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FORMATION OF HIGH-POWER SQUARE CURRENT PULSES ON INDUCTIVE LOADS USING PASSIVE QUADRIPOLES

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Abstract. We used the theory of quadripole circuits to design a passive linear shaping line that generates square current pulses on inductive loads. We also calculated the values of the shaping-line elements using specific values for the parameters of the current pulse and the load selected bearing in mind experiments on the combined action of high-intensity magnetic fields and high-power laser pulses.

High-intensity constant or pulsed magnetic fields are applied in a wide variety of physical experiments yielding valuable information on the properties of solids, especially when used in combination with optical radiation [1–4]. Generation of high-intensity steady-state or pulsed magnetic fields, however, necessitates the use of high-power large-size stabilized current sources characterized by their low efficiency. Thus, the development of linear circuits generating high-power current pulses with nearly rectangular shape on inductive loads becomes important — these can be used to create high-intensity pulsed (quasi steady-state) magnetic fields.

The theoretical considerations presented below were provoked by our intent to carry out experiments on the effect of the combined action of high-power pulsed laser radiation and high-intensity magnetic field on thin films with superconducting and magnetic properties. We will, therefore, discuss the synthesis of circuits generating square current pulses (flat portion with duration 150–800 μs, amplitude 1000–3000 A) realized on a load consisting of a pair of Helmholtz coils with inductance 7–10 μH.

A large number of works [e. g. 5, 6] has been devoted to the synthesis of such circuits with lumped reactive elements. The analyses and calculations have mostly treated the case of bipolar shaping circuits in series with the load, when the output-pulse voltage amplitude is equal to half the supply voltage. An essential requirement in such theoretical considerations is that the Laplace representation $RI(p)$ of the current derivative be a positive real function. For bipolar circuits, however, and for pulses with finite leading and trailing edges, this requirement is not fulfilled. This is why square pulses cannot be shaped with sufficient accuracy by means of bipolar circuits.

Bearing the above in mind, we decided to apply the theory of quadripole circuits since they can be employed to produce pulses with arbitrary shape and specified accuracy. A particularly important advantage of these circuits is the possibility to achieve coefficient K of usage of the voltage source greater than 0.5; indeed, depending on the value of the pulse delay, K can exceed unity. Increasing this coefficient requires increasing the order of the transfer function and the number of the shaping-line elements [7]. As a consequence, the value of the current in the inductive load can also be increased and a high current-transfer coefficient realized [8]:

$$K_i = \frac{I_2^m}{I_1^m} = 2\,. \tag{1}$$

Where I_1^m, I_2^m are the maximal values of the input and output current, respectively.

Let us suppose that a square-shaped periodical voltage (period $T = \frac{2}{\pi}$) is fed to the quadripole's input. The input current $i_1(t)$ can then be expressed by a Fourier series. Assuming that its maximal value $I_1^m = 1$, the input current has the form [8]:

$$i_1(t) = \frac{4}{\pi}\sum_{k=1}^{4}\frac{1}{2k-1}\sin(2k-1)t \tag{2}$$

where k is the order number of the artificial line loops.

The current $i_2(t)$ at the output of the quadripole coincides with the current in the load for a time interval 0–$\frac{T}{2}$; it can be expressed as a pulse delayed by $t_2 = \frac{T}{8}$ with respect to the square-shaped periodical signal at the input and can be approximated by a Fourier series with improved convergence:

$$i_2(t) = I_2^m\frac{283}{\pi}(\sin t - 0.277\sin 3t + 0.122\sin 5t - 0.0643\sin 7t) \tag{3}$$

for the case when $T = 2\pi$ and $t = \frac{\pi}{4}$. The function $i_2(t)$, constructed using (3), is shown in Fig.1 and has the following parameters: flat portion $\tau_{\mathrm{fl}} = 0.305\pi$, width at half maximum $\tau_{0.5} = 0.5\pi$, and width $\tau_0 = 0.7\pi$.

The transfer function of the circuit considered can be described by the transfer conductance

$$y_{21}(p) = \left.\frac{I_2(p)}{U_1(p)}\right|_{U_2=0} \tag{4}$$

when the quadripole output is short-circuited.

One also has to calculate the input conductance

$$y_{11}(p) = \left.\frac{I_1(p)}{U_1(p)}\right|_{U_2=0} \tag{5}$$

corresponding to a given transfer function that ensures the desired pulse shape in the inductance L_H connected in series with the quadripole.

In the case when a step-like single voltage jump ($U_1(t) = U_1 1(t)$) appears at the quadripole input, using Eqs (1–5) we can obtain the following expressions for the quadripole parameters:

$$y_{21}(p) = \frac{1751p(p^2+15.921)K_i}{\pi U_1(p^2+1)(p^2+9)(p^2+25)(p^2+49)}, \tag{6}$$

and

$$y_{11}(p) = \frac{16p(p^2+4.46)(p^2+17.74)(p^2+40.8)}{\pi U_1(p^2+1)(p^2+9)(p^2+25)(p^2+49)}. \tag{7}$$

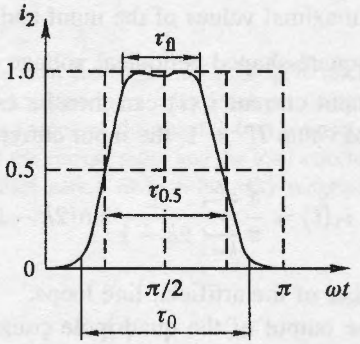

Fig. 1.

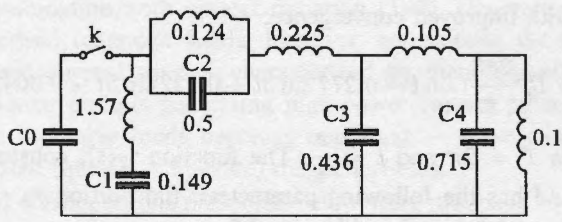

Fig. 2.

Fig. 2 presents a shaping line synthesized by using the "y" parameters of a quadripole without a recharging circuit. The actual values of the elements are calculated from the preset values of L_H, τ_{fl}, and I_2^m in the following manner:

$$L = L^* \frac{L_H}{L_H^*}, \qquad C = C^* \left(\frac{3.3\tau_{fl}}{\pi}\right)^2 \frac{L_H}{L_H^*}. \tag{8}$$

In the above formulae the quantities marked by an asterisk (*) are calculated using (6, 7); their values are given in Fig.2. The value of the capacitor C_0 is chosen equal to the sum of the values of capacitors C_1, C_2, C_3 and C_4; its role, together with switch k, is to imitate a single voltage jump at the circuit's input.

The charging voltage U_1 is calculated from:

$$U_1 = \frac{I_2^m \tau_{\text{fl}}}{C_0} = \frac{I_2^m \tau_{\text{fl}}}{C_0^* \left(\dfrac{3.3\tau_{\text{fl}}}{\pi}\right) \dfrac{L_H}{L_H^*}}. \tag{9}$$

To test the above theoretical discussion, let us choose the following concrete parameters of a square current pulse: $\tau_{\text{fl}} = 150\,\mu\text{s}$; $I_2^m = 3\,\text{kA}$ and $L_H = 7\,\mu\text{H}$; then $C_0 = C_1 + C_2 + C_3 = 700\,\mu\text{F}$ and $U_1 = 640$ V.

In conclusion, using the theory of quadripoles, we synthesized a lumped-elements shaping line that generates square current pulses. In addition, we calculated the values of the line's elements and the charging voltage using specific pulse parameters and a value for the inductive load that are often encountered in practice. The results can be applied to an experimental setup for generating high-intensity quasi-steady-state or pulsed magnetic fields.

References

1. E. G. Haanappel et al. *Physica C*, **209** (1993) 39.
2. A. V. Dvurechenski et al. *Pulsed Annealing of Semiconducting Materials* (Nauka Publishers, M. 1982) 23 (in Russian).
3. K. I. Krylov et al. *Proc. Intern. Conf. on Laser Applications in Modern Technologies* (Znanie Publishers, L. 1971) (in Russian).
4. R. R. Alfano et al. *Journal of Applied Physics* **39** (1968) 2931.
5. O. N. Litvinenko et al. *Calculation of Shaping Lines* (Gostehizdat Publishers, Kiev 1962) 96 (in Russian).
6. I. V. Volkov et al. *Power Supplies for Lasers* (Tehnika Publishers, Kiev 1976) 136 (in Russian)
7. P. N. Methanov, *Synthesis of Quadripoles Using Temporal Functions* (Energiya Publishers, Leningrad 1970) (in Russian).
8. Yu. V. Lebedev. *Izvestiya Vuzov, Radiotehnika* **14** (1971) (in Russian).