**Parametric Voltage Converter on an Amorphous Alloy Core**

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**Abstract.** The article discusses the amplitude-phase relationships in a single-phase to six-phase voltage converter using an amorphous alloy core. The expressions obtained confirm the possibility of converting an unstable single-phase voltage into a stabilized six-phase one, and the use of an amorphous core makes it possible to obtain a device with high technical and economic parameters.

**Key words:** phase number converter, ferro resonance oscillations, three-rod transformer, amorphous alloys, capacitors, magnetization curve, amplitude-phase relations

**INTRODUCTION**

As you know, production, transmission and distribution are currently underway. Electricity is provided by three-phase sinusoidal current systems. However, for some consumers (electrified transport, electro technological installations, welding), single– and two-phase power is used. The presence of such consumers leads to asymmetry or non-sinusoidal currents of the three-phase supply network. To preserve the advantages of a three–phase system when powering such receivers, it is necessary to use intermediate devices - phase number converters. This article discusses a converter of a parametric nature from a single-phase unstable system to a stabilized six-phase one. Such a converter can be used to power a six-phase load of low and medium power from a single-phase network. Converters of this type can be implemented using three-rod transformers. The use of amorphous alloy cores in their design makes it possible to significantly improve the device's performance due to their high magnetic permeability, as well as a significant reduction in losses due to hysteresis, magnetization reversal and eddy currents [5, 6, 10].

**MATERIALS AND METHODS**

The physical model of the converter is implemented on the basis of a three-rod transformer. [4, 7, 9, 11], constructed using an amorphous alloy of Chinese production 1K101 or its Russian equivalent, AMAG492. A core with a cross-section of s was used to build the model , the number of turns of coils *w =350-400*, the length of the average magnetic line of the core *l =0.35 m*, saturation induction – *1.56 T*, coercive force is *8 A/m*, relative magnetic permeability at a frequency of 10 kHz it is equal to 5000.

The mathematical model of the converter was implemented using the harmonic balance method, while only the first harmonics of sinusoidal quantities were taken into account, which made it possible to simplify the model as much as possible while maintaining its adequacy and permissible calculation errors not exceeding 6% [4].

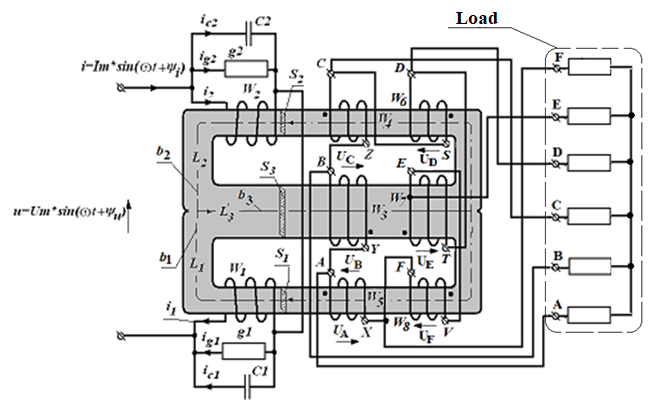
The hypothesis of the study suggests that magnetization curves can be used as models of magnetization for magnetically soft amorphous alloys, since these alloys have a very narrow hysteresis loop, and the obtained amplitude-phase ratios at the time of current resonance will allow obtaining the necessary phase shifts for the phase transformation process.

When creating the mathematical model, the following assumptions were made:

– the magnetization curve can be approximated by the function , which gives acceptable results for the amorphous alloy type AMAG492 used in the design of the converter [1];

– all active losses are accounted by the conductivities *g1*, *g2* [2, 3];

– the inductions of scattering of windings and the value of their own capacitance are not taken into account [2, 3].



**FIGURE 1.** Single-phase to six-phase voltage converter circuit

For the scheme shown in Figure 1, the following designations are adopted: *S1, S2, S3* – cross sections of rods;   
*L1, L2, L3* –average lengths of the magnetic lines of the rods; *b1, b2, b3* – instantaneous inductions in the rods; *g1, g2* – active conductivities of the windings of oscillatory circuits; *W1, W2* – the number of turns coils; *W3, W4, W5, W6, W7, W8* – secondary windings of the converter, on which the artificial conversion of the number of phases takes place; *C1, C2* – capacitance capacitors of oscillatory circuits; *R*– load of artificial phases; *A, B, C, D, E, F, x, y, z ,s, t, v* are the beginnings and ends of artificial phases, respectively; *ic1, ic2*, are instantaneous currents in capacitors; *ig1, ig2* are currents in active conductors of coils *W1, W2*; *i1, i2* are currents in coils of oscillatory circuits; is the instantaneous value of the supply current; is the instantaneous value of the supply voltage; *UA, UB, UC, UD, UE, UF* are the values of the phase voltages of the artificial phases.

The electric and magnetic parts of the circuit in Fig. 1 are described by a system of equations for instantaneous values of electric and magnetic quantities, while at certain values of the supply voltage and frequency, ferro resonance of currents is possible in it:

(1)

The values of the instantaneous currents in (1) can be determined using known expressions:

(1.2); (1.3); (1.4); (2)

(1.6); (3)

Given the expression:

as well as expressions for currents (2 and 3), we obtain:

(4)

To simplify the analysis of the circuit, we will take into account only the first harmonic of the inductions *b1* and *b2* in the calculations, and we will look for solutions for the inductions in the form of sinusoidal functions  
. After substituting this solution in (4) and considering (2 and 3), after some transformations we obtain

(5)

In expression (1.9), we raise the multiplier to the right of the equal sign to the 9th power by Newton's binomial, replace the degrees of the sine function with the sum of harmonics to the 1st power, and assume that the terms containing even harmonics are zero, and the constant components that appear when decomposing even powers of the sine will be included in the resulting expression in the form of constant factors for terms with odd degrees of sine. Taking into account only the first harmonic, we get:

(6)

We reduce such terms to (6) for and . We denote the resulting expressions for as , and for as . After all these mathematical operations, we get:

(7)

(8)

The final expression looks like this:

(9)

Let's denote some coefficients

(10)

Taking into account these coefficients and the notation (7 – 10), expression (10) is written as:

(11)

After the transformation (11) using the harmonic balance method, and some simplifications, we obtain the system:

(12)

Let's square the expressions to the left and right of the equal sign in (12), reduce the resulting expressions to , and after some transformations, we obtain an expression defining the relationship between the magnitudes of magnetic inductions and the functionals and :

(13)

From expression (13), we can also determine the phase shift between the amplitudes and :

(14)

The instantaneous induction in the middle rod is determined by the expression . Given the previously accepted notation, it can be written as:

(15)

Let's denote the relations between the areas as , we will have:

. (16)

After converting in (16) the difference of the sines of the angles into their product by the harmonic balance method, we obtain the system:

(17)

After the transformation (17) by the harmonic method and some simplifications, the amplitude of the first harmonic of the magnetic induction in the middle rod can be found:

(18)

and its initial phase

(19)

The expression for the current in the unbranched part of the circuit can be written as

(20)

Substituting in (20) the solution for the magnetic induction in the first rod, after some transformations, we obtain:

(21)

We introduce the notation of the coefficients before the sines and cosines.

(22)

We transform (22) using the harmonic balance method, replacing the sums of the arguments of the sine and cosine functions by their product and comparing the coefficients for and both to the left and to the right of the equal sign

(23)

From where we get the expression connecting the amplitudes of induction *B1* and the supply current *I1m*

. (24)

The initial phase of the supply current can also be determined from (24).

. (25)

The supply voltage *Um* can be found according to Kirchhoff's second law, compiled for instantaneous voltage values.

(26)

We substitute the solutions in (26) , perform the necessary mathematical transformations, and replace the sine and cosine of the sum and difference of the arguments in the resulting expression with their products. By introducing new notation , we obtain:

(27)

Converting (27) by the harmonic balance method, we obtain the system:

(28)

from which an expression can be derived relating the input voltage to the magnetic inductions in the rods.

(29)

The phase shift between the supply voltage and the induction in the first rod can also be calculated from (29).

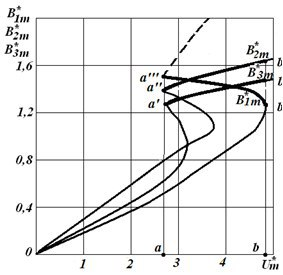
(30)

The phase shift between current and voltage is calculated using the well-known formula.

(31)

**RESULTS AND DISCUSSION**

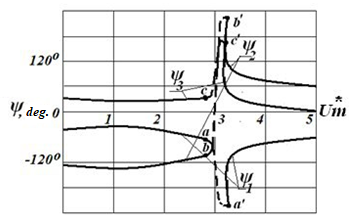
We investigate the dependencies , which are analogous to the adjustment characteristics of the converter . Figure 2 shows a family of curves  
 .



**FIGURE 2.** Calculated adjustment characteristics of the phase number converter at

It can be seen from the curves that in the zone of existence of ferro resonance vibrations located between points *a* and *b* of the control characteristic, the inductions in the rods practically do not change.: In this area, highlighted by thicker lines, the induction varies in a narrow range *a' – b'*, the induction varies in a narrow range between points *a”* - *b”*, and the induction varies in a narrow range between points *a’’’* and *b’’’*. Since the voltages on the windings *W3 – W8* are proportional to the magnetic inductions , this indicates the possibility of using the circuit in question as a voltage stabilizer on the windings located on the rods of the magnetic circuit.

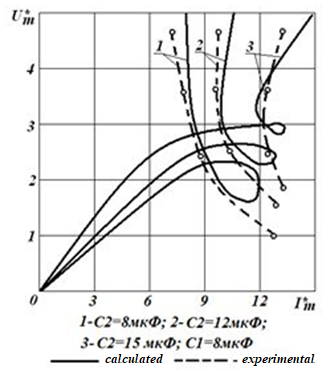
According to the expressions (27), (28), (29), (30) and (31) we plot the dependences of the phase shifts *ψ1, ψ2, ψ3* on the amplitude of the supply voltage, expressed in relative units , which are shown in Figure 3. from the graphs it can be seen that up to points *a, b, c,* which are the lower boundary of the ferro resonance voltage surge, the phases of the extreme rods (designated as *ψ1* and *ψ2*) have a capacitive load character, and the phase of the middle rod (designated as *ψ3*) has an inductive load character. After the occurrence of ferro resonance phenomena in the circuit (from points *a’, b’, c’* and above), the *ψ2* curve changes its character to inductive with a phase shift close to +60°, the *ψ1* curve remains capacitive with a shift close to –60°, and in the middle rod the phase shift *ψ3* is approximately zero.



**FIGURE 3.** Dependence of phase shifts between magnetic inductions in the rods of the magnetic circuit converter number of phases on the amplitude of the supply voltage

If the ends of the windings *W3* and *W7* on the middle core rod are reversed, a phase shift of approximately 600 will be established between the output voltage vectors *UA, UB, UC, UD, UE,* and *UF*, and the values of the inductions and, accordingly, the voltages, as can be seen from Figure 2, will stabilize.

Figure 4 shows the voltage characteristic of the converter . It represents the relationship between the amplitude of the input voltage and the amplitude of the current, expressed in relative units. The characteristic has a loop-like appearance, on which there is a section where the current practically does not change. Thus, according to its properties, the circuit under study is a current source with stable properties when the capacitance *C2* changes from 8 to 15 *mkF*.



**FIGURE 4.** Current-voltage characteristic of the phase number converter at different capacitor capacitance values

Since the circuit in the ferro resonance mode is powered practically from a current source, according to [2, 3, 8, 9] this makes it possible to stabilize the modes of both the amplitudes of magnetic inductions and the associated amplitudes of the phase voltages *UA, UB, UC, UD, UE, UF* of artificial phases.

**CONCLUSION**

1. The type of adjustment characteristic of the converter shows that in the ferro resonance mode of currents, when the supply voltage of the induction in the rods of the amorphous magnetic core changes, they remain practically unchanged, which indicates the stabilization of the voltages on the windings located on these rods.

2. The phase shifts in the ferro resonance mode of the currents remain almost unchanged and are approximately 600, which allows us to conclude that it is possible to convert the number of phases with shifts between phase voltages of approximately 600.

3. The sections of stable current of the voltage characteristic at the moment of ferro resonance of the currents indicate that the circuit in question is powered by a current source, which means that voltage stabilization is possible in the circuit in accordance with the properties of the Bouchereau circuit.

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