnetic flowmeter is a device which was developed mainly by A. Kolin since 1936 and applied for the volumetric flow measurement in industrial and biological fields. This device has many advantages, such as: a) high sensitivity and sustained accuracy, b) unaffected instrument calibration for fluids whose resistivity between the electrodes is less than 5 KΩ, c) variable range from about 1 m/s to maximum flow rate without any limitation, d) independent of flow direction, e) linear output, f) available with electric totalizer.[2] Moreover, the device is applicable to measuring the volumetric flow rate of slurries, corrosive acids, paper pulp stock, etc. which present extremely difficult handling problems in other flow mersuring devices.

In this paper, some troubles in the electromagnetic flowmeter are described, such as quadrature effect,[3] errors due to conductivity change of liquid and fluctuations in power supply voltage to amplifier and electromagnet.

II. Supression of Quadrature Effect

According to Faraday's law of electromagnetic induction, electromotive force is induced in a conductive fluid moving at right angles to a magnetic field as shown

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1) Kolin, A., R. S. I. **16**. 110 (1945).
2) Considine, D. M., Process Instruments and Controls Handbook, p. 4-93 (1957), Mc Graw-Hill.
3) Partridge, G. R., Principles of Electronic Instruments. p. 266 (1958), Prentice-Hall.

in Fig. 1 and induced electromotive force E is given by the following expression:

$$E = cHdv,$$

(c, constant; H, magnetic field intensity; d, distance between the electrodes; v, velocity of fluid.)

When the fluid is non-polarizable, direct current magnetic field may be applied and the output of the transmitter is a direct voltage, but when the fluid is polarizable as the case of most conductive fluids, alternative magnetic field must be employed. In latter case, electromagnetic induction occurs in two ways. As

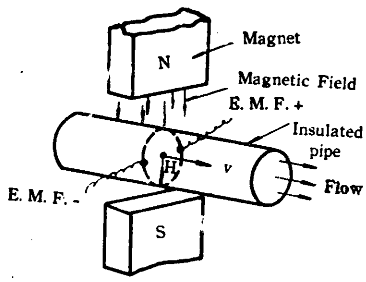


Fig. 1. Electromagneticaly induced E. M. F., magnetic field H and fluid velocity v.

shown in Fig. 2, it will be convenient to consider that the lead wires, electrodes and fluids form a secondary winding and the primary winding consists of the coil of driving electromagnet. Thus spurious voltage will be induced in the secondary winding which differs in phase by 90° to driving voltage. On the contrally, electromagnetically induced flow signal between the electrodes due to fluid motion in the pipe is in phase with the driving voltage. In Fig. 3, induced spurious and signal voltages between the electrodes are shown respectively.

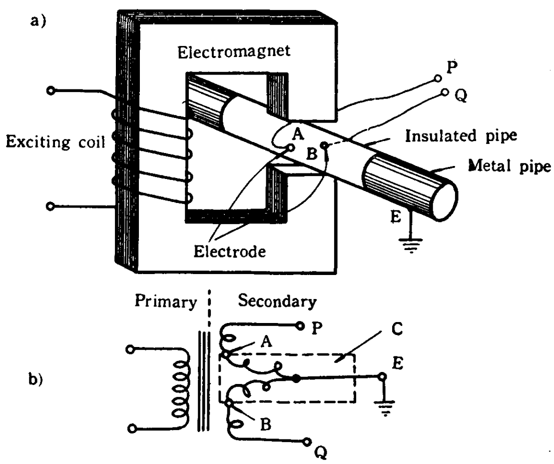


Fig. 2. Electromagnet and electrode arrangement. a) A and B are earthed through liquid C and P AE and QBE form secondary winding. This secondary winding will be represented schematically as shown in b).

This phase differing phenomena between two kinds of induced voltage is called "quadrature effect". In flow measurement, induced spurious voltage must, off course, be eliminated to pick up the flow signal alone.

One method of the elimination is to apply the *bucking voltage* which has the same amplitude but differs in phase by 180° to the noise voltage. Recently, Denison[4] used modulated dc method to avoid several troubles in ac method. In this

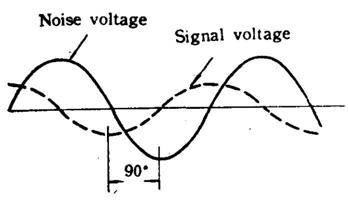


Fig. 3. Quadrature effect. In this figure, electrode B is earthed. Noise and flow signal voltage at A is shown.

4) Denison, A. B. and Spencer, M. P., R. S. I., **27**, 707 (1956).

paper, another method of noise voltage elimination is described and its circuit is shown in Fig. 4. Input impedance of this amplifier is about 30 MΩ. Electrode and electromagnet is shown in Fig. 5. Considering the application of this instrument

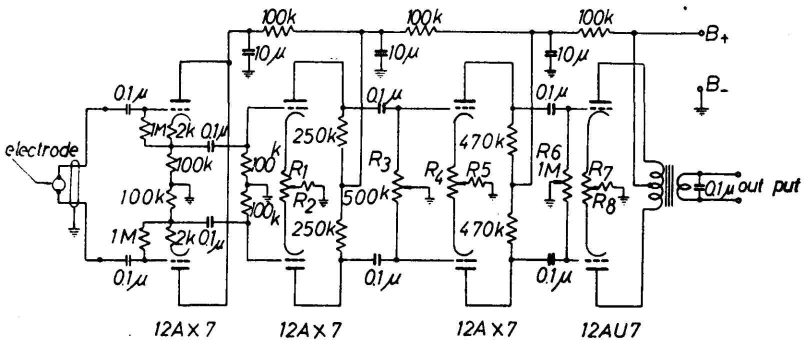


Fig. 4. Flowmeter circuit. Values of resistance $R_1, R_2, \cdots\cdots R_8$ were changed in stability test and are listed in Fig. 8 and Fig 9.

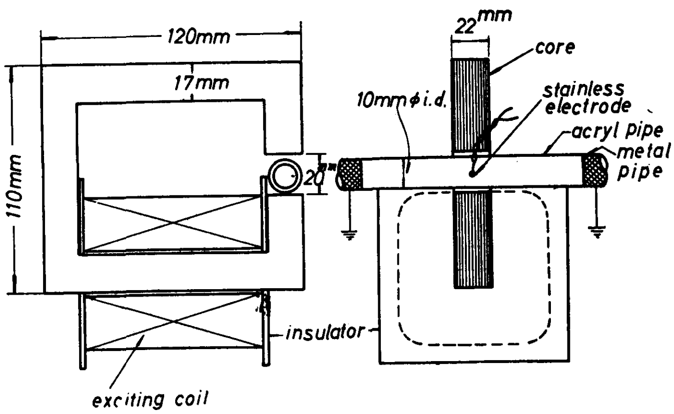


Fig. 5. Electrode and Electromagnet. Exciting coil consists of 1000 turns of 1 mmφ copper wire.

to blood velocity measurement, the eletromagnet has unsymmetrical construction. The principle of the circuit is based on differential amplifier and the operation will be explained below briefly.

Consider the secondary winding which is earthed at the middle as shown in Fig. 2, where A and B are electrodes and C is the fluid. Noise voltage of each electrode changes as Fig. 6–a against the earth. Now consider the flow signal voltage which is superimposed on those noise signals. The signal voltage has primarily no potential difference with earth because no potential gradient does exist along pipe axis. Since this signal voltage at A with repect to electrode B will be represented as shown in Fig. 6–b, superimposed voltage at A will be shown as dotted line in Fig. 6–a. In practice, noise voltage can be eliminated by balancing the amplifier with respect to each noise by adjustment of variable resistances R_1, R_3, R_4,

R_6, R_7 and the signal voltage alone remains as the output of the amplifier as shown in Fig. 6–c. Self balancing action of differential amplifier helps to stabilize the amplifier and the balancing. In our laboratory type instrument, accuracy of within 0.5 % can be obtained for 1 m/s scale. An example of calibration curve is shown in Fig. 7.

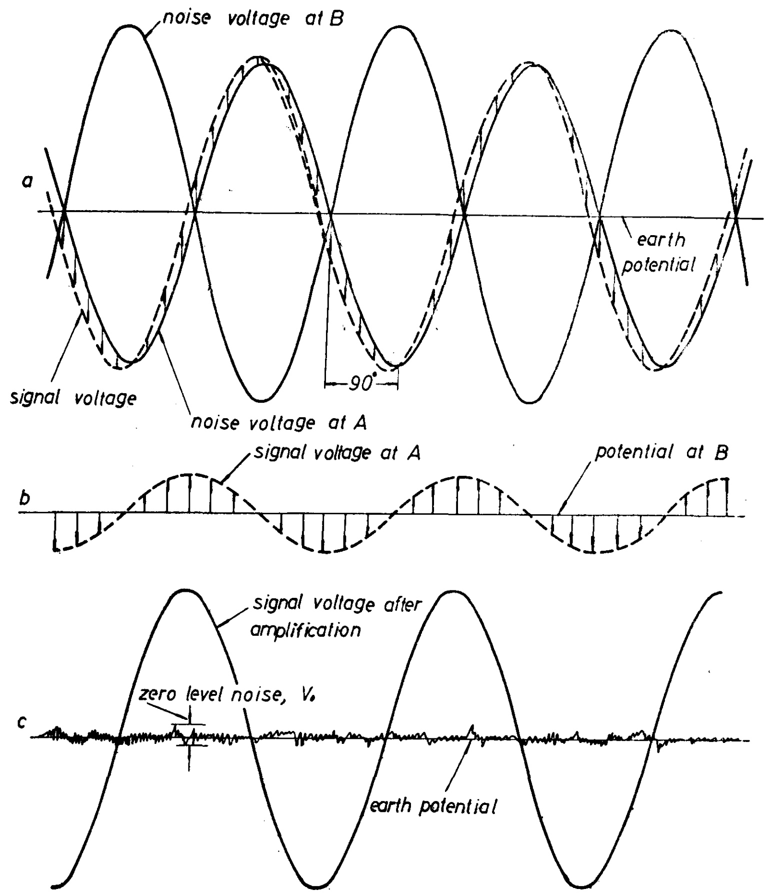


Fig. 6. Schematized noise and signal voltage. a), Input voltage at electrode A and B. Dotted line represents signal plus noise voltage at A with respect to B. Amplitudes are arbitral. b), Signal voltage induced by fluid flow. Signal at A is conveniently represented with respect to B. c), After amplification and summation of each noise at A and B, noise is eliminated remaining zero level noise v_0 and signal voltage alone is picked up as output.

III. Stability of Instrument

In Fig. 8, effects of the fluctuation in supplied voltage on balancing are shown in an arbitrary preliminary setting. This setting is established when the flow is zero.

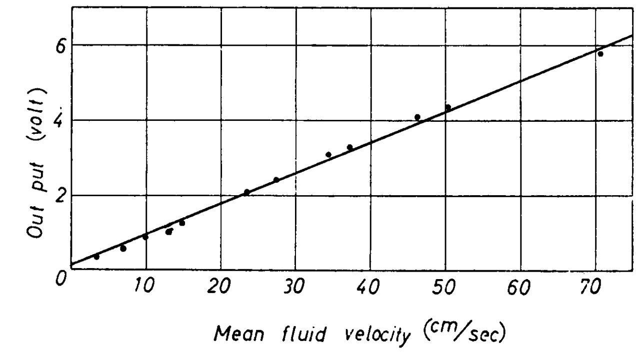
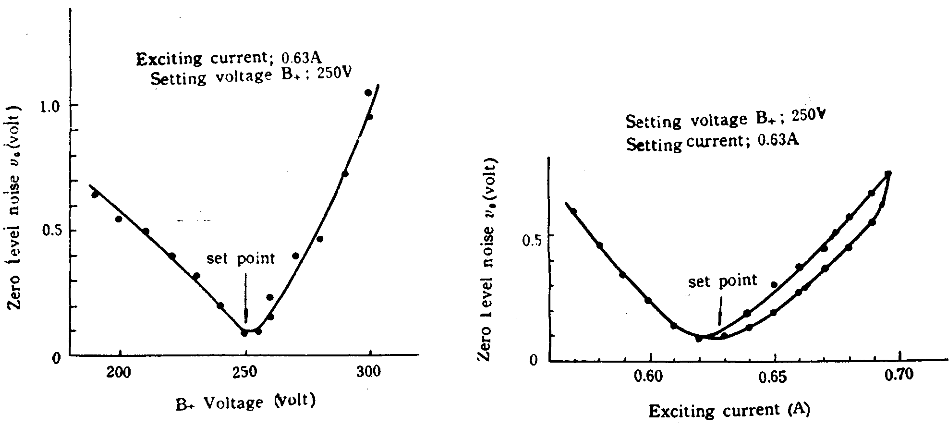


Fig. 7. Calibration curve. { 260 Volt. D. C. supply. 0.63 Amp. excite current.

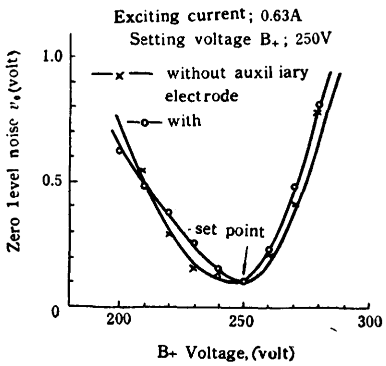


a). Effet of B + Voltage on zero set balance.

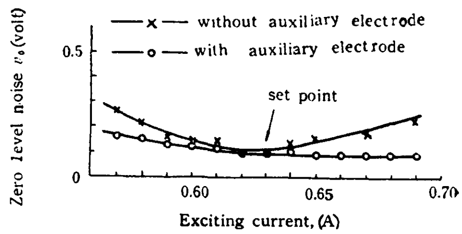
b). Fffect of exeiting current on zero set balance.

Fig. 8. Effet of power supply on zero level noise. R_1, R_2, R_4, R_5, R_7, R_8 = 1KΩ

Thus, zero level noise v_0 (noise voltage which remains after balancing) increases with the deviation from the set point of the supplied voltage in amplifier and the current of magnet. Thus it will be noted that the stability of direct current power supply for the amplifier must be within 0.4 % when 1 % accuracy must be obtained for 10 volt output. Exciting current must be stabilized at the same time. Zero level noise can be decreased and stabilized when the value of balancing cathode resistance is decreased as shown in Fig. 9. Here, total cathode resistance was kept constant and the value of variable resistances R_1, R_4, R_7 were changed. Thus, it is clear that inital distribution of noise voltage at electrodes A and B against earth must be balanced if best stability and least unbalanced noise voltage be expected. In most of the industrial instrument, symmetrical arrangement of electromagnet, lead wires and piping including earthing circuit is established but in biological purposes, such symmetrical device cannot be adapted. Since distribution of this noise voltage is determined according to the position of earthing point, the method of earthing must be considered further.



a). Effect of B+voltage on zero set balance.



b). Effect of exciting current on zero set balance. Setting voltage B+; 250 V. Setting current; 0.63 A.

Fig. 9. Effect of power supply on zevo level noise. R_1, R_4, R_7 = 260 KΩ. and R_2. R_5, R_8 = 1.9 KΩ.

Only when the earth point is in the plane including both electrodes and parallel to the magnetic flux, signal voltage of two electrodes against earth is dependent on earthing position, but when earthing position is on an other plane besides the plane including eletrode and parallel to the flux, earth point decides primarily the potential of electrodes A and B corresponding to noise voltage. In practice, changes in the conductivity and temperature of the fluid affect the zero level noise. Especially, the effect of dewing phenomena due to low fluid temperature and high humidity is marked, since wet pipe surface destroy zero set balance. Accordingly, the position of earthing point must be discussed how to balance the noise voltage of electrodes A and B against earth without receiving the effects of the fluid condition.

Thus, lead wires of all electrodes must necessarily be rigid, because the lead wires enclose the earthing circuit which determines the amplitude of noise which is induced in each side of secondary winding with respect to earth point. Even when these noise voltages differ in amplitude because of inevitably unbalanced earthing in secondary winding, we can minimize the zero level noise by changing the gain of the amplfier in each half side. Unfortunately, such balancing condition is easily disturbed when conductivity of the flowing fluids is changed and insulation of pipe wall lining deteriorates. Moreover, even if the balancing is set mannualy following the change in conductivity, zero level noise in amplifier output increases as the conductivity decreases as shown in Fig. 10.

Following the above mentioned principle of electrode design, auxiliary electrodes were attached as shown in Fig. 11. Addition of auxiliary electrodes is effective to stabilize the earthing circuit. This effect is shown in Fig. 9 and the effect of exciting current change on zero level noise is minimized. Effect of this auxiliary

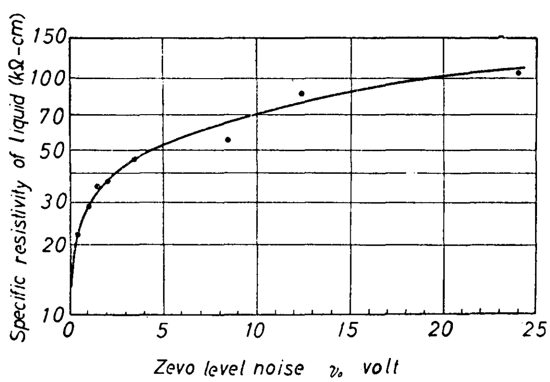


Fig. 10. Effect of resistivity on zero base noise which is minimized mannualy.

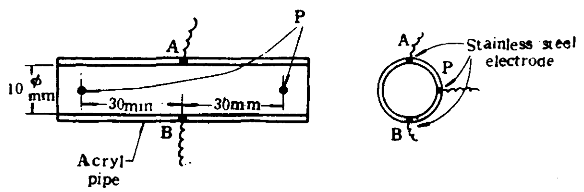


Fig. 11. Auxiliary electrode P.

electrode appears again on the stability of zero level noise. The fluctuation of zero level noise and meter indication for the electrode without earthing electrcde was about ± 0.2 volt, but they bcome about ± 0.03 volt when the earth electrode was attached. Moreover, addition of this earthing electrode shown in Fig. 11 did not affect the calibration for tap water.

It seems to be most important in industrial instrument to minimize the fluctuation of zero level noise. Compensation of errors due to the conductivity change is not a difficult problem, because any electronic device which contains conductivity detection element will be applicable for the compensation.

IV. Discussions and Conclusions

On the electrode design, in most of available electrcmagnetic flowmeters, little attention has been called on earthing techique. They have long pipe with electrodes insulated on the inside wall. The length must be considered according to the conductivity of the flowing fluid. Smaller the conductivity, the shorter the insulated pipe will be satisfactory to minimize the zero level noise and its unstability. In the case of tap water, attached auxiliary electrode reduced the noise to about 1/6, from ± 0.2 to ± 0.03 volt. Moreover, this device did not affect the meter calibration. Advantage of this earthing electrode lies also in minimizing the effect of exciting current change on balancing. Thus the voltage stabilizer will be necessary only for the power supply of amplifier. It is believed that more useful adaptation of magnetic flowmeter will become possible for wider range of fluid conductivity by the use of auxiliary electrode.

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