ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 11 , November 2020

Mathematical Models of Electromagnetic Converters with Fluid Flow Measure

AmirovSultonFayzullaevich, AtaullayevAminjonOdilovich

Doctor of Technical Sciences, Professor, Head of the Department of Power Supply, Tashkent State Transport University; Tashkent Uzbekistan
P.h.D Associate Professor of the Department of Power Engineering Navoi State Mining Institute.Navoi Uzbekistan

ABSTRACT: Mathematical models of magnetic circuits of electromagnetic flow transducers with an annular channel have been developed, taking into account the distribution of the parameters of the magnetic circuit and leakage fluxes closed through non-working air gaps. The possibility of compensating for the difference in magnetic resistance of coaxially arranged concentric ferromagnetic cores due to the difference in their circumference by selecting the thickness of the cores is shown.

KEYWORDS: Electromagnetic flow sensor, mathematical model, static characteristic, the annular channel, the core, the weight function, electromagnetic flow transducer, mathematical model, static characteristic, annular channel, core, weighting function, pipeline, flow rate, magnetic system, sensor, water flow.

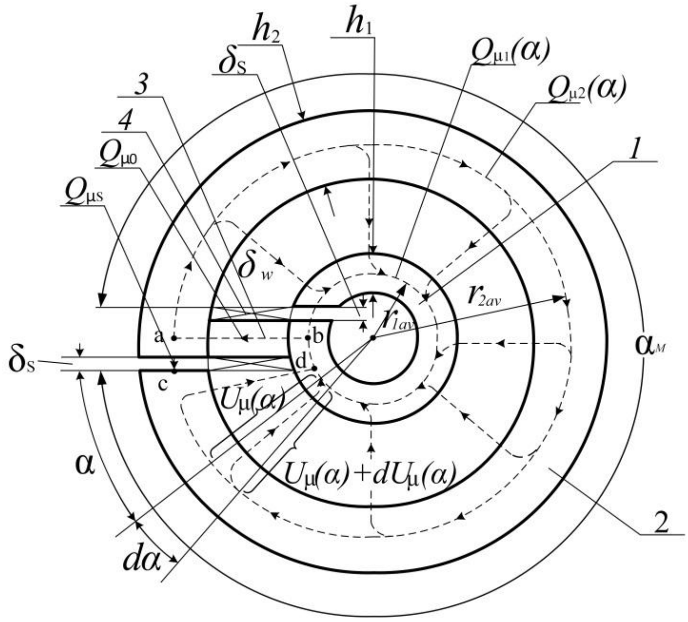
I. INTRODUCTION

Electromagnetic transducers (EMOs) are widely used in process control systems, along with other types of transducers [1]. In this regard, in addition to mass-produced EMOs in large batches, specially designed EMOs are also used in the control and management of systems of special technological processes (quantity and quality of dairy products, heat supply, processing of liquid metals and acids, etc.) [2,3].
Since the metrological characteristics of EMOs measuring liquid flow are directly related to the basic properties of the magnetic field in the working air gaps, great attention is paid to the study of the magnetic fields of these transducers.

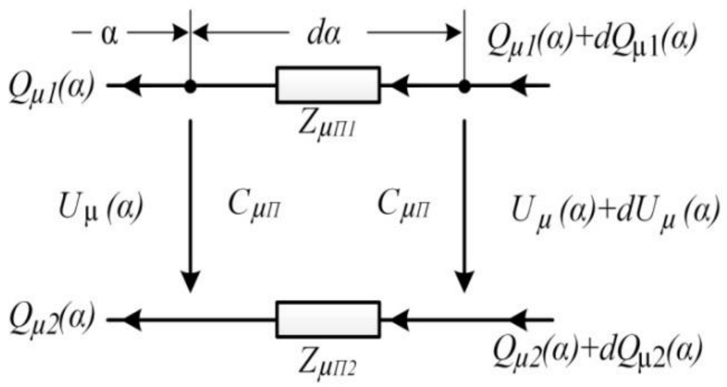
II. ENERGY EFFICIENCY

This article is devoted to the development of mathematical models of the ring-chain EMO magnetic circuit created with the participation of the authors [4]. Although a mathematical model of this EMO magnetic circuit was developed in its time, the calculation error of the chain was 10-15% because it did not take into account the magnetic capacity of the non-working air gap (magnetic permeability according to the classical analogy of electric and magnetic chains) [5].
Figure 1 shows the schematics of the exchange of the constructive and its elementary part of the ring chain EMO magnetic circuit.
In order to simplify the analysis of magnetic chains, we introduce the following limitations: 1) annular ferromagnetic cores and the ferromagnetic rod connecting them are made of the same material in a monolithic form; 2) the scattered magnetic fluxes at both ends of the annular ferromagnetic cores along the pipe axis are negligibly low; 3) the magnetic resistance of ferromagnetic cores does not depend on the value of the magnetic field induction in them, i.e. the magnetic chain operates in the linear part of the main magnetization curve; 4) Since the frequency of change of the magnetic field over time is very low, the oscillating currents in the ferromagnetic cores have an insignificantly small value.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 11 , November 2020



a)



b)

Fig 1. Schematic diagrams of the constructive (a) and its $d\alpha$ elementary part exchange (b) of the ring chain EMO magnetic chain

Although the above limitations do not significantly affect the accuracy of magnetic chain analysis, they do greatly simplify the calculations [7].
A distinctive feature of this magnetic circuit is that the same conditions are created for the magnetic flux power lines joining through the working air gap, i.e. the magnetic resistance of the path where each power line of the magnetic flux joins is mutually equal. In this case, the difference caused by the difference in the magnetic resistances of the concentric ferromagnetic cores, which are coaxially placed, can be eliminated by selecting the thickness of these cores by the relationship $(h_2/h_1) = r_{2av}/r_{1av})$. It can be assumed that$Z_{\mu p1} = Z_{\mu p2} = Z_{\mu p}$this equation is reasonable.
In order to simplify the calculations, we assume that the magnetic capacitances of the non-working and air gaps are mutually equal, i.e. $C_{\mu s1} = \mu_0 (bh_1)/\delta_{s1} = C_{\mu s2} = \mu_0 (bh_2)/\delta_{s2}$ From this equation: $\delta_{s2} = \delta_{s1}(h_2/h_1)$ When this equation is fulfilled δ_{s1} and δ_{s2} the same amount of scattered magnetic fluxes from the non-working air gaps are combined, i.e.$Q_{\mu s1} = Q_{\mu s2} = Q_{\mu s}$
In the elementary part of this chain, the differential equations based on Kirchhoff's laws for the magnetic flux and magnetic voltage generated by the excitation coil EMFF_{ex} are as follows:

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 11 , November 2020

$$\frac{dQ_{\mu1}(\alpha)}{d\alpha} = U_\mu(\alpha)C_{\mu p}, \frac{dQ_{\mu2}(\alpha)}{d\alpha} = -U_\mu(\alpha)C_{\mu p}, \frac{dU_\mu(\alpha)}{d\alpha} = Z_{\mu p}\left[Q_{\mu1}(\alpha) - Q_{\mu2}(\alpha)\right] \quad (1)$$

where, $Q_\mu(\alpha)$, $U_\mu(\alpha)$ - is the magnetic flux in the annular ferromagnetic cores and the magnetic voltage between them, respectively; $Z_{\mu p1} = \frac{2\pi r_{1av} - h_3 - \delta_{s1}}{\mu\mu_0 b h_1 \alpha_M}$, the pogon values corresponding to the α angular unit along the magnetic chain of the resistors; $C_{\mu п} = \mu_0 \frac{b\pi(r_{1av} + r_{2av}) - (\delta_{s1} + \delta_{s2} + h_3)}{\delta_w \alpha_M}$ - the step value of the air gap between the mutually coaxially located ring ferromagnetic cores, which corresponds to the angular unit of magnetic capacity; $h_1 h_2$, h_3, b, and δ_w - the thickness of the ferromagnetic cores and the rods connecting them, respectively, their length along the channel axis and the working air gap between the cores; μ, $\mu_0 = 4\pi \cdot 10^{-7}\, {}^{H}/_{M}$ - relative magnetic permeability of ferromagnetic core material and absolute magnetic permeability of air (magnetic constant), respectively; α, α_M - is the angle coordinate and its maximum value.

After less complex substitutions, we obtain the following differential equation:

$$\frac{d^2U_\mu(\alpha)}{d\alpha^2} = 2Z_{\mu p}C_{\mu p}U_\mu(\alpha). \quad (2)$$

The general solution of this differential equation is written as follows, as above:

$$U_\mu(\alpha) = A_1 e^{\gamma\alpha} + A_2 e^{-\gamma\alpha}, \quad (3)$$

where $\gamma = \sqrt{2(Z_{\mu p1} + Z_{\mu p2})C_{\mu p}}$ is the coefficient of propagation of the magnetic flux along the magnetic chain; A_1 and A_2 - integration constants.

The following equation is appropriate for the magnetic circuit under study:

$$Q_{\mu1}(\alpha) + Q_{\mu2}(\alpha) = Q_{\mu2}(\alpha_M) - Q_{\mu s} = Q_{\mu1}(0) - Q_{\mu s}. \quad (4)$$

We find $Q_{\mu2}(\alpha)$ from (4) and put it in the third equation of (1) and find the expression $Q_{\mu1}(\alpha)$ from the resulting equation as follows:

$$Q_{\mu1}(\alpha) = \frac{\gamma}{2Z_{\mu p}}\left(A_1 e^{\gamma\alpha} - A_2 e^{-\gamma\alpha}\right) + \frac{1}{2}\left[Q_{\mu2}(\alpha_M) - Q_{\mu s}\right]. \quad (5)$$

By finding the expression $Q_{\mu2}(\alpha)$ in equation (4) and putting (5) in it, we obtain $Q_{\mu2}(\alpha)$ the following equation:

$$Q_{\mu2}(\alpha) = -\frac{\gamma}{2Z_{\mu p}}\left(A_1 e^{\gamma\alpha} - A_2 e^{-\gamma\alpha}\right) + \frac{1}{2}\left[Q_{\mu2}(\alpha_M) - Q_{\mu s}\right]. \quad (6)$$

A_1 and A_2 are found using the following boundary conditions:

$$\left.\begin{aligned} Q_{\mu1}(\alpha)|_{\alpha=0} = Q_{\mu1}(0) = Q_{\mu2}(\alpha_M), \\ Q_{\mu2}(\alpha)|_{\alpha=\alpha_M} = Q_{\mu2}(\alpha_M). \end{aligned}\right\} \quad (7)$$

Substituting the found values of A_1 and A_2 into equations (3), (5) and (6), we obtain the following expressions for the magnetic voltage between the mutually coaxially located concentric ferromagnetic cores and the magnetic fluxes in them:

$$U_\mu(\alpha) = -\frac{Z_{\mu p}Q_{\mu 0}}{\gamma sh(\gamma\alpha_M)}\{ch(\gamma\alpha) + ch[\gamma(\alpha_M - \alpha)]\} \quad (8)$$

$$Q_{\mu1}(\alpha) = -\frac{Q_{\mu0}}{2sh(\gamma\alpha_M)}\{sh(\gamma\alpha) - sh[\gamma(\alpha_M - \alpha)]\} + \frac{1}{2}\left[Q_{\mu2}(\alpha_M) - Q_{\mu s}\right]. \quad (9)$$

$$Q_{\mu2}(\alpha) = \frac{Q_{\mu0}}{2sh(\gamma\alpha_M)}\{sh(\gamma\alpha) - sh[\gamma(\alpha_M - \alpha)]\} + \frac{1}{2}\left[Q_{\mu2}(\alpha_M) - Q_{\mu s}\right]. \quad (10)$$

In order to find the magnetic voltage $U_\mu(\alpha)$ and magnetic fluxes $Q_{\mu1}(\alpha)$ and $Q_{\mu2}(\alpha)$ the expressions of which depend on the EMF, F_{ex} it is necessary to determine the expressions of the magnetic circuit $Q_{\mu0}$ under study (the total magnetic flux generated by EMF), $Q_{\mu s}$ and $Q_{\mu2}(\alpha_M)$ the magnitudes of which depend on the EMF. To do this, we construct the following equations based on Kirchhoff's laws for the "a" node of the chain and the closed contours " $aa'b'ba$ " and " $baa'a''b''b$ ":

$$Q_{\mu0} = Q_{\mu2}(\alpha_M) + Q_{\mu s}, \quad (11)$$

$$Z_{\mu0}Q_{\mu0} + U_\mu(\alpha_M) + W_{\mu s}Q_{\mu s} = F_{ex}, \quad (12)$$

$$Z_{\mu0}Q_{\mu0} + Z_{\mu p}\int_0^{\alpha_M} Q_{\mu2}(\alpha)d\alpha + U_\mu(0) = F_{ex}, \quad (13)$$

where $W_{\mu s} = \frac{1}{C_{\mu s}}$ - is a parameter inverse to the magnetic capacity according to the energy-information model of chains, which is called magnetic stiffness (according to the classical model of chains, this parameter is called magnetic resistance [7,9].

Equations (11) - (13) are unknown together, $Q_{\mu0}$, $Q_{\mu s}$ and $Q_{\mu2}(\alpha_M)$ by solving them, we obtain the following expressions:

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 11 , November 2020

$$Q_{\mu 0} = F_{ex}\frac{2\beta sh\beta(W_{\mu s}-Z_{\mu})}{\Delta_1} \quad (14)$$
$$Q_{\mu 2}(\alpha_{\text{м}}) = F_{ex}\frac{2\beta sh\beta(W_{\mu s}-0{,}5Z_{\mu})}{\Delta_1} \quad (15)$$
$$Q_{\mu s} = -F_{ex}\frac{\beta sh\beta Z_{\mu}}{\Delta_1} \quad (16)$$

Where $\Delta_1 = 2[Z_{\mu 0}\beta sh\beta - Z_{\mu}(1+ch\beta)](W_{\mu s}-Z_{\mu}) - \beta W_{\mu s}Z_{\mu}sh\beta$;
$Z_{\mu} = Z_{\mu\text{p}}\alpha_{\text{м}}$; $\beta = \gamma\alpha_{\text{м}}$is the extinction coefficient of the magnetic flux along the magnetic chain.
Substituting (14), (15) and (16) into equations (8) - (10), we obtain the following final expressions for the magnetic voltage between the coaxially located concentric ferromagnetic cores and the magnetic fluxes in them:

$$U_{\mu}(\alpha) = -F_{ex}\frac{2Z_{\mu}(W_{\mu s}-Z_{\mu})}{\Delta_1}\{ch(\beta\alpha^*) + ch[\beta(1-\alpha^*)]\}. \quad (17)$$
$$Q_{\mu 1}(\alpha) = -F_{ex}\frac{\beta}{\Delta_1}\{(W_{\mu s}-Z_{\mu})\{sh(\beta\alpha^*) - sh[\beta(1-\alpha^*)]\} - W_{\mu s}sh\beta\}. (18)$$
$$Q_{\mu 2}(\alpha) = F_{ex}\frac{\beta}{\Delta_1}\{(W_{\mu s}-Z_{\mu})\{sh(\beta\alpha^*) - sh[\beta(1-\alpha^*)]\} + W_{\mu s}sh\beta\}, (19)$$

Here $\alpha^* = \frac{\alpha}{\alpha_{\text{м}}}$

III. RESULTS

The expression for the law of change in the induction of the magnetic field α in the annular air gap between the concentric ferromagnetic cores located coaxially in the magnetic chain under study can be found using the following formula:

$$B(\alpha) = \mu_0\frac{U_{\mu}(\alpha)}{\delta_{wor}} = F_{ex}\frac{2(W_{\mu s}-Z_{\mu})\mu_0}{\delta_{wor}\Delta_1}\{ch(\beta\alpha^*) + ch[\beta(1-\alpha^*)]\}. (20)$$

The law of change in the induction of the magnetic field in the annular air space is determined using the following expression:

$$B(\rho) = \left|\frac{Q_{\mu 2}(\alpha_{\text{м}})}{b[2\pi\rho-(\delta_{s1}+\delta_{s2}+h_3)]}\right| = \left|F_{ex}\frac{2\beta sh\beta(W_{\mu s}+0{,}5Z_{\mu\text{p}}\alpha_{\text{м}})}{b[2\pi\rho-(\delta_{s1}+\delta_{s2}+h_3)]\Delta_2}\right|. (21)$$

$W_{\mu s} \to \infty$,that is, (14), (15), and (16) are assumed to be scattered magnetic fluxes $Q_{\mu s} = 0$through a non-working air gap:

$$Q_{\mu 0} = Q_{\mu 2}(\alpha_{\text{м}}) = -F_{ex}\frac{2\beta sh\beta}{\Delta_2}, Q_{\mu s} = 0 (22)$$
$$U_{\mu}(\alpha) = F_{ex}\frac{2Z_{\mu}}{\Delta_2}\{ch(\beta\alpha^*) + ch[\beta(1-\alpha^*)]\}. \quad (23)$$
$$Q_{\mu 1}(\alpha) = F_{ex}\frac{\beta}{\Delta_2}\{sh(\beta\alpha^*) - sh[\beta(1-\alpha^*)] - sh\beta\}. \quad (24)$$
$$Q_{\mu 2}(\alpha) = -F_{ex}\frac{\beta}{\Delta_2}\{sh(\beta\alpha^*) - sh[\beta(1-\alpha^*)] + sh\beta\}, (25)$$
$$Q_{\mu 2}(\alpha) = -F_{ex}\frac{\beta}{\Delta_2}\{sh(\beta\alpha^*) - sh[\beta(1-\alpha^*)] + sh\beta\},. \quad (26)$$

here$\Delta_2 = 2Z_{\mu 0}\beta sh\beta - 2Z_{\mu}(1+ch\beta) - Z_{\mu}\beta sh\beta$;$Z_{\mu} = Z_{\mu\text{p}}\alpha_{\text{м}}$.

IV. CONCLUSION

Thus, expressions (8) - (10) and (17) - (26) are mathematical models of a ring-channel EMO magnetic circuit created with the participation of the authors. These mathematical models were created taking into account the distribution of magnetic chain parameters and scattered magnetic fluxes through non-working air gaps and can be used to study the basic characteristics of magnetic chain design parameters and EMOs that measure fluid flow. It was found that the difference between the models and the experimental results did not exceed 5-7%.

REFERENCES

[1]. Welt I.D., MikhailovaYu.V. Measurement of flow and level of electrically conductive liquids: Monograph. LAP LAMBERT Academic Publishing.Germany, 2018. - 155 p.
[2]. Electromagnetic flowmeterMagnetoflow® Primo Installation and Maintenance Manual VERSION 1.1/01-04 Czech. 2006. - 41 p.
[3]. Specifications Integrated two-wire electromagnetic flowmeter. AHR Japan series. 2008. - 60 c.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 11 , November 2020

[4]. Pugach E.E. Development of high-precision electromagnetic flowmeter of liquids for agricultural production: diss. ... Ph.D. Moscow, 2007. - 134 p.
[5]. Loginov N.I. Electromagnetic transducers consumption of liquid metals. - Moscow: Energoizdat, 1981. - 104 p.
[6]. Zaripov M.F. Converters with distributed parameters for automation and information-measuring equipment. Moscow: Energy. 1969. - 176 p.
[7]. Theoretical foundations of electrical engineering: In 3 volumes. Textbook for universities.Volume 2. - 4th ed./K.S. Demirchyan, L.R. Neyman, N.V. Korovkin, V.L. Chechurin. - St. Petersburg: Peter, 2006. - 576 p.
[8]. Patent RUz. №04960. Electromagnetic flow transducer / Amirov S.F., Ataullaev A.O., Turdybekov K.X., Juraeva K.K., Ataullaev N.O.// Herald. - 2014. - №4.
[9]. Amirov S. F., Ataullaev A.O. Mathematical Models of Linear Magnetic Chains of Electromagnetic Converters of Flow with a Ring Channel// International Journal of Advanced Research in Science, Engineering and Tehnology. India. ISSN (Online): 2350 – 0328. Vol. 6, Issue 6, June 2019. P. – 9677 - 9682