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# Current stabilizer based on magnetic amplifier with electromagnetic control circuit

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**ABSTRACT:** The article discusses the use of electroferromagnetic circuits in the control circuits of magnetic amplifiers as control signal generators necessary to create a stabilization mode for the main working circuit, where the ferroresonant circuit serves as an integral part of the circuit, performing the function of a sensitive organ of a stabilizing property, consuming little power. To analyze the steady state of a ferromagnetic current stabilizer, the method of repeated approximation was used, which allows obtaining the necessary characteristics and by selecting the value of capacitance C, a current stabilizer can be created in the control circuit of the magnetic amplifier.

**KEYWORDS:** electroferromagnetic, ferroresonant current stabilizers, control circuit, current stabilizer, magnetic amplifier.

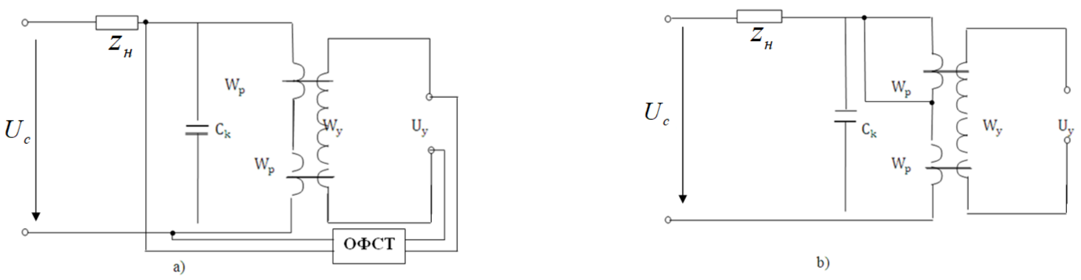
## I. INTRODUCTION

The use of electroferromagnetic circuits as generators, control signals necessary to create a stabilization mode for the main working circuit. The ferroresonance circuit serves as an integral part of the circuit, performing the function of a sensitive organ of the stabilizing device. This leads to a significant improvement in output power without a significant increase in weight and dimensions. It is known that the sum of the installed powers of the reactive elements of ferroresonant current stabilizers exceeds the load power by more than 4 times, which limits their use for high powers. It is proposed to use such circuits in control circuits of magnetic amplifiers, where low power is required. It is known that the power gain factor for a 100-watt controlled choke when using cold-rolled steel $f$=50 *Hz* is 50-200. As the power of the magnetic amplifier increases, its gain increases [1, 2].

Thus, the electromagnetic stabilizing device combines the advantages of a ferroresonant circuit and a magnetic amplifier. Such a device consists of two interconnected non-linear circuits, one of which performs the function of an actuating element, the other is a sensitive element [3, 4].

The simplest ferromagnetic current stabilizer is a saturation choke, biased by direct current. Detailed studies of such stabilizers have shown that it is advisable to use them for low-power installations. To improve the energy performance of current stabilizers based on ferromagnetic elements, it is proposed here instead of a permanent magnet to use a DC winding fed from the previously considered ferroresonant current stabilizer through a rectifier. Variants of the circuits of such a stabilizer are shown in Fig.1, where the capacitor $C_k$ is taken from the consideration of compensating for the deviation of the operating current of the magnetic amplifier when the mains voltage and load resistance change. A rectified current of a single-phase ferroresonant stabilizer flows through the control circuit of the magnetic amplifier. In the first circuit (a), with a sinusoidal current, due to the nonlinearity of the magnetization curve, even harmonics appear in the core fluxes, which induce an EMF of double frequency in the current control winding.

This causes a current with a frequency of 2$f$ to appear in the control circuit. In the second version of the current stabilizer circuit, with a sinusoidal input voltage, even harmonics appear in the current of the working windings and circulate only inside the circuit formed by the parallel windings $W_p$. The load current has a symmetrical shape and no EMF of even harmonics is induced on the controlled winding. However, a short circuit consisting of $W_p$ windings increases the time constant of the amplifier. But this is not essential for the mode of operation of the considered current stabilizer, since the device operates at a constant value of the bias current.



a) b)

**Fig. 1. Ferromagnetic current stabilizer circuit options**

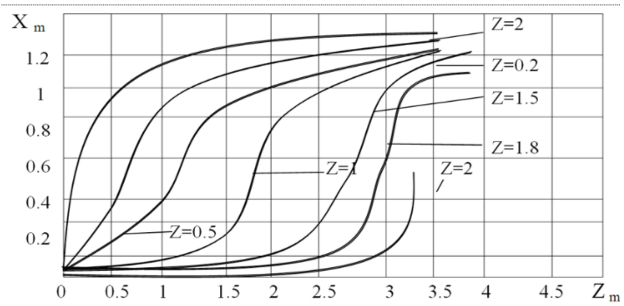


**Fig. 2. Simultaneous magnetization curves.**

To analyze the steady state of a ferromagnetic current stabilizer, we use the method of repeated approximation, which makes it relatively easy to obtain the necessary characteristics of the device. The essence of the method is as follows: analytically describing the magnetization curve of a ferromagnetic element by a power function, taking into account the main harmonics of the magnetic flux and current, based on the harmonic balance method, we obtain the basic equations for the generalized characteristics of the controlled ferromagnetic element [3, 6].

Let's build the dependencies:

$X_{1m}=f\ (Z_{1m})$ for different $x_0$

$X_{1m}=f\ (Z_{1m})$ for different $z_0$

In what follows, we are interested in the second characteristic, which has no explicit analytic expression. In order to obtain a more convenient mathematical dependence for $X_{1m}=f(Z_{1m})$ (Fig. 2), it is proposed to use the following approximating function.

$$Z_{1m} = K_0 + K_1X_{1m} + K_2X_{1m}^N \quad , \tag{1}$$

here, $K_0$, $K_1$, $K_2$ - approximation coefficients; $n$ - can be taken equal to 3, 5, 7, 9, 11, ....

Denoting by $\varepsilon_1$ the deviation of the $Z_{im}$ value from the value obtained by (1), we write the following dependencies:

$$\varepsilon_1 = K_0 + K_1X_{1m} + K_2X_{1m}^n - Z_{1m}$$
$$\varepsilon_2 = K_0 + K_1X_{2m} + K_2X_{2m}^n - Z_{2m}$$
$$\dots\dots\dots\dots\dots\dots\dots\dots$$
$$\varepsilon_n = K_0 + K_1X_{nm} + K_2X_{nm}^n - Z_{nm}$$

The best values of the coefficients $K_0$, $K_1$, $K_2$ are observed when the sum of the squared deviations is the smallest:

$$\sum_i^n \varepsilon_i^2 = \varepsilon_1^2 + \varepsilon_2^2 + \cdots + \varepsilon_n^2 = f(K_0, K_1, K_2)$$

$$\sum_i^n (K_0 + K_1X_{1m} + K_2X_{1m}^N - Z_{1m})^2 =$$
$$= (K_0 + K_1X_{1m} + K_2X_{1m}^n - Z_{1m})^2 + (K_0 + K_1X_{2m} + K_2X_{2m}^n -$$
$$-Z_{2m})^2 + \cdots + (K_0 + K_1X_{nm} + K_2X_{nm}^n - Z_{nm})^2 \tag{2}$$

In order to find the smallest value of the function $f(K_0, K_1, K_2)$, we take partial derivatives with respect to $K_0$, $K_1$ and $K_2$ and equate to zero, that is:

$$\frac{\partial f}{\partial K_0} = 0, \qquad \frac{\partial f}{\partial K_1} = 0, \qquad \frac{\partial f}{\partial K_2} = 0,$$

For the case when the degree of the approximating function is 7, we have:

$$\left.\begin{aligned} nK_0 + K_1(X_{1m} + X_{2m} + \dots + X_{nm}) + K_2(X_{1m}^7 + X_{2m}^7 + \dots + X_{nm}^7) = \\ = Z_{1m} + Z_{2m} + \dots + Z_{nm}, \\ K_0(X_{1m} + X_{2m} + \dots + X_{nm}) + K_1(X_{1m}^2 + X_{2m}^2 + \dots + X_{nm}^2) + \\ + K_2(X_{1m}^8 + X_{2m}^8 + \dots + X_{nm}^8) = Z_{1m}X_{1m} + Z_{2m}X_{2m} + \dots + Z_{nm}X_{nm} \\ K_0(X_{1m} + X_{2m} + \dots + X_{nm}) + K_2(X_{1m}^8 + X_{2m}^8 + \dots + X_{nm}^8) + \\ + K_2(X_{1m}^{14} + X_{2m}^{14} + \dots + X_{nm}^{14}) = Z_{1m}X_{1m}^7 + Z_{2m}X_{2m}^7 + \dots + Z_{nm}X_{nm}^7 \end{aligned}\right\} \tag{3}$$

The system of equations (3) is a system of algebraic equations. Число уравнений равно числу неизвестных и число пар заданных значений $X_{1m}$ and $Z_{1m}$ должно быть больше, чем число неизвестных коэффициентов. As you can see, from the analysis of the system of equations, you have to perform a large number of calculations, and therefore it is necessary to use computer technology in the calculation.

Thus, after approximating the curve $X_{1m}=f(Z_{1m})$, we obtain an explicit analytical expression for the curves of simultaneous magnetization of a ferromagnetic material by constant and alternating fields. Figure 2 shows the characteristics $X_{1m}=f(У_{1m})$ obtained by (3) for various $Z_0$. The values of the coefficients $K_0$, $K_1$ and $K_2$ depend on the value of $Z_0$ (Fig. 4.6). This makes it easy to present the analytical expression of the function $X_{1m}=f(Z_{1m})$ for a fixed value of the bias current. Comparison of the characteristics presented in Figures 2 and 3 shows that the analytical description of the characteristics of simultaneous magnetization using (1) gives qualitatively correct results when $Z_0<1.5$. We will analyze the steady state of the ferromagnetic current stabilizer circuit based on the method of taking into account the fundamental harmonic of the induction.

For the case when $n=7$

$$Z_{1m} = K_0 + K_1K_{1m} + K_2X_{1m}^7 \tag{4}$$

Current consumed from the network

$$Z_m = Z_{1m} - Z_{cm} \qquad Z_{cm} = \frac{\omega C U_m}{i_\delta} \tag{5}$$

For a ferromagnetic current stabilizer circuit.

$$\omega\frac{d\Phi_a}{dt} + \omega\frac{d\Phi_b}{dt} = \frac{1}{C}i_c dt \tag{6}$$

If we take into account the equality of flows in cores A and B, then we accept.

$$X = \frac{\Phi}{\Phi_\delta}, \quad Z_c = \frac{i_c}{i_\delta} \tag{7}$$

We will receive

$$\frac{d^2x}{d\tau^2} = \frac{i_\delta Z_c}{2\omega^2 W C \phi_\delta},$$

Designating

$$m = \frac{i_\delta}{2\omega^2 W C \phi_\delta}, \tag{8}$$

We have

$$Z_c = \frac{1}{m}\frac{d^2x}{d\tau^2}. \tag{9}$$

Taking into account the last dependence from (4.10), we write.

$$Z_m = K_0 + K_1X_{1m} + K_1X_{1m}^7 - \frac{X_{1m}}{m}$$

Let's construct the characteristic $X_{1m}=f(Z_m)$ for different values of m (fig.4.7). When K0=1.4; K1=1; K2=0.2.

$$Z_m = 1.4 + \left(1 - \frac{1}{m}\right)X_{1m} + 0.2X_{1m}^7 \tag{10}$$

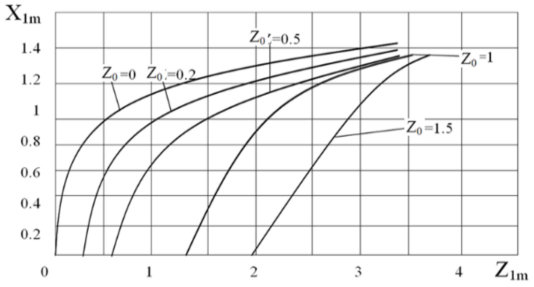


Fig. 3. Dependences $X_{1m}=f(Z_{1m})$ for various $z_0$

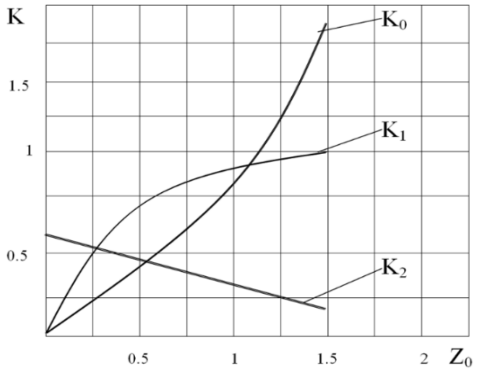


Fig. 4. Dependences $K_0$, $K_1$, $K_2 = f(z_0)$

From the analysis of the characteristics obtained, it can be seen that the stabilization effect is more pronounced when *m*=0.95. Thus, by selecting the desired value of capacitance C, we can create a current stabilizer using ferroresonant current stabilizers in the control circuit of the magnetic amplifier. With the correct selection of the value of C, the current-voltage characteristic of the capacitor will be almost parallel to the linear part of the characteristic of the ferromagnetic element [7].

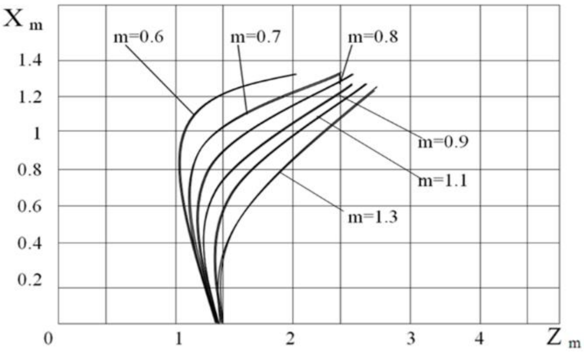


Fig. 5. Dependences $X_{1m}=f(Z_{1m})$ for various

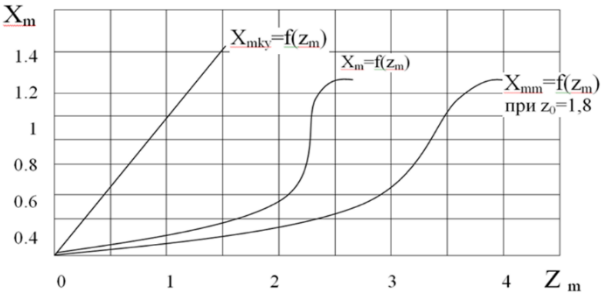


Fig. 6. Characteristics $X_m=f(Z_m)$

From (6) it follows that

$$C = \frac{i_\delta}{2\omega^2 W \phi_\delta}$$

Figure 6 shows the characteristics of the elements of a ferromagnetic current stabilizer and the resulting dependence $X_m=f(Z_{1m})$, obtained graphically.

The current-voltage characteristic of a ferromagnetic current stabilizer is the dependence of the effective value of the first harmonic of the alternating voltage at the terminals of the device on the effective value of the first harmonic of the current, which is the algebraic sum of the currents of the working windings and the capacitor. To construct this characteristic, we use the results obtained in the previous section. We will consider the magnetization curves of ferromagnetic materials to be known, since at present these characteristics have been sufficiently studied by researchers and there are extensive materials on the theoretical foundations of electromagnetic processes in ferromagnetic media [1, 2, 8]. The relationship between the magnetic induction *B* and the field strength *H* is approximated by a power function of order *n*. With known parameters of the nonlinear inductance, we can proceed to the characteristics $I_w=f(\Phi)$, given that:

$$H_m * l = l_m * W, \qquad \Phi_m = B_m * S$$

Where $H_m$ - amplitude of the first harmonic of the magnetic field strength;
*l* - length of the middle magnetic line;
$I_m$ - amplitude of the first harmonic of alternating current;
*S* - core cross section.

In the future, introducing dimensionless parameters, we proceed to the generalized characteristics of the ferromagnetic element and build the dependence $X_{1m}=f(Z_m)$ for the current stabilizer. In this case, we take into account the value of m, which is selected from the stabilization conditions and depends on the value of the capacitance *C*. The transition to the current values is carried out taking into account:

$$u = 2W\frac{d\Phi}{dt} = U_m cos\omega t\,,$$

Then

$$\Phi = \Phi_m sin\omega t\,.$$

Here

$$\Phi_m = \frac{\sqrt{2}U}{4\pi aW}\,.$$

Thus, for the transition from the curve $X_{1m}=f(Z_{1m})$ to $U=f(I)$ it is necessary to change the scale of the ordinate axis by $\frac{4\pi Wf\Phi_\delta}{\sqrt{2}}$ times, and the scale of the abscissa axis by $\frac{i_\delta}{\sqrt{2}}$ times**.**

## II. CONCLUSION

1. By selecting the desired value of capacitance C, we can create a current stabilizer using ferroresonant current stabilizers in the control circuit of the magnetic amplifier. With the correct selection of C, the current-voltage characteristic of the capacitor will be almost parallel to the linear part of the characteristic of the ferromagnetic element.
2. To build the current-voltage characteristic of a ferromagnetic current stabilizer, which depends on the effective value of the first harmonic of the alternating voltage on the primary harmonic of the current, representing the algebraic sum of the currents of the windings and the capacitor, it is necessary to change the scale of the ordinate axis to $4\pi W f\Phi/\sqrt{2}$ times, and the scale of the abscissa axis to $\frac{I_\delta}{\sqrt{2}}$ times.

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