MAGNETIC-FLUX GENERATION BY MULTISTEP TRANSFER

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Certain uses require the development of techniques and devices that enable one not only to generate large amounts of electromagnetic energy but also to produce in the load a magnetic flux exceeding the initial flux introduced into the compression circuit, e.g., in supplying high-power explosive magnetic generators working in the megajoule range and above. A method exists [1-3] for producing a magnetic flux in an inductive load, which has been implemented in various devices and which involves the following sequence of operations: One introduces an initial magnetic flux into the primary circuit of the explosive magnetic device, deforms the circuit by means of the energy of an explosive, compresses the flux and displaces it into the transformation region, while the compressed magnetic flux is transformed in the secondary circuit, which is then closed, and at the same time the primary circuit is opened in some cases, and then the secondary circuit is deformed, with compression and displacement of the transformed flux into the next transformation region, etc. The main disadvantage of this method is the reduction in the magnetic flux in the load by comparison with the initial flux. Another disadvantage of the method is that it is impossible to increase the electromagnetic energy in the load if the inductance exceeds the initial inductance of the compression circuit. These deficiencies are a consequence of irrational choice of the set of operations and the mode of execution of some of them. For example, breaking the primary circuit complicates the method, and it is difficult to perform technically and requires additional measures to provide the necessary sequence in executing the operations. The transformation of the compressed magnetic flux is performed under conditions that do not provide an increase in the flux linkage in the secondary circuit. Therefore, none of the devices described in [1] can implement this method of flux generation fully.

The use of a transformer to transmit energy from the deformed circuit into the load [2, 3] in principle allows one to obtain a magnetic flux in the inductive load larger than the initial flux introduced into the compression loop, and it makes it possible to obtain more electromagnetic energy than the initial level although the inductance of the load exceeds the initial inductance of the compressed circuit.

The transformer method involves the following sequence of operations: The initial magnetic flux is introduced into the compressed circuit of the explosive magnetic generator, the circuit is deformed by means of the explosive energy, the flux is compressed and displaced into the transformation region, the compressed flux is transformed into the secondary circuit under conditions of increasing flux linkage while keeping the circuits closed, and at the end of compression of the primary circuit the closed secondary circuit is additionally compressed, with the transfer of part of the increased flux linkage to the next transformation region, etc. A disadvantage of this method is the large loss of flux and energy. These losses occur because the method contains the operation of separating the magnetic flux transformed into the secondary circuit into two parts, only one of which is compressed again. Another part of the flux (and energy) is lost completely, as it remains in the undeformed part of the secondary circuit.

A new method of generating a magnetic flux was proposed by one of the authors (V. K. Chernyshev).

The essence of the method is readily appreciated from the scheme in Fig. 1. The slider S_1 driven by the explosion deforms the primary circuit L_1, compressing and displacing the magnetic flux into the transformation region L_{1f}–L_2; in the transformation, increased flux linkage is provided by making the ratio of the numbers of turns in L_2 and L_{1f} greater than 1 while providing a magnetic coupling coefficient close to 1. At the end of the deformaiton of the primary circuit, switch K_2 driven by the explosion closes the secondary circuit (without breaking the primary one) and completely encompasses the increased flux linkage.

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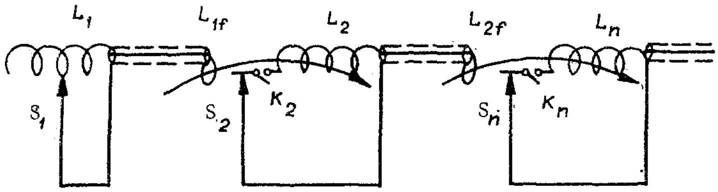

Fig. 1

TABLE 1

K	Ψ	φ
0,75	0,20	1,69
0,80	0,25	1,60
0,85	0,30	1,55
0,90	0,40	1,43
0,95	0,52	1,32

Then slider S_2, also driven by explosion, deforms the secondary circuit L_2, compressing and displacing the magnetic flux into the region of the next transformation, etc.

This sequence of operations is repeated the necessary number of times, in accordance with the required increase in the magnetic flux. The performance of the new method by comparison with the transformer one may be characterized by

$$\varphi = K_\Phi / K_{\Phi_{tr}},$$

where

$$K_\Phi = \frac{\Phi_l}{\Phi_0} = \sqrt{\frac{E_l L_l}{E_0 L_0}} = \sqrt{\frac{E_f K^2 L_l}{E_0 L_0}} = \sqrt{\frac{E_0 \frac{L_0}{L_{1f}} \eta^2 K^2 L_l}{E_0 L_0}} = \sqrt{\frac{\eta^2 K^2 L_l}{L_{1f}}};$$

and Φ_l is the magnetic flux in the load, where in the present case the load is the inductance in the deformed part of the secondary circuit L_2, Φ_0 is the initial magnetic flux introduced into the primary circuit, η is the flux-retention coefficient in the deformed circuit, and K is the coupling coefficient for the undeformed part L_{1f} of the primary circuit and the deformed part L_2 of the secondary circuit;

$$K_{\Phi_{tr}} = \frac{\Phi_l}{\Phi_0} \sqrt{\frac{E_l L_l}{E_0 L_0}} = \sqrt{\frac{E_f \Psi L_l}{E_0 L_0}} = \sqrt{\frac{E_0 L_0}{L'_{1f} \frac{1+\alpha-K^2}{1+\alpha}} \eta^2 \frac{\Psi L_l}{E_0 L_0}} = \sqrt{\frac{\eta^2 \Psi L_l}{L'_{1f} \frac{1+\alpha-K^2}{1+\alpha}}},$$

where Ψ is the energy-transfer coefficient for the transformer, $\Psi = E_l/E_f$; E_0, E_f, and E_l are the values of the energy in the initial circuit, the final circuit, and the load, respectively; $\alpha = L_l/L_2$ is the ratio of the load inductance L_l to the inductance of the secondary winding of the transformer.

Then we have for φ that

$$\varphi = \frac{\sqrt{\frac{\eta^2 K^2 L_l}{L_{1f}}}}{\sqrt{\frac{\eta^2 \Psi L_l}{L'_{1f} \frac{1+\alpha-K^2}{1+\alpha}}}} = \sqrt{\frac{K^2 L'_{1f} \frac{1+\alpha-K^2}{1+\alpha}}{\Psi L_{1f}}}.$$

To provide identity in both methods for the deformation of the primary circuit and the displacement of the magnetic flux into the transformation region it is necessary to have $L_{1f} = L'_{1f}(1 + \alpha - K^2)/(1 + \alpha)$, and therefore $\varphi = K/\sqrt{\Psi}$.

Table 1 gives values for the performance factor φ of this method by comparison with the transformer one as calculated for various K.

Table 1 shows that the new method is considerably more effective. A point here is that the energy-amplification coefficient is proportional to φ^2 when one generates a magnetic flux in a load whose inductance is equal to the initial inductance of the previous deformed circuit, i.e., the factor is 2.86-1.75 for K of 0.75-0.95, respectively, this applying for each stage.

This method of generating a magnetic flux has been implemented in practice. Experiment has given an energy amplification coefficient of $0.9 \cdot 10^6$ and a flux increase coefficient of 310.

LITERATURE CITED

1. USA Patent No. 3,356,869, 5.12, 1967.
2. A. I. Pavlovskii, R. Z. Lyudaev, L. N. Plyashkevich, and V. E. Gurin, Inventor's Certificate 266100, 17.03.1970, Byull. Izobret., No. 11 (1970).
3. H. Knoepfel, Pulsed High Magnetic Fields, American Elsevier, New York (1970).

MAXIMUM FORCE BETWEEN CURRENT CARRYING CONDUCTORS

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1. The ponderomotor interaction of current-carrying conductors is the basis of numerous technological applications. In a number of cases the question arises of the maximum possible interaction force per unit length between parallel cylindrical conductors, through each of which there flows a current I. For a specified current value this force depends on the form of the conductor cross section and the relative distance and configuration of the conductors, and can increase without limit if the conductor cross sections are sufficiently small and they are located sufficiently close to each other. However, such a technique of increasing ponderomotor force leads to an increase in conductor resistance and ohmic losses. Therefore it is of interest to determine the form of the conductor cross section for fixed conductor area S and uniformly distributed current density j which will maximize the force. This problem arose in optimizing the parameters of an electrodynamic vibrator used for vibroseismic sounding. The solution obtained was (Fig. 1) that the interaction force was maximal with each conductor having a semicircular cross section (naturally with currents flowing in opposite directions in each conductor there must be an insulation layer between the conductors, the thickness of which we will neglect in formulating the mathematical problem).

2. For simplicity, we will solve the problem with the assumption that the maximum interaction force F is achieved with the cross sections of the two conductors being identical, and these sections being located symmetrically with respect to the x and y axes (Fig. 2). The sections are described by the equation $x = \pm f(|y|)$, where $0 \leqslant y \leqslant a$ for the upper section and $-a \leqslant y \leqslant 0$ for the lower section. Each pair of elements dS_1 and dS_2 of the conductor cross sections interact producing a force the vertical component of which is equal to (notation as in Fig. 2)

$$dF = k dS_1 dS_2 \frac{\cos\theta}{r_{1,2}} = k dS_1 dS_2 \frac{y + |y'|}{(y + |y'|)^2 + (x - x')^2}, \tag{1}$$

where $k = (\mu_0/2\pi) j_1 j_2$. Therefore the total interaction force, which is a function of f(y), can be written in the form

$$F[f(y), f(y')] = k \int_0^a dy \int_0^a dy' \int_{-f(y)}^{f(y)} dx \int_{-f(y')}^{f(y')} \frac{y + y'}{(y + y')^2 + (x - x')^2} dx'. \tag{2}$$

It is necessary to find the maximum of this function with the additional condition

$$\int_0^a 2f(y)\, dy = S. \tag{3}$$

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