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DYNAMIC MODEL OF MAGNETIC AMPLIFIER WITH SELF-SATURATION

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ABSTRACT

In control systems, we often use magnetic amplifier with self-saturation circuit. In the loop of functioning windings, we include diodes and those windings with diodes are opposite-parallel connected.

Diodes are the source of increasing amplification coefficients and thus permit to control magnetic amplifier with low control windings currents. The presence of diodes also significantly changes the Volt-Ampere characteristics. In this paper, we present a model of magnetic amplifier with self-saturation

KEYWORDS: Dynamic model, magnetic amplifier, self-saturation

I. INTRODUCTION

Although called a magnetic amplifier, this application really uses an inductive element as a controlled switch. A mag amp is a coil of wire wound on a core with a relatively square B-H characteristic. This gives the coil two operating modes: when unsaturated, the core causes the coil to act as a high inductance capable of supporting a large voltage with little or no current flow. When the core saturates, the impedance of the coil drops to near zero, allowing current to flow with negligible voltage drop. Thus a mag amp comes the closest yet to a true ideal switch with significant benefits to switching regulators. There are a few overview statements to be made. First, this type of regulator is a pulse-width modulated down switcher implemented with a magnetic switch rather than a transistor. It is a member of the buck regulator family and requires an output LC filter to convert its PWM output to DC. Instead of DC for an input, however, a mag amp works right off the rectangular waveform from the secondary winding of the power transformer. Its action is to delay the leading edge of this power pulse until the remainder of the pulse width is just that required to maintain the correct output voltage level.Like all buck regulators, it can only substract from the incoming waveform, or in other words, it can only lower the output voltage from what it would be with the regulator bypassed [1].

As a leading-edge modulator, a mag amp is particularly beneficial in current mode regulated power supplies as it insures that no matter how the individual output loading varies, the maximum peak current always occurs as the pulse is terminated.

II. VOLT-AMPERE CHARACTERISTICS OF MAGNETIC AMPLIFIER WITH SELF-SATURATION FUNCTIONING WINDINGS[2][3]

The presence of diodes included in series with functioning windings of magneto-conductors A and B (figure 1) provokes the circulation of currents i_{1A} and i_{1B}in one positive direction.
According to 1st Kirchhoff law, we assume that $i_1 = i_{1A} - i_{1B} = I_{m1}\cos(\omega t)$
With the circulation of i_{1A}, i_{1B}, i_2, there will be the following voltages in functioning windings:
$u_{1A} = R_1 i_{1A} + L_1 p i_{1A} + p\psi_{11A}(i_{1A}, i_2);$
$u_{1B} = R_1 i_{1B} + L_1 p i_{1B} + p\psi_{11B}(i_{1B}, i_2);$

Where R_1 – active resistance of functioning winding;
L_1– dispersion inductance of functioning winding;

$\psi_{11A}(i_{1A}, i_2)$, $\psi_{11B}(i_{1B}, i_2)$ – main flux linkages of functioning windings for magneto-conductors A and B;
p – operator of differentiation.

The main flux linkages of functioning windings have non-linear dependences on currents, and in per units system can be expressed as follows:

$$\psi^*_{11A}(i^*_{1A}, i^*_2) = \arctan(i^*_{1A} + i^*_2) \in [0, \pi]; \quad (1)$$
$$\psi^*_{11B}(i^*_{1B}, i^*_2) = \arctan(i^*_{1B} + i^*_2) \in [0, \pi];$$

Thus the curves of currents in functioning windings and voltages will be different from sinusoids.

In absence of losses in windings, diodes are opened during the whole period of network voltage, and along the loop of parallel connected windings, there will circulate current i_0 that is called self-induction current.

Let us express the value of i_0 :
We have $i_{1A} = i_0 + i_1/2; i_{1B} = i_0 - i_1/2$ (2)

We neglect the voltage drop in diodes, active resistances and inductances of dispersion windings.
Voltages in main inductances are:

$$u^*_{11} = p\psi^*_{11A}(i^*_{1A}, i^*_2) = -p\psi^*_{11B}(i^*_{1B}, i^*_2),$$

Where $\psi^*_{11A}(i^*_{1A}, i^*_2), \psi^*_{11B}(i^*_{1B}, i^*_2)$ are defined by (1) and currents i_{1A}, i_{1B} by (2).

From the former equation, we have

$$i^*_0 = \frac{\sqrt{A^2\cos^2(t^*) + B^2} - 1 - i^{*2}_2}{I^*_{m_1} + 2i^*_2} \quad (3)$$

Where $\begin{cases} A = I_{m_1}^{*2} \cdot \left(I_{m_1}^{*2}/4 + i^*_2 . I^*_{m_1} + 2i^*_2 \right) \\ B = \left(1 + i_2^{*2}\right) . [(i^*_2 + I^*_{m1})^2 + 1] \end{cases}$

The illustration of currents plots in functioning windings is shown in figure 2.

When magneto-conductors work on linear part of induction characteristic, i_0 will be constant.

When they work on nonlinear part of characteristic, self-induction i_0 will have a pulsation character.

The aspect of voltage in functioning windings with considerable induction of windings will be different from sinusoid (figure 3).

The main voltage in functioning winding is approximated by sinusoid $-U_{m11}\sin(\omega t)$.

Let us find the dependence of the amplitude U_{m11} of main voltage on current amplitude I_{m1}. For that purpose,

$$\int_{\pi}^{2\pi} u^*_{11} dt^* = \omega[\psi^*_{11A}(I^*_{m1}, i^*_2) - \psi^*_{11A}(0, i^*_2)]$$

Will be equal to the equivalent sinusoid

$$\int_{\pi}^{2\pi} U^*_{m11}\sin(t)\, dt \approx 2U^*_{m11}$$

From equality of integrals, we have:

$$U^*_{m11} = \omega[\psi^*_{11A}(I^*_{m1}, i^*_2) - \psi^*_{11A}(0, i^*_2)]/2$$

Written in per unit system,

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$$U_{m11}^{*} = \frac{[\arctan(I_{m1}^{*}+i_2^{*})-\arctan(i_2^{*})]}{2} \in \left[0, \frac{\pi}{2}\right] \quad (4)$$

Apart from main voltage, in functioning windings we have voltage drops in dispersion inductance $\omega L_1 I_1$and active resistance $R_1 I_1$. We neglect $R_1 I_1$.

Then the equivalent sinusoid voltage amplitude in functioning windings will be considered as follows:

$$U_{m1}^{*} = [\arctan(I_{m1}^{*} + i_2^{*}) - \arctan(i_2^{*}) + L_1 . I_{m1}^{*}]/2 \quad (5)$$

It is the Volt-ampere characteristic of the magnetic amplifier with self-saturation functioning winding. It is represented in figure4 by using equation (4).

Functioning windings of magnetic amplifier with self-saturation for high values of currents I_{m1} have the property of voltage stabilization.

The amplitude of stabilization voltage is related to the winding control current by the expression:

$$U_{mST}^{*} = \frac{\pi}{2} + \arctan(i_2^{*})$$

Considering the dispersion inductance, the volt-ampere characteristic will have a slope and can be built using equation (5).

III. DYNAMIC PROPERTIES OF MAGNETIC AMPLIFIER WITH SELF-SATURATION CONTROL WINDING [4][5][6]

When currents i_1 and i_2 circulate along magnetic amplifier windings, it appears a voltage at the control winding:

$$u_2 = R_2 i_2 + L_2 p i_2 + p\psi_{22} \quad (6)$$

Where R_2- active resistance of control winding;
L_2- dispersion inductance of control winding;
p – operator of differentiation;
ψ_{22}- Main total flux linkage of control winding.

Equation (6) characterizes electromagnetic processes in the control winding of magnetic amplifier with self-saturation.

We have:

$$\psi_{22}^{*} = \psi_{11A}^{*}(i_{1A}^{*}, i_2^{*}) + \psi_{11B}^{*}(i_{1B}^{*}, i_2^{*}),$$

Where functioning windings currents are determined by equations (2).

We replace in the expression of main total flux linkage of control winding the value of functioning windings self-induction current (3). We then obtain

$$\psi_{22}^{*} = 2.\arctan\left(\frac{\sqrt{(i_2^{*2}+1).[(I_{m1}^{*}+i_2^{*})+1]} + i_2^{*}.(I_{m1}^{*}+i_2^{*}) - 1}{I_{m1}^{*}+2i_2^{*}}\right)$$

The main total flux linkage of control winding is a complex non-linear function of control winding current and amplitude of functioning current.

Graphics are shown in figure 5.

The flux linkage of control winding is the sum of main flux linkage ψ_{22}^{*} and flux linkage of dispersion $\psi_2^{*} = L_2^{*}.i_2^{*}$

$$\psi_{02}^{*} = \psi_{22}^{*} + \psi_2^{*}$$

Differential inductance of control winding is therefore $L_{02}^{*} = \frac{d\psi_{02}^{*}}{di_2^{*}}$ that considerably depends not only on amplitude of functioning windings currents, but also on control winding current.

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IV. CONCLUSION

The main functioning regime of magnetic amplifier with self-saturation is the electrical disruption regime, that occurs when currents amplitudes in functioning windings $I_{m1}^{*} > 3.5$.

In the electrical disruption regime, magnetic amplifier with self-saturation behaves as a controlled e.m.f. source. The amplitudes of current and voltage equivalent sinusoids in functioning windings are deviated without consideration of energy loss with $90°$.

Control winding of magnetic amplifier with self-saturation is a nonlinear dynamic element whose time constant depends on amplitude of functioning winding summary current, and also on control winding current

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FIGURES

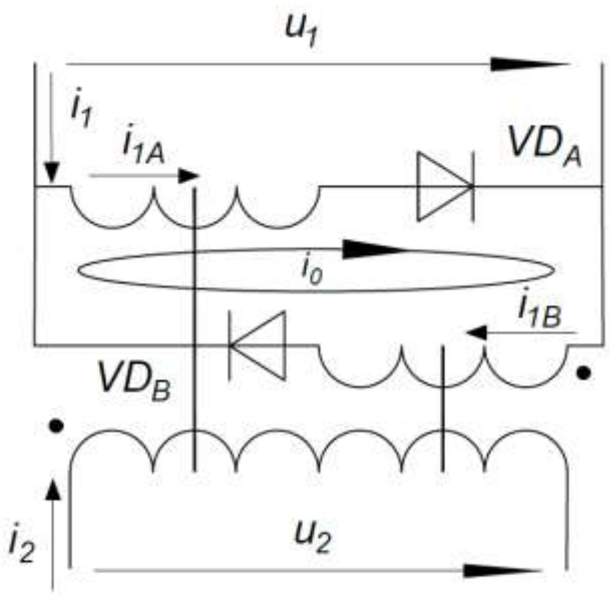

Figure 1 :Circuit of magnetic amplifier with self-saturation and parallel connection of functioning windings

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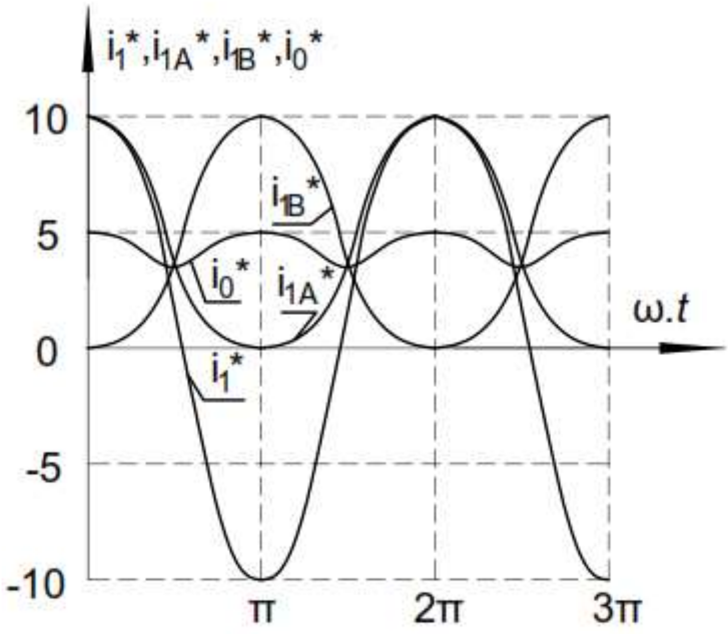

Figure 2 :Current characteristics in functioning windings with $I^*_{m1} = 10, i^*_2 = 7$

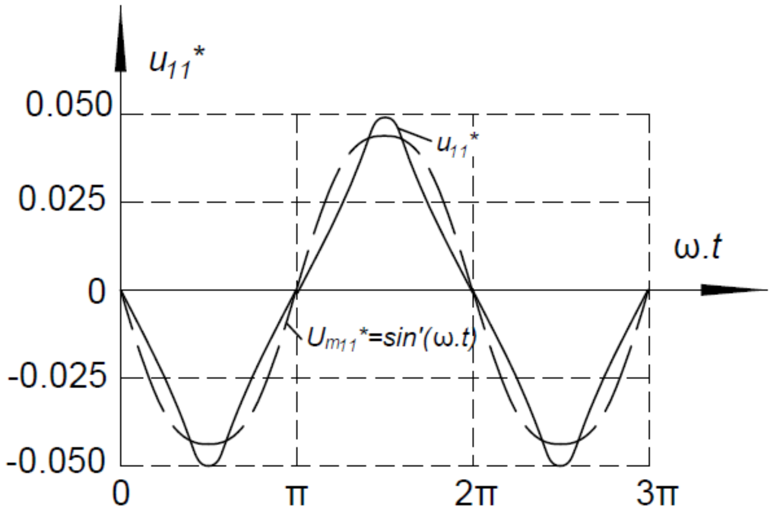

Figure 3 :Voltage characteristics in functioning windings for $I^*_{m1} = 10$ *,* $i^*_2 = 7$

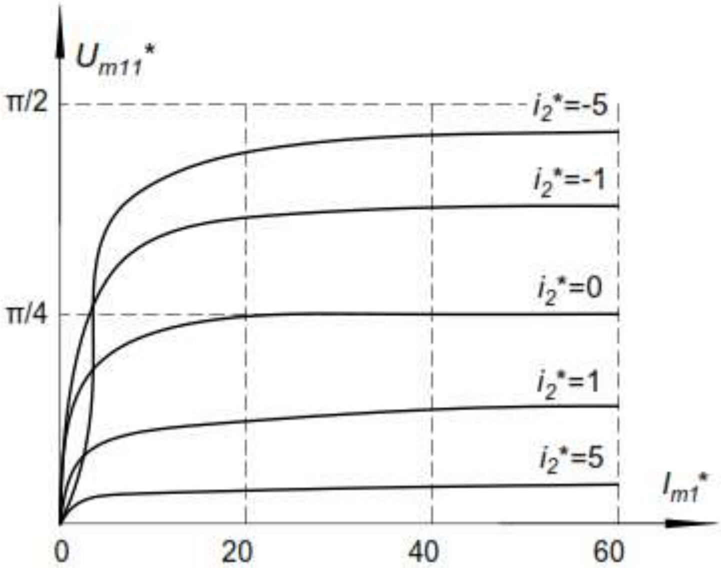

Figure 4 : Volt-Ampere characteristics of functioning windings

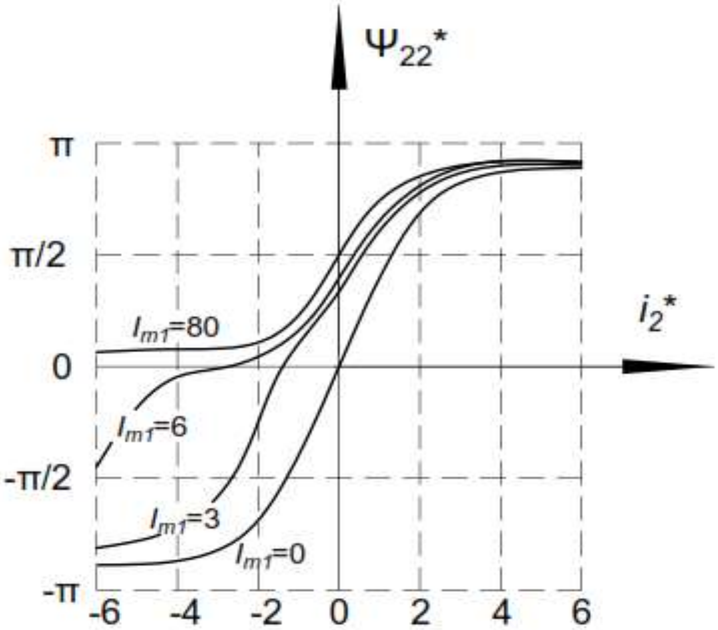

Figure 5 : Graphics for dependence of flux linkages of control winding on current

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