Metal vapor lasers with increased reliability

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ABSTRACT

Results of investigation and development of an excitation pulse generator with magnetic pulse compression by saturation chokes for pumping of active media of CuBr, Sr, and Ca vapor lasers are presented. A high-power IGBT transistor is used as a commutator. The generator can operate at excitation pulse repetition frequencies up to 20 kHz. The total average power for all laser lines of the CuBr laser pumped by this generator is ~6.0 W; it is ~1.3–1.7 W for the Sr and Ca lasers.

Keywords: metal vapor lasers, excitation pulse generator.

Metal vapor lasers (MVL) are widely used to solve a wide range of scientific and practical problems due to a number of unique characteristics, including small duration of radiation pulses ~10–100 ns, high lasing pulse repetition frequency >10 kHz, high average and pulsed power, and efficiency ~1% high for gas lasers. Moreover, because the active medium is a gas, the MVL have small lasing line width and high stability of its position in the scale of frequencies, high laser beam quality, and large gain (10–100 dB/m) [1–2].

Pulsed hydrogen thyratrons [3] have found the widest application as commutators in excitation circuits of pulsed-periodic MVL. However, they have a number of principal disadvantages caused by the character of processes accompanying a discharge in gases. First of all, this is the instability of triggering equal to ~20–40 ns that complicate synchronization of complex laser systems and short service lifetime ~100–500 h caused by fast electrode failure due to high reverse voltage on the thyratron anode in the case of mismatch of the power supply unit with the load [4]. In addition, thyratrons need a special cathode heating circuit consuming sufficiently large power.

To develop reliable, economic, and compact MVL excitation sources, already in the 80s of the last century magneto-thyristor generators of excitation pulses were investigated and developed (for example, see [5]). Considering the main features of operation of magneto-thyristor generators, we must note the following. The application of diode-choke charging of the storage capacitor C_1 in the primary circuit of the power supply unit provides the absence of the direct voltage on the thyristor anode during its switching off. When the storage capacitor C_1 is commutated to the thyristor, the capacitor C_2 is charged through a pulse step-up transformer in the secondary circuit of the power supply unit. The voltage rise time on the capacitor C_2 is ~5 μs. Then magnetic compression of a pulse is performed by two saturation chokes based on ferrite elements. In this case, the pulse rise time after each choke is 900 and 300 ns, respectively. The given principle – charging of the capacitor through a step-up transformer with subsequent magnetic compression of the pulse by the saturation chokes – was used in MVL power supply units being developed nowadays. Only high-power IGBT transistors are used as commutators.

In the present work, results of investigation and development of an excitation pulse generator with magnetic pulse compression by saturation chokes for pumping of active media of CuBr, Sr, and Ca vapor lasers are given.

Figure 1 shows structural block diagram of the developed excitation pulse generator with magnetic pulse compression by saturation chokes L1, L2 and L3 based on ferrite elements. In this excitation pulse generator, just as in [5], diode-choke charging of storage capacitor C1 in the primary circuit of the power supply unit is used with subsequent pulse commutation using the high-power IGBT transistor through the pulse step-up transformer providing charging of the capacitor C2 in the secondary circuit of the power supply unit. However, the difference between the block diagrams of pumping generators, as can be seen from Fig. 1, is not only the replacement of the thyristor by the high-power IGBT transistor.

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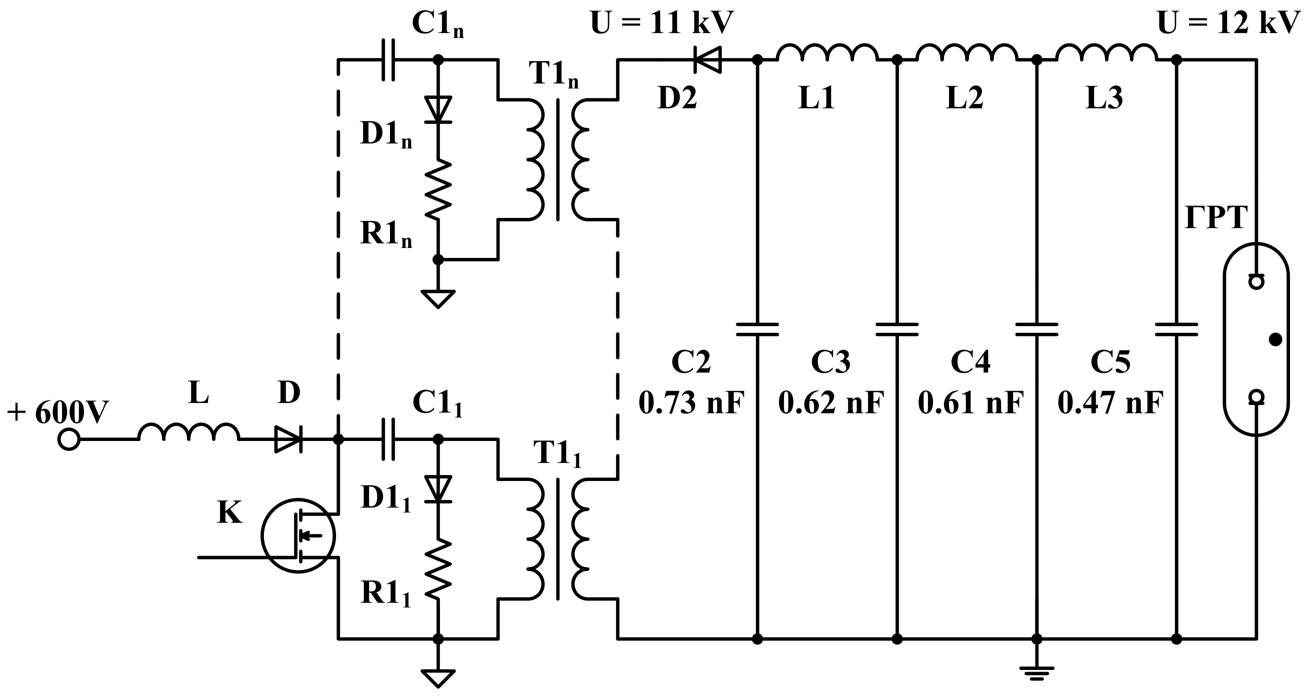

Fig. 1. Structural block diagram of the excitation pulse generator with magnetic pulse compression by saturation chokes L1, L2, and L3 based on on ferrite elements. Here L–D denote the diode-choke charging of the storage capacitor $C1 = C1_1 + C1_2 + \ldots + C1_n$, K is for the high-power IGBT transistor, $T1_1$–$T1_n$ denote the pulse transformer, C2 is for the capacitor in the secondary circuit of the power supply unit, C3–C4 denote the capacitors of the magnetic units of pulse compression, C5 is for the peaking capacitor, and GDT is for the gas-discharge tube

The pulse step-up transformer is designed in the form of n pulse step-up transformers (where $n = 9$ in the given generator). The primary windings of the transformer are connected in parallel in the primary circuit through the storage capacitors $C1_1 - C1_n$, and the total capacitance of these capacitors is determined by the expression

$$C1 = C1_1 + C1_2 + \ldots. + C1_n. \tag{1}$$

The secondary windings of the pulse transformers are connected in series. The expediency of this design is that first, it simplifies the manufacture of pulse transformers and second, it allows the leakage inductance of the transformers to be decreased significantly providing recharging of the storage capacitor C1 to the capacitor C2 for ~1–1.5 μs. In combination with the subsequent magnetic pulse compression (using saturation chokes L1, L2, and L3 based on ferrite elements), this allows laser excitation pulses (see Fig. 2) commensurable with the excitation pulses characteristic for pumping generators with thyratron commutators to be generated in the gas-discharge tube (GDT).

One of the problems of the design of these pumping generators is that the breakdown voltage (U_{br}) of the GDT discharge gap at the moment of laser triggering, when metal vapors are absent in the discharge channel, is much higher than the working voltage (U_w) of pulsed-periodic pumping of the active medium. An engineering solution eliminating the given problem was to connect the diode D2 to the secondary circuit of the generator. The diode did not allow the capacitor C2 to be discharged (without breakdown of the discharge gap, that is, when $U_{br} > U_w$). Hence, the subsequent pulses of the generator operating at high pulse repetition frequency charged additionally the capacitor C2 in the course of the recharge of the storage capacitor C1 to the capacitor C2, which caused the output voltage of the generator to increase, and when the voltage reached the value $U_w > U_{br}$, a breakdown occurred in the discharge gap of the GDT.

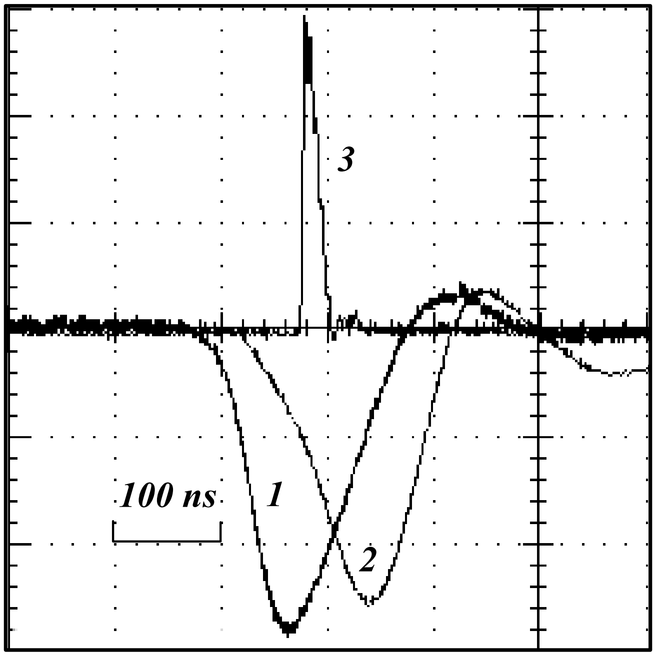

Fig. 2. Pulse waveforms. Here curve 1 is for the voltage pulse, curve 2 is for the current pulse, and curve 3 is for the lasing pulse in the gas-discharge tube

Figure 3 shows the external view of the metal vapor laser comprising the gas-discharge tube placed in the resonator and the excitation pulse generator developed based on the above-described principle of magnetic pulse compression with the saturation chokes.

Fig. 3. External view of the laser

The energy characteristics of CuBr, Sr, and Ca lasers pumped with the developed excitation pulse generator are given in the table. The period of setting of the working regime for the CuBr laser is shortened (see Fig. 4), because in this case the

GDT is placed in a special furnace to provide the optimal temperature for containers with CuBr. The time of setting of the working regime for Sr and Ca lasers was ~35–40 min (typical time of setting of the working regime for the MVL in the self-heating regime). Figure 5 shows the distribution of the output CuBr-laser radiation intensity over the cross section of the discharge channel. Analogous distributions of the radiation intensity were also observed for Sr and Ca lasers [6], but only with complete filling of the field stop of the GRT channel.

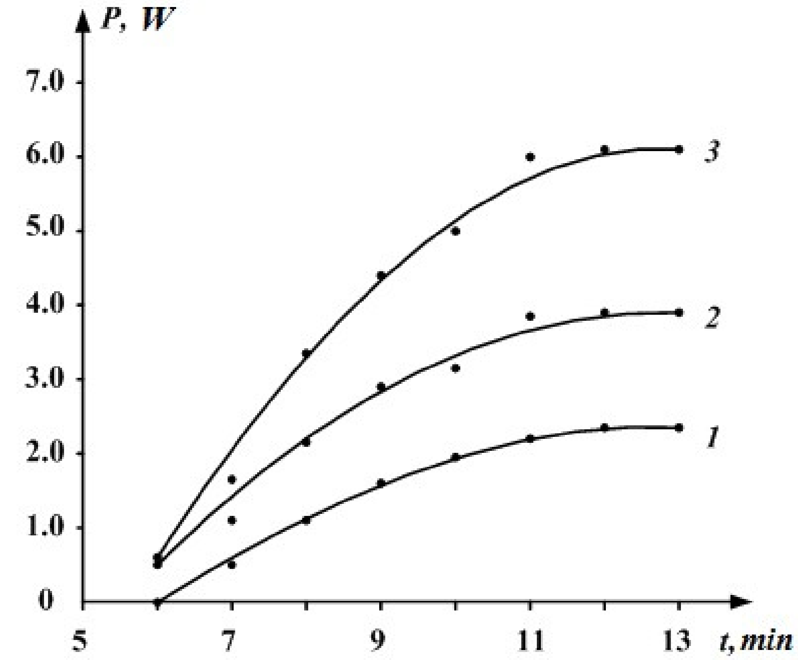

Fig. 4. Time of setting of the working regime of the CuBr laser. Here curve 1 is for the average lasing power at λ = 578.2 nm, curve 2 is for the average lasing power at λ = 510.6 nm, and curve 3 is for the total average lasing power

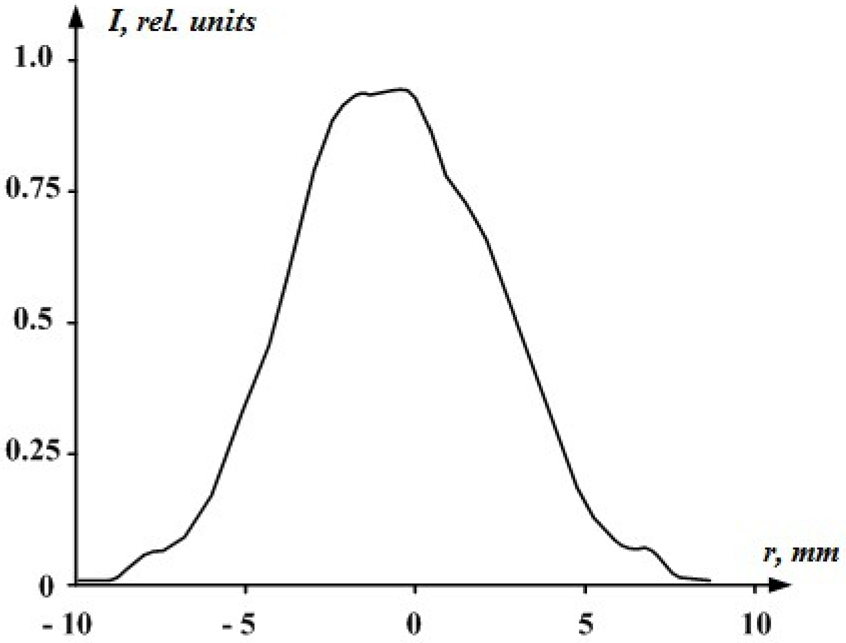

Fig. 5. Distribution of the intensity of CuBr-laser radiation over the GDT cross section

Table. Energy characteristics of CuBr-, Sr-, and Sa-laser radiation: *f* is pulse repetition frequency, *d* and *l* are the diameter and length of the discharge channel of the GRT, and *P* is the total average lasing power.

Active medium	*f, kHz*	*d, mm*	*l, mm*	*P, W*
CuBr	15-20	20	500	6.2
Sr	15-16	15	500	1.72
Ca	15-16	15	500	1.30

CONCLUSIONS

In conclusion, it should be noted that our investigations showed that the efficiency of pumping of active media of CuBr, Sr, and Ca lasers with the developed excitation pulse generator depends not only on the magnetic pulse compression by the saturation chokes, but also on a number of electrophysical processes proceeding in the gas-discharge tubes with electrodes located in cold buffer zones. The active medium for such gas-discharge tube design, as demonstrated investigations performed earlier in [7–8], was pumped after the breakdown excited at the ends of the discharge channel of the GRT after charging of capacitive elements of the GDT and the peaking capacity C5. Exactly this effect determines the efficiency of the magnetic pulse compression with the saturation chokes. It should be noted that the discharge evolution and hence, pumping of the active medium of the Sr and Ca lasers differs essentially from the corresponding process in the CuBr laser because of the design features of these GDT lasers [9–11].

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