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Application of an auto-parametric circuit for controlling thyristor converters

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Abstract. This article discusses the issues of excitation of second-order subharmonic oscillations, in circuits representing a two-core electro-ferromagnetic circuit with a capacitive load, in order to use it to control the states of thyristors, frequency converters. The stability of the solutions of the equations of the two-core chain is investigated. Recommendations are given for obtaining stable subharmonic oscillations of the order $\frac{1}{2}f$ when using these circuits as a control element of thyristor frequency dividers by two.

1 Introduction

The development of semiconductor technology led to various developments of thyristor devices: voltage and current stabilizers, inverters and frequency converters. Interest in auto-parametric circuits, as circuits for controlling the states of thyristors, has increased due to the fact that the latter in circuit combinations with thyristors provide ample opportunities for solving many technical problems.

Periodic second-order subharmonic oscillations can be excited in an electroferromagnetic oscillatory circuit at certain ratios of parameters and voltage of the power source.

This feature of a two-core autoparametric circuit can be used to solve the issue of creating a reliable thyristor frequency divider by two [1-8].

The circuit under consideration consists of two identical ferromagnetic elements, the primary windings of which are connected in series - according to and connected to a source of sinusoidal voltage, the secondary windings are connected in series - opposite and together with the capacitor C connected to them form a closed oscillatory circuit, and there is also a third winding connected in series - according to and connected to a direct current source, serving to create a constant bias flux (Fig. 1). Let us study the issues of excitation of second-order subharmonic oscillations in a two-core ferromagnetic circuit in order to use it to control the states of thyristors [9-15].

To analyze the processes occurring in the circuit, we make the following assumptions:

1. Active resistance of the secondary windings and losses in ***ФЭ*** are taken into account by a constant resistance R. connected in parallel with the capacitor C,

2. Losses in capacity C are not taken into account.

3. Inductance leakage windings ***ФЭ*** we neglect them in view of their smallness.

4. The magnetization curve of ferromagnetic elements is approximated by a third-order power function.

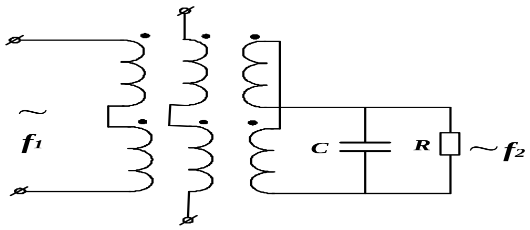

Fig. 1. Equivalent circuit of a two-core auto-parametric circuit.

Let's take:

ϕ_A and ϕ_B - instantaneous values of the fluxes in the cores of the first and second ФЭ;

i_1 - current in the primary circuit;

i_2 - current in the secondary circuit;

i_c - the current flowing through the capacitance C;

i_R - the current flowing through the resistance R; i_g - constant bias current.

Based on the law of total current for the first and second **ФЭ** we have a system of equations:

$$\begin{aligned} i_1 w + i_0 w + i_2 w &= K\phi_A^3 \\ i_1 w + i_0 w - i_2 w &= K\phi_B^3 \end{aligned} \quad (1)$$

Solving together the system of equations (1), we obtain:

$$i_2 = \frac{K}{2w}\left(\phi_A^3 - \phi_B^3\right) \tag{2}$$

Let's compose the equation for the secondary circuit:

$$w\frac{d\phi_A}{dt} - w\frac{d\phi_B}{dt} + \frac{1}{C}\int i_C dt = 0$$

we differentiate this equation

$$w\frac{d^2\phi_A}{dt^2} - w\frac{d^2\phi_B}{dt^2} + \frac{1}{C} = 0$$

or

$$w\frac{d^2}{dt^2}(\phi_A - \phi_B) + \frac{1}{C} = 0 \tag{3}$$

The current in the secondary winding is:

$$i_2 = i_C + i_R$$

from where

Where

$$i_R R + U_C = 0$$

$$i_R = \frac{U_C}{R} = -\frac{w}{RC}\frac{d}{dt}(\phi_A - \phi_B) \tag{4}$$

substituting (2) and (4) into (3) we get:

$$w\frac{d^2}{dt^2}(\phi_A - \phi_B) + \frac{w}{RC}\frac{d}{dt}(\phi_A - \phi_B) + \frac{K}{2wC}\left(\phi_A^3 - \phi_B^3\right) = 0 \tag{5}$$

Assuming that

$\phi_A = \Phi_0 + \phi_1 + \phi_2$ and $\phi_B = \Phi_0 + \phi_1 - \phi_2$,

Where

Φ_0 - constant bias flux;

ϕ_1 - the instantaneous value of the flux due to the voltage of the primary circuit;

ϕ_2 – the instantaneous value of the flow due to the excitation of autoparametric oscillations.

Substitute (6) in (5)

$$w\frac{d^2}{dt^2}(\Phi_0 + \phi_1 + \phi_2) - w\frac{d^2}{dt^2}(\Phi_0 + \phi_1 - \phi_2) + \frac{w}{RC}\frac{d}{dt}(\Phi_0 + \phi_1 + \phi_2) - \\ - \frac{w}{RC}\frac{d}{dt}(\Phi_0 + \phi_1 - \phi_2) + \frac{K}{2wC}(\Phi_0 + \phi_1 + \phi_2)^3 - \frac{w}{RC}\frac{d}{dt}(\Phi_0 + \phi_1 - \phi_2)^3 = 0 \tag{6}$$

After a series of transformations, this equation will take the form:

$$w\frac{d^2\phi_2}{dt^2} + \frac{w}{RC}\frac{d\phi_2}{dt} + \frac{K}{2wC}\left[3(\Phi_0 - \phi_1)^2\phi_2 + \phi_2^3\right] = 0 \tag{7}$$

Let's introduce dimensionless quantities:

$$x = \frac{\phi_2}{\Phi_б};\quad y = \frac{\phi_1}{\Phi_б};\quad \Phi_б = \sqrt{\frac{2\omega^2 w^2 C}{K}};\quad \delta = \frac{1}{\omega CR};\quad \tau = \omega t;\quad Z = \frac{\Phi_0}{\Phi_б}.$$

We take

$$\frac{d^2x}{dt^2} + \delta\frac{dx}{dt} + 3(Z + y)^2 x + x^3 = 0 \tag{8}$$

Let's pretend that

$$x = X_m Sin(\tau + \varphi), \tag{9}$$

$$y = Y_m Sin2\tau \tag{10}$$

In the future, the problem is solved by the method of slowly varying amplitudes. According to the methodology, we are looking for a solution in the form:

$$\frac{dx}{dt} = X_m Cos(\tau + \varphi) \tag{11}$$

The second derivative of the required quantity is defined as

$$\frac{d^2x}{dt^2} = -X_m Sin(\tau + \varphi) + 2\frac{dx}{dt}Cos(\tau + \varphi) - 2X_m\frac{d\varphi}{d\tau}Sin(\tau + \varphi) + \\ + \delta X_m Cos(\tau + \varphi) + \left[3(Z + Y_m Sin2\tau)^2 X_m Sin(\tau + \varphi) + X_m^3 Sin(\tau + \varphi)\right] = 0 \tag{12}$$

after a series of transformations we have:

$$-X_m Sin(\tau + \varphi) + 2\frac{dx}{dt}Cos(\tau + \varphi) - 2X_m\frac{d\varphi}{d\tau}Sin(\tau + \varphi) + \delta X_m Cos(\tau + \varphi) + \\ + 3Z^3 X_{m+} Sin(\tau + \varphi) + \frac{3}{2}Y_m^2 Sin(\tau + \varphi) + \frac{3}{4}X_m^3 Sin(\tau + \varphi) = 0 \tag{13}$$

Grouping the sine and cosine components, we obtain the following system of algebraic equations for the stationary mode:

$$-1 + 3Z^2 + 3ZY_m Sin2\varphi + \frac{3}{2}Y_m^2 + \frac{3}{4}X_m^2 = 0, \tag{14}$$

$$\delta + 3ZY_m Cos2\varphi = 0 \tag{15}$$

From (15) we have

$$Cos2\varphi = -\frac{\delta}{3ZY_m} \tag{16}$$

As

$$Sin2\varphi = \sqrt{1 - Cos^2 2\varphi}$$

taking into account (16), this equality takes the form:

$$Sin2\varphi = \sqrt{1 - \frac{\delta^2}{9Z^2Y_m^2}} = \pm 3ZY_m\sqrt{9Z^2Y_m^2 - \delta^2} \tag{17}$$

Substituting the value ***Sin2φ*** into equation (14) we have

$$X_m^2 = \frac{4}{3}\left(1 - 3Z^2 - \frac{3}{2}Y_m^2 \pm \sqrt{9Z^2Y_m^2 - \delta^2}\right) \tag{18}$$

On the basis of the obtained expression, the amplitude characteristics of Fig. 2 and fig. 3. The width of the excitation zone of subharmonic oscillations can be adjusted by changing the magnitude of the bias current, capacitance and losses in the circuit. In fig. 2 shows the amplitude characteristics at different values of Z, curve 1 at Z - 0.4; curve 2 at Z = 0.5; curve 3 at Z = 0.6. In fig. 3 shows a series of amplitude characteristics with a change in the dimensionless coefficient δ, curve 1 at δ - 0,4;

2 at δ = 0,5; 3 at δ = 0,6 [16-24].

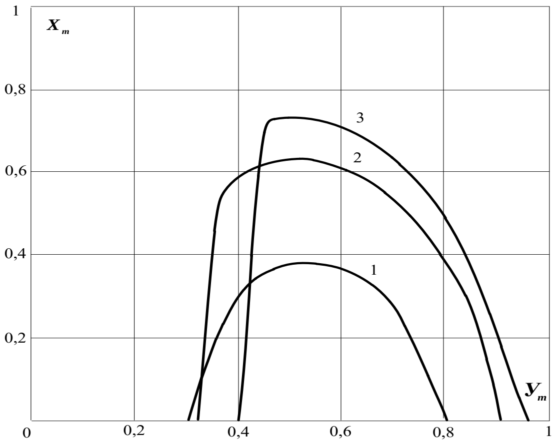

Fig. 2. Amplitude characteristics of the ventricular chain with a change in Z, curve 1 at Z = 0,4; 2 - 0,5; 3 – 0,6

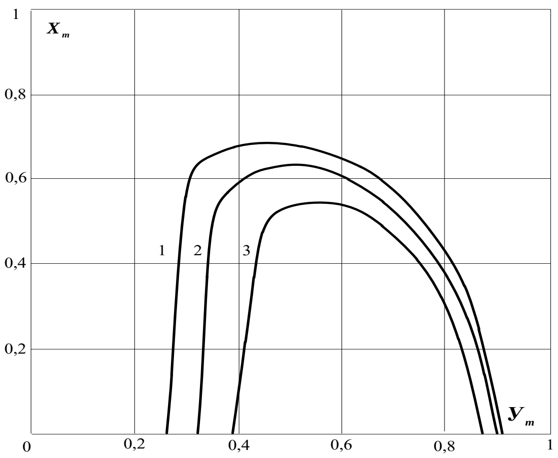

Fig. 3. Amplitude characteristics of the ventricular chain with a change in β, curve 1 at β = 0,4; 2 – 0,5; 3 – 0,6.

Consider the question of the stability of solution (18) based on the Lyapunov theory. The characteristic equation of the system is as follows: $a^2 + pa + q = 0$..

We take the notation

$$\frac{dx}{d\tau} = A(X_m;\varphi); \qquad \frac{d\varphi}{d\tau} = B(X_m;\varphi),$$

Here

$$A(X_m;\varphi) = -\frac{3}{2}ZY_m X_m Cos2\varphi - \frac{\delta}{2}X_m;$$
$$B(X_m;\varphi) = -\frac{1}{2} + \frac{3}{2}Z^2 + \frac{3}{2}ZY_m Sin2\varphi + \frac{3}{4}Y_m^2 + \frac{3}{4}X_m^2$$

Next , we obtain the system of equations

$$\frac{dA}{dx} = \ \frac{3}{2}ZY_m Cos2\varphi \quad \frac{\delta}{2} \qquad\qquad \frac{dA}{d\varphi} = 3ZY_m X_m Sin2\varphi \qquad (19)$$
$$\frac{dB}{dx} = \ \frac{3}{2}X_m \qquad\qquad \frac{dB}{d\varphi} = 3ZY_m Cos2\varphi$$

The coefficients of the characteristic equation of the first-order approximation system are obtained in the form:

$$p = -\left\lfloor \frac{dA}{dx} + \frac{dB}{d\varphi} \right\rfloor \qquad (20)$$

$$q = \left\lfloor \frac{dA}{dx}\cdot\frac{dB}{d\varphi} - \frac{dB}{dx}\cdot\frac{dA}{d\varphi} \right\rfloor \qquad (21)$$

Substituting of (16) and (17) meaning Cosφ and Sinφ in (19), solving equations (20) and (21) we get;

$$p = \delta \qquad q = \frac{3}{4}X_m^2\sqrt{9Y_m^2Z^2 - \delta^2} \qquad (22)$$

According to the Hurwitz criterion, the system is stable when $p > 0$ and $q > 0$. First condition $p > 0$ does not restrict the stability of the solution, since δ is always greater than zero. Taking into account the second condition, we determine the solution corresponding to the stable regime:

Thus, second-order subharmonic oscillations are excited when

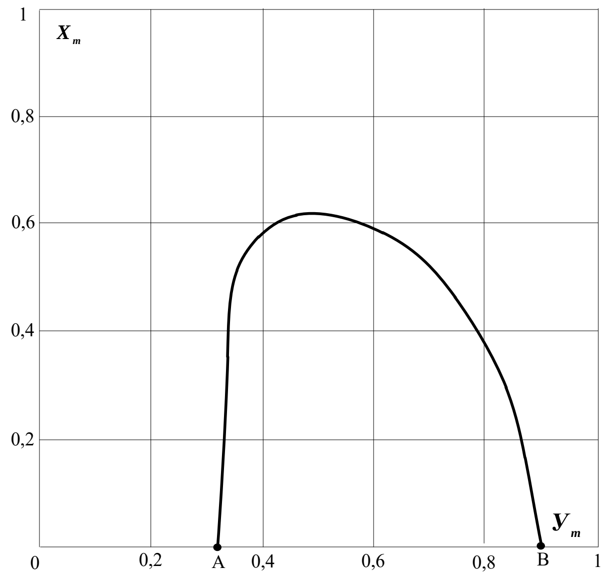

Fig. 4 A stable part of the amplitude characteristic of a two-core chain.

In fig. 4 shows a zone (section AB) of stable oscillations in a two-core chain.

$$Y_m^2 > \frac{\delta^2}{9Z^2} \qquad (23)$$

Hence, we can conclude that the solution corresponding to a stable state depends significantly on the values of the parameters C and R.

In the investigated symmetric two-core circuit, at the moment of the impulse of the supply voltage with equal strength, there are oscillations of two types shifted relative to each other by 180° [25-28].

The literature discusses in detail the issues of obtaining fixed oscillations of one or another type in two-core auto-parameter circuits, by introducing asymmetry into the PV windings,

Experiments have shown that an increase in the number of turns in the primary winding of one of the transformers by 1.6 times in comparison with the number of turns of the second transformer leads to the excitation in the autoparametric oscillatory circuit of subharmonic oscillations of the order, the initial phase of which coincides with the initial phase of the supply network [29-31].

2 Conclusions

The analysis showed that when creating a thyristor frequency divider it is twice effective to use a two-core oscillatory circuit circuit with asymmetry in the primary windings as a control system for the states of thyristors, and the power of the considered circuit does not exceed 10 Watts, regardless of the power of the power thyristors

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