Methods of reduction of interference signals in electromagnetic conductors that measure fluid flow

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Abstract. The pressure in the fluid flow, especially in the pipes of closed water supply systems, is generated mainly by pumps, and the water flow is usually pulsating. Electromagnetic transducers used to measure such nonstationary and pulsating fluid flow rates must have low inertia and high dynamic accuracy. In such cases, the frequency characteristics of electromagnetic transducers that measure fluid flow are their main parameters. It should be noted that the performance of the converters used to measure the flow rate of pulsating fluids should not depend on the change in the distribution profile of the flow velocities, otherwise additional measurement errors will occur. It is used in measuring non-stationary and pulsating fluid flow rates in controlled and controlled technological processes.

Complex electrochemical, electrokinetic and other types of processes occur in the zone of contact of the electrodes with the moving fluid [5]. As a result, an electric potential of a certain value is generated at the electrodes. This potential magnetic field at the electrodes depends on time-varying factors such as fluid temperature, pressure, concentration, phase and ion composition, and electrochemical polarization between individual sections of the electrodes. These factors lead to the appearance of signals that interfere with the signal ("obstacle"), which is useful (carrier of information that assesses the flow of fluid) [1, 7].

The first group of interferences occurs in the presence of a magnetic field. They have a multiplicative character and result from the fluctuations of the fluid flow and the dispersion of the medium in which the flow is measured. The second group of interferences arises from external factors (sources), which are additive in nature.

Interference of the first group is defined by the following expression [5]:

\[ U_x = \int W \, div[v_f(t)B] \, dV + \int W \, \frac{\partial \sigma(t)}{\partial r} [vB] \, dV + \int \frac{\partial \ln \sigma(t)}{\partial r} \frac{\partial B}{\partial t} \, dS \]  (1)

Here \( V \) - the working volume of the pipe; \( W \) - is the volume fraction ("weigh-house") function; \( v_f(t) \) - fluid flow fluctuation vector; \( \sigma(t) \) - electrical conductivity of the measured medium; \( B \) - magnetic field induction vector; \( r \) - radius-vector; \( S \) - channel cutting surface where the electrodes are located.

\[ \begin{align*}
    \nabla(-\epsilon \nabla u + au + \gamma) + \beta \nabla u + au &= f \\
    n(\epsilon \nabla u + au - \gamma) + qu &= g - h^T \chi \\
    hu &= r
\end{align*} \]  (2)
All interference can be divided into two groups (figure 1) [3].

\[ \text{Figure 1. Classification of barriers.} \]

Equation (2) describes the signal to the right of the first term due to turbulent pulsation in the liquid, while the second and third terms in it analytically describe the class and quadratic disturbances caused by the dispersion of the liquid medium. The spectrum of the fundamental frequencies of large-scale pulsations resulting from fluid flow turbulence corresponds to the $3 \div 10^3$ Hz range. Its amplitude can be (2-12)% of the useful signal amplitude, and it depends significantly on the Reynolds number (Re). The frequency spectrum of interference signals generated by various mixtures in the medium being measured depends on the number and size of the solid particles in the liquid, the gas bubbles, and their velocity. The amplitude of this interference signal is the ratio of the useful signal, and the frequency range is $1 \div 5 \cdot 10^3$ Hz.

In addition, interference signals of a multiplicative nature are caused by the following factors: - fluctuations of the current amplitude in the source circuit; - magnetic field fluctuations; - Electrical noise in electronic devices.

The second group of interferences includes signals that occur independently of the magnetic field [7]. The most noticeable of these is the voltage that results from the polarization of the electrodes. This voltage is caused by the following electrochemical reactions:

- balance between the ions of the electrode crystal lattice and similar ions in the liquid;
- redox reactions in the process of recharging of liquid ions;
- equilibrium in the oxidized metal layer (shell) of the electrode; - formation of hydrogen and oxygen gas bubbles at the electrodes, etc.

The following complex electrochemical processes take place at the electrode-liquid boundary: as a result of the electrode melting, it transfers its positive ions to the liquid. In turn, the liquid ions are discharged at the electrodes.
As a result of electrostatic forces, electric charges are generated in thin layers of liquid sticking to the electrodes. These layers form a double electrical layer along the electrode surface. The electrode surface is similar to a charged capacitor: the value of the electrode surface capacitance varies from 0.01 to 0.8 μF/mm² depending on the amount of electrode, the temperature of the liquid and the capacity [5].

The formation of a double electric field results in a potential difference between the electrode and the liquid, the value of which is in the range of (0.05–0.7) V [5].

Typically, both electrodes are made of the same material. The potential change (jump) between the electrode and the liquid compensates for each other because they are in opposite directions at both boundaries. However, due to the fact that the electrodes are not chemically homogeneous and the deformations that occur during machining, the formation of molecules on the surface as a result of adsorption, oxidized thin layers and contaminants, the interfering voltage between the electrodes is tens of millivolts, is also possible.

The movement of the fluid in the active zone of the tube causes some change in the binary electrical layer. For example, the double-layer ions that are furthest from the surface of the electrodes and are poorly connected to them flow together with the liquid flow. In some cases, the double electrical layer is often disrupted by fluid flow. This process occurs chaotically and causes voltage fluctuations (play) in the measuring circuit. If the conditions under which each electrode is washed by the liquid flow or the electrodes are different, then the specific potential difference between the electrodes will vary depending on the liquid velocity. During the motion of a liquid, its concentration, temperature, and pressure change, which affects the potentials of the electrodes.

Thus, the polarization signal has the following two components:

1) a low-frequency component that depends on the movement of ions;
2) the frequency spectrum is a high-frequency component that corresponds to the frequency spectrum of fluid flow turbulent pulsation.

Since the polarization process is observed to some extent by the movement of ions, its frequency spectrum is very low, ranging from $10^{-3}$ Hz to 10 Hz.

External electrical signals received by the electrodes include: - various industrial interference, including interference signals from industrial sources with a frequency of 50 Hz and more; - currents on the ground; - one-time pulses; - thermal interactions at the entrance to the fluid and measuring circuits; - electrodes heat EUK.

The fluid flow between the electrodes forms a contour equal to the surface of the input resistance of the contact line connecting the electrodes to the measuring circuits and the measuring circuit. As a result of the intersection of the magnetic field lines of the alternating magnetic field of this contour, the interference EUK, which is defined by the following expression, is induced:

$$U_n = \oint \mathbf{E} \cdot d\mathbf{S} = -\frac{d}{dt} \oint \mathbf{B} \cdot d\mathbf{L},$$

(3)

where $\mathbf{E}$ - electric field strength; $\mathbf{L} - \mathbf{S}$ a closed contour that borders the surface.

Ideally, the phase shift angle between the rated voltage and the “transformer” interference voltage is 90°. In practice, however, a random change in the electrical conductivity of a fluid as a result of a change in the frequency of the magnetic field in the excitation coil and the temperature of the fluid flow causes the above phase shift angle to vary by 90°. Therefore, standard compensation methods are not effective enough. In such cases, it is necessary to find solutions that completely eliminate or reduce the negative impact of the above-mentioned random variables on the zero signal stability.

There are the following ways to reduce the effect of the transformer interference voltage on the useful signal of electromagnetic converters measuring liquid consumption:

1) ensuring the symmetry of the primary converter design;
2) increase the accuracy of fabrication and assembly of converter parts;
3) the use of pulsed excitation magnetic field;
4) selection of signal processing algorithm, etc.

External interferences also occur due to thermal interactions in the input cascade of the fluid and the measuring circuit. The magnitude of these interactions depends on the physical properties of the medium being measured, the elements of the measuring chain, and the temperature. The electrical resistance of a liquid between the electrodes of an electromagnetic transducer that measures fluid consumption depends on its electrical conductivity and the size of the electrodes, which can be a value of \((10^3 \div 10^5)\) Om or greater. At these values of resistance, the noise significantly affects the useful signal. Its effect can be reduced by using a measuring system where the frequency band is narrow. When the frequency band of the measuring instrument is 1 Hz, the noise level is around 1 mkV. It should be noted that the narrowing of the frequency response of the measuring instrument leads to a deterioration of its dynamic characteristics. This, in turn, limits its applicability to measuring unstable or pulsating fluid flow rates.

It should be noted that the probability of the occurrence of the above-mentioned obstacles is far from the truth. In general, the composition and value of the interference will depend significantly on the operating conditions, design features, type, and size of the electromagnetic transducer that measures the fluid flow rate.

In order to drastically reduce interference, it is expedient to use a modern element base of electronics and algorithms that ensure the separation of a useful signal from electromagnetic interference of various natures \([6,8,9]\). In order to minimize the effect of interference, the secondary measuring transducer is made as small as possible and placed directly on the primary measuring transducer. It is recommended that the flow meter be mounted on a vertical section of pipe in order to ensure the symmetry of the kinematic structure and phase composition of the fluid flow relative to the pipe axis.

Yokogawa (Japan) has recommended the use of a double-frequency magnetic field to measure the consumption of contaminated liquids, suspensions, and sediments. In such flow meters, the magnetic field consists of two components, 75 and 6 Gts, whose output signal is not affected by low-frequency noise caused by low-frequency electrochemical reactions, high viscosity and (or) low electrical conductivity of liquids.

The noise generated from the additional layers on the surface of the electrodes is low frequency because the electrochemical potential at the electrodes changes very slowly. This noise is eliminated by using a low frequency filter with a large time constant \([5]\).

An analysis of monographs, patents, and scientific papers devoted to electromagnetic transducers for measuring fluid flow shows that zero signal instability is one of the main components of this type of transducer error \([5]\).

The zero signal instability is mainly due to the instability of the EMO interference signal and is affected by the physical properties of the fluid being measured (temperature, pressure, electrical conductivity, chemical composition, etc.) and the ambient temperature \([5]\).

The output signal of a liquid flow meter electromagnetic transducer can be expressed analytically as follows:

\[
\dot{U} = U_0(t, T, B) + k(t, T, B, m, n, ...)I_h, \tag{4}
\]

Where - the temperature of the liquid and the external environment, respectively, affecting the zero signal asymmetry, the induction of the magnetic field; - other influencing factors; - coefficient of proportionality (sensitivity of the transducer); - volumetric flow rate of the liquid.

Factors affecting zero signal instability are divided into internal and external factors. Internal factors can be attributed to factors related to the magnetic field of the converter magnetic system. External factors include factors related to external magnetic and electric fields. In most cases, zero signal instability caused by internal factors is the main one.

When the electromagnetic converter magnetic system is supplied from the sinusoidal current or voltage source of the excitation coil, the zero signal can be shifted to any angle in phase relative to the
useful signal of the converter. Therefore, the interference signal is studied in relation to the useful signal by dividing it into two components: 1) the component that is phase-squared relative to the useful signal; 2) class-forming (phase-compatible) relative to the useful signal.

One of the main sources of zero instability is the interaction of the magnetic field created by the magnetic field in the electrodes and the adjacent liquid layer with the inverse electric field of the electrodes. If the magnetic field induction in the annular channel tube is of equal size and is not affected by external effects, then the maximum electric field strength that appears near the electrodes and is directed along the axis of the tube is:

$$E_y = E_{max} = \omega B \delta,$$  \hspace{2cm} (5)

Where \(\omega\) - the angular frequency of the magnetic field induction, \(\delta\) - the width of the annular channel.

Given that the liquid flow meter is the sensitivity of the electromagnetic transducer of the annular channel (the distance between the electrodes along the annular channel)

$$U_{e,ex}(p) = R_{el} I_{eR2}(p),$$ \hspace{2cm} (6)

The formula can be written as follows:

$$E_y = E_{m} = \omega \frac{s}{l} \delta$$ \hspace{2cm} (7)

The effect of the inverted electric field on the variability of the converter zero signal can be explained using the exchange scheme of the ring-channel electrical circuit shown in figure 3 [4].

In order to simplify the analysis, the induced electric field was replaced by voltage sources in the circuit. The design of a ring-channel electromagnetic transducer measuring the fluid flow rate and the switching circuit shown in figure 3 are completely symmetrical, \(R_{el1} = R_{el2} = R_{el3} = R_{el4};\) \(R_{i,q1} = R_{i,q2} = R_{i,q3} = R_{i,q4};\) \(C_{i,q1} = C_{i,q2} = C_{i,q3} = C_{i,q4}.\) \(U_{y1} = U_{y2} = U_{y3} = U_{y4}\) i.e., if the condition is met, the transmitter output signal does not contain interference signals. If there is an asymmetry in the layer of liquid close to the electrodes, then the phase output signal of the converter will be accompanied by class and quadrature interference signals.

The analysis of the switching circuit in figure 3 shows that the interference voltage can be located at any phase shift angle relative to the useful voltage. The dependence of the amplitude and phase of the interference voltage on the temperature, pressure, electrical conductivity, and chemical composition of the fluid being measured has a random appearance. The phase-to-phase component of the interference voltage can reach several tens of \(\mu V\) [5]. SSOK HK EMO sensitivity and fluid flow rate change range (when 0, the converter reaches the specified measurement error.

Methods for reducing the effect of a ring-channel electromagnetic transducer measuring the fluid flow rate of a rotating electric field on the zero signal stability are derived from the analysis of the exchange scheme in figure 2.

1) Reduction of the inertial electric field near the electrodes;
2) Reducing the sensitivity of the electrodes to the inverted electric field.
Figure 2. Switching scheme of the electrical circuit of the active zone of the electromagnetic transducer with a liquid channel measuring fluid flow. 1 - electrodes; 2 - compensation contour - useful signal voltage; - resistance of the corresponding sections of electrodes, - resistances of sections belonging to the double electric layer; - resistance of the corresponding sections of the liquid; - voltages of sources characterizing the inverted electric field.

Another internal factor of zero signal instability of the converter is the twisting currents that occur in the annular monolithic ferromagnetic cores and other metal elements of the converter. Under the influence of these currents, the magnetic field induction vector in the annular working channel lags behind the excitation current vector by a certain angle.

Studies have shown [7,11] that when the phase shift angle between the above-mentioned vectors is moderate, the voltage change between the electrodes as a result of the effect of the inverted electric field on the binary electric layer does not lead to a change in the class component of the interference signal. When the above-mentioned phase shift angle changes (e.g. due to changes in the electrical and magnetic properties of the annular ferromagnetic core material as a result of a change in liquid or ambient temperature) the class component of the interference signal changes, resulting in an electromagnetic transducer zero signal of up to 5%.

The compensation circuit is widely used to reduce the effect of alternating currents on the zero signal moderation (figure 2). This circuit ensures that the voltage phase between the electrodes corresponds to the voltage phase of the compensation circuit and prevents the formation of a phase component of the interference signal.

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