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MATHEMATICAL SIMULATION OF THE OUTPUT STAGE OF A HIGH-POWER VOLTAGE PULSE GENERATOR FOR PUMPING METAL VAPOR LASERS

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Abstract

A two-circuit compression scheme for a high-power pulse generator and a method for its calculation taking into account the hysteresis loop of each nonlinear inductance are proposed. It is shown that the use of two thyratrons terminating in a compression scheme with nonlinear chokes makes it possible to increase the energy in a pulse taken off the load by no less than 50%.

Nowadays, high-power repetitively pulsed metal vapor lasers are extensively studied. Improvement of the average laser power depends on designing high-power voltage pulse generators (VPGs). One of the promising VPGs is represented by a scheme with nonlinear ferrite elements and the output to a cable line transmitting a high-voltage (HV) pulse to a discharge gap of a laser cavity. The output power of the VPG is limited by the thyratron used as a switch. Here, we propose a scheme with several parallel-connected thyratrons. However, the instability of their triggering limits the output power of the VPG. To evaluate the effect of this instability on the performance of the scheme (Fig. 1), we constructed a mathematical model taking into account the initial state of the magnetic material and the hysteresis.

The hysteresis loop can be modeled in different ways. A piecewise continuous approximation of the magnetization curve is most suitable for ferrites with a rectangular hysteresis loop and is extensively used for them. For magnetically soft ferrites with a narrow nonrectangular hysteresis loop, which are used in the present scheme, this method gives an unsatisfactorily rough approximation and a large error. The effect is most pronounced for transitions from one nonlinear section to another. For some kinds of cores, such a separation into linear sections is rather difficult. The description of dynamic core characteristics with the help of continuous dependences gives a better agreement with experimental results, but adds complexity to the calculations. The limiting hysteresis loop is rather well approximated by hyperbolic tangents:

$$b = \frac{B}{B_r}\ ; \qquad h = \frac{H}{H_c}\ ;$$

$$\begin{aligned} b_m^+(h) &= \frac{\tanh k(h-1)}{\tanh k}\ ; \\ b_m^-(h) &= \frac{\tanh k(h+1)}{\tanh k}\ . \end{aligned}$$

Here, B_r is the residual induction; H_c is the coercive force; H is the magnetic field strength for the saturation induction; k is a constant.

The model must describe not only the limiting hysteresis loop but also the partial remagnetization cycles. For this purpose, the ferrite magnetization is considered to be the result of superposition of two independent

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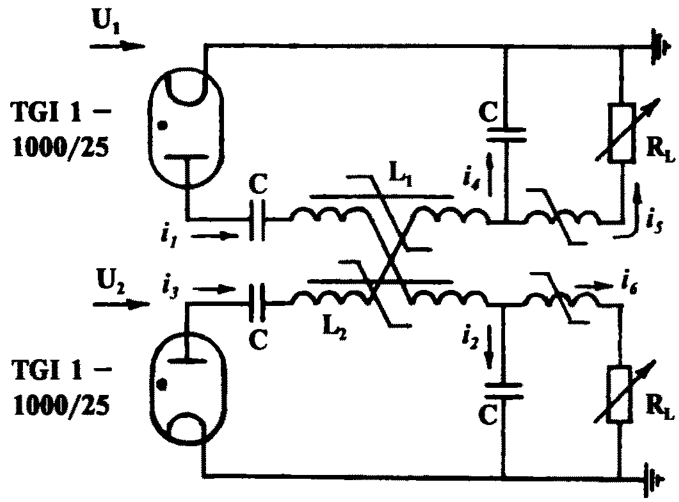

Fig. 1. Two-circuit compression scheme.

processes [1], a limiting and a residual one. Let (H_0, B_0) be the initial ferrite state. Then the magnetization induction $B^+(H)$ is given by the expression

$$B^+(H) = B_m^+(H) + [B_0 - B_m^+(H)]\,\varphi(H, H_0)\ ,$$

where $B^+(H)$ is the magnetization induction corresponding to the maximum hysteresis loop and φ is a function characterizing the residual process and is equal to unity in the initial state. In the specific case where $H_0 = 0$ and $B_0 = 0$, we have the equation for the curve of initial magnetization

$$B(H) = \rho\, B_m^+(H) + \rho\, v\, \varphi(H)\ ,$$

$$H \geq 0, \qquad \rho = \operatorname{sign}\left(\frac{dH}{dt}\right)\ .$$

At the moment of remagnetization reversal when the field strength has an extreme value, the remagnetization factor v changes jumpwise. Its value at a recurrent remagnetization step can be determined at the initial point of this stage from the expression

$$v = \frac{\rho\, B_0 - B_0\,(\rho H)}{\varphi(\rho H)}\ .$$

The mathematical formulation of the problem is represented by the system of equations

$$\begin{aligned}
v_1 &= \frac{1}{C}\int i_1\,dt + L_1\left(\frac{dB}{dH(i_1)}\right)\frac{di_1}{dt} + L_2\left(\frac{dB}{dH(i_1)}\right)\frac{di_1}{dt} + \frac{1}{C}\int i_2\,dt\ ;\\
\frac{1}{C}\int i_2\,dt &= i_6 R_H + L_4\left(\frac{dB}{dH(i_6)}\right)\frac{di_6}{dt}\ ;\\
v_2 &= \frac{1}{C}\int i_3\,dt + L_2\left(\frac{dB}{dH(i_3)}\right)\frac{di_3}{dt} + L_1\left(\frac{dB}{dH(i_3)}\right)\frac{di_3}{dt} + \frac{1}{C}\int i_4\,dt\ ;\\
\frac{1}{C}\int i_4\,dt &= i_5 R_H + L_3\left(\frac{dB}{dH(i_5)}\right)\frac{di_5}{dt}\ .
\end{aligned}$$

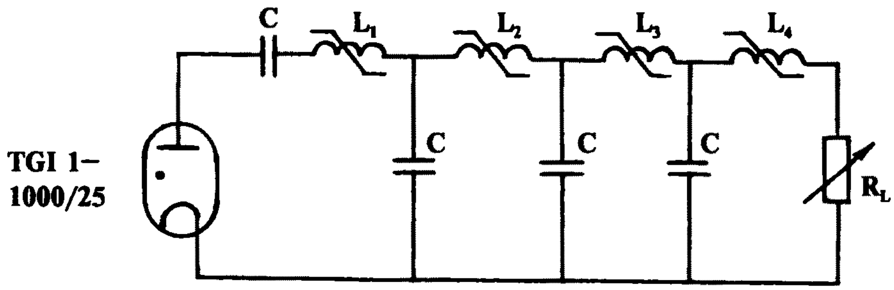

Fig. 2. Four-circuit compression scheme.

This system is nonlinear and cannot be solved analytically. We solved it numerically on a BÉSM-6 computer by using a special program. The system of self-consistent equations was solved by the Runge–Kutta method. We took into account inductive circuit nonlinearities which varied during the hysteresis loop formation and changes of current amplitudes and directions in each LC circuit. The calculation algorithm followed the behavior of the hysteresis loop shape and was changed at the moments corresponding to extreme currents.

The model was tested for its correspondence to the results of an experiment in which a VPG with a TGI 1-1000 thyratron and subsequent compression circuits was used (Fig. 2). The voltage pulse measured on the load coincided with an accuracy of 5–7% with the calculated pulse. The experimental test of the results obtained in our study was carried out by using a comparative analysis of the calculated relations and actual processes. We compared compression circuits with the following parameters:

ferrite 1000 NN;

$D_{out} = 120$ mm, $D_{in} = 80$ mm;

number of turns $w_1 = 35$, $w_2 = 10$, $w_3 = 4$, $w_4 = 2$;

ferrite cross-section $S_1 = 5 \cdot 10^{-4}$ m^2, $S_2 = 25 \cdot 10^{-4}$ m^2, $S_3 = 25 \cdot 10^{-4}$ m^2, $S_4 = 25 \cdot 10^{-4}$ m^2;

thyratron voltage 20 kV.

As an example illustrating the performance of the model we used a two-circuit compression scheme with two TGI 1-1000/25 thyratrons and nonlinear elements on the basis of a ferrite 1000 NN.

For a maximum difference in triggering times of the thyratrons equal to 300 ns and a current pulse duration of 2 μs, the pulse energy taken off the load was 30% lower in comparison with the value obtained in the case of synchronous triggering.

Thus, a method is proposed for calculating the two-circuit compression scheme of a high-power VPG. The method takes into account the hysteresis loop of each nonlinear inductance.

References

1. N. A. Zolotarev, *Izv. Vyssh. Uchebn. Zaved., Élektromekh.*, No. 9, 47 (1983).