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Modification and simulation of the power supply of a metal vapor laser

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Abstract. The modification of a power supply circuit used for pumping metal vapor lasers is analyzed. The results of OrCAD simulation of the processes that occur in the power supply are presented. The effect of the capacitance ratio on the charging process of a storage capacitor is described. The mode which provides more time for the recovery of the thyatron is discussed. The results of the development of the small-size high pulse repetition frequency laser with up to 3 W average output power are presented.

1. Introduction

The range of applications of metal vapor lasers is wide, including a number of medical ones. The main purpose of modification of a laser power supply is optimization of the pumping circuit, and therefore an increase in the laser pulse repetition frequency (PRF) and its efficiency [1-3]. Thyratrons are used most often as the power switches for constructing pumping circuits of metal vapor lasers. A thyatron provides a high rate of the current rise in the gas discharge tube (GDT) to obtain the required parameters of the pump pulse. Short lifetime and the deterioration of switching characteristics over a period of time are the disadvantages of these power switches [4].

Laser pumping circuits based on the direct discharge of the storage capacitor, are described in [4-6]. The disadvantage of these circuits is that a thyatron recovers its electrical resistance when the anode voltage is applied since the storage capacitor begins to charge immediately after its discharge on the GDT. Furthermore, this makes it impossible to increase the PRF of these devices.

The results of research and development of such power supplies at the Laboratory of Quantum Electronics of the Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Science (IAO SB RAS) are published in [4-5]. The analysis and simulation of a metal vapor laser power supply based on the half-bridge inverter are presented in [6]. The aim of this work is to upgrade the power supply and study its operation modes using OrCAD models. Another aim is to develop a compact high frequency CuBr laser with the pumping circuit based on a TGI1-270/12 thyatron.

2. A power supply with the pulse charge of the storage capacitor

Unlike the circuit described in [6], the upgraded inverter is based on an H-bridge circuit. The functional circuit of the power supply is shown in Figure 1. The storage capacitor charges sinusoidally



because of inductor L_2 connected in series with capacitor C_2 and primary winding w_p of transformer TV_1 .

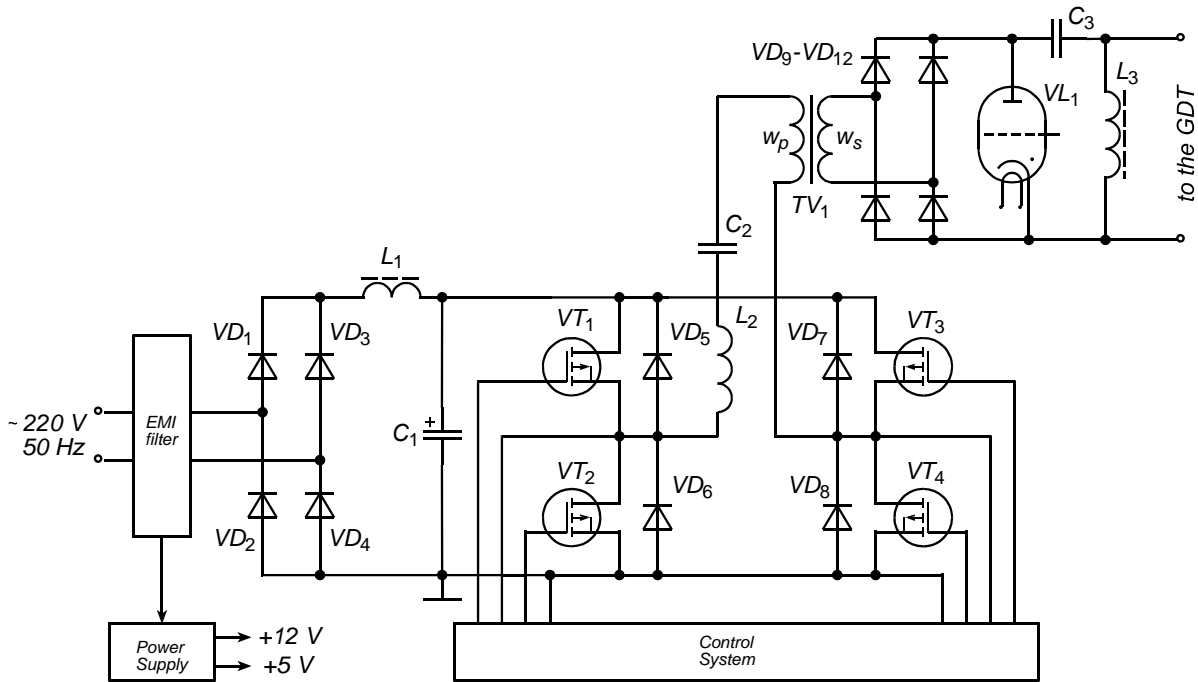


Figure 1. A functional circuit (H-bridge topology) of the power supply.

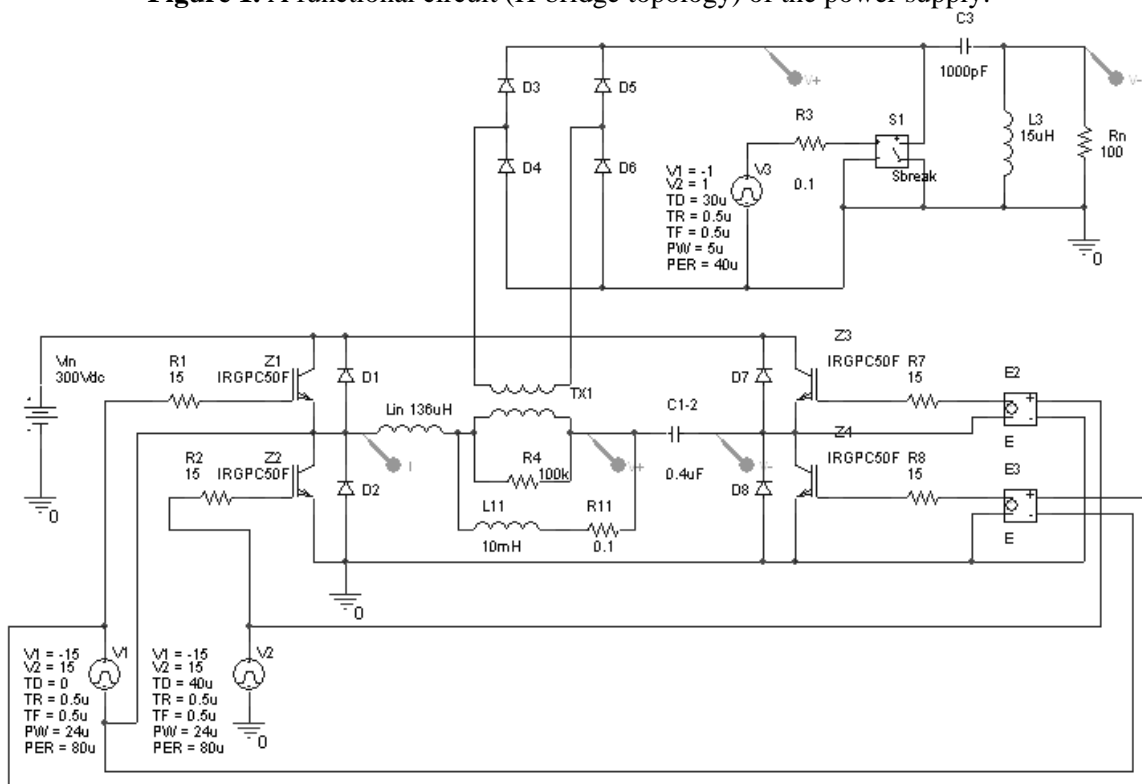


Figure 2. An OrCAD simulation circuit of the power supply (the capacitance ratio $a = 1$).

The control system (CS) provides the algorithms of operation of H-bridge power transistors and thyatron VL₁. Storage capacitor C₃ is charged through a pair of transistors which are switched on. After that the thyatron is triggered by the pulse from the control system. The storage capacitor quickly discharges through the GDT. Then there is a pause during which the thyatron anode voltage is zero, and the device switches off. Such mode ensures strong recovery of the thyatron. The control system forms signals to switch on the transistors of the other pair of the H-bridge. The inductor current and the current of the TV₁ windings start to flow in the opposite direction. The storage capacitor charges again, and the processes repeat periodically.

3. OrCAD simulation of the power supply

The OrCAD simulation circuit is shown in Figure 2. Compared to the half-bridge inverter [6] in this circuit the conversion ratio of TX1 is reduced by half to obtain the same amplitude of the storage capacitor voltage. Consequently, there is a four-time reduction of the value of the storage capacitor for the transformer primary circuit. Hence, when the capacitance ratio remains unchanged there is also a fourfold reduction of the equivalent capacitance of the oscillating circuit. Therefore it is necessary to ensure a fourfold increase of the oscillating circuit inductance to obtain the same resonant frequency.

The simulation results for different capacitance ratios are presented in Figures 3-5. The first waveform is the current of inductor L_{in} of the H-bridge inverter. The voltage across storage capacitor C₃ and the steady state voltage across H-bridge inverter capacitor C₁₋₂ are shown together on the second graph. Let us note that for convenience, the display size of the storage capacitor voltage experiences a 40-time reduction. You can also see that after the end of the storage capacitance charge process (every 40 μs), switch S1 is on, and the capacitance is quickly discharged through the load.

For the case when $a = 1$, we can see that the charge time is minimal, i.e. the resonant frequency is maximal. However, for capacitor C₁₋₂ the voltage swing exceeds 600 V. In this case, the amplitude of the capacitor charging current is maximal. As we can see from Figures 4 and Figures 5, the inductor current amplitude becomes lower when the capacitance ratio is increased, but a capacitor needs more time for charging. Steady state simulation results are shown in Table 1.

Table 1. Simulation Results.

a	C ₁ (μF)	U _{C0} (V)	U _{Ctp} (V)	U _{C2m} (kV)	I _{Lm} (A)	tp (μs)
1	0.4	-300	339	11.1	21.2	16.8
3	1.2	-100	88	10.7	16.2	20.5
10	4.0	-26	25	10.1	13.6	22.0

From the simulation results obtained using model parameters we can see that the current amplitude has decreased from 21.2 A to 13.6 A, and the capacitor charge time increased from 16.8 μs to 22 μs. In the modernized circuit the amplitude of the inductor current decreased twice if compared to the half-bridge inverter. Thus, the use of the H-bridge inverter circuit can reduce the size of the pulse transformer, thus reducing the size of the pumping circuit as a whole. This circuit is more preferable for a multistage charging of the storage capacitor.

4. The Power Supply of High Pulse Repetition Frequency

The development of a high pulse repetition frequency of the CuBr laser with PRF up to 50 kHz was the next stage.

The GDT is the self-heated active element with independent heaters for containers with CuBr and for the HBr generator. A laser tube with the active zone diameter of 15 mm and the length of 38 mm is used. The Ne buffer-gas pressure is 30 Torr. The TGI1-270/12 thyatron is used to increase the operating frequency. The storage capacitance of 330 pF is used. For the 1 kW power supply the half-bridge inverter is chosen. The main circuit is similar to that in [5].

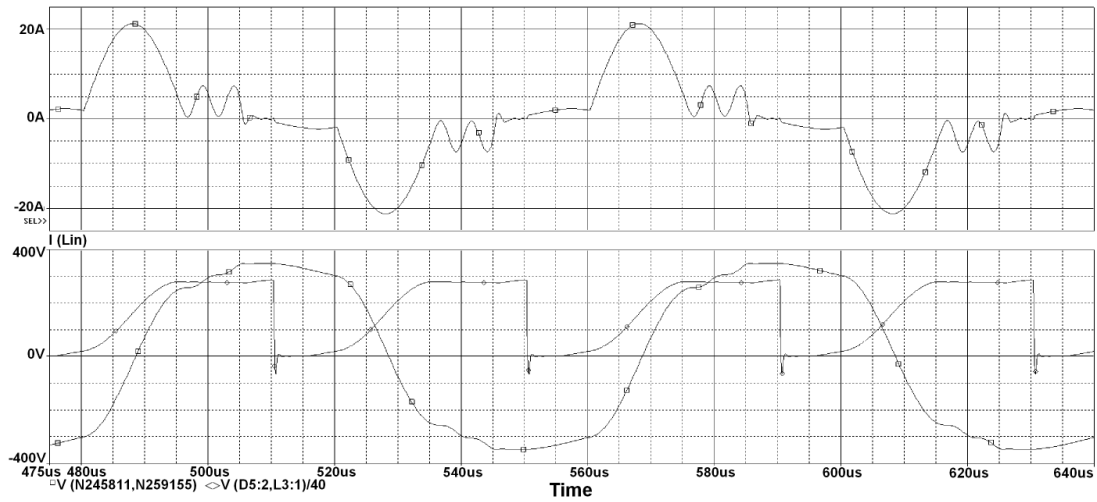


Figure 3. Current and voltage waveforms, capacitance ratio $a = 1$.

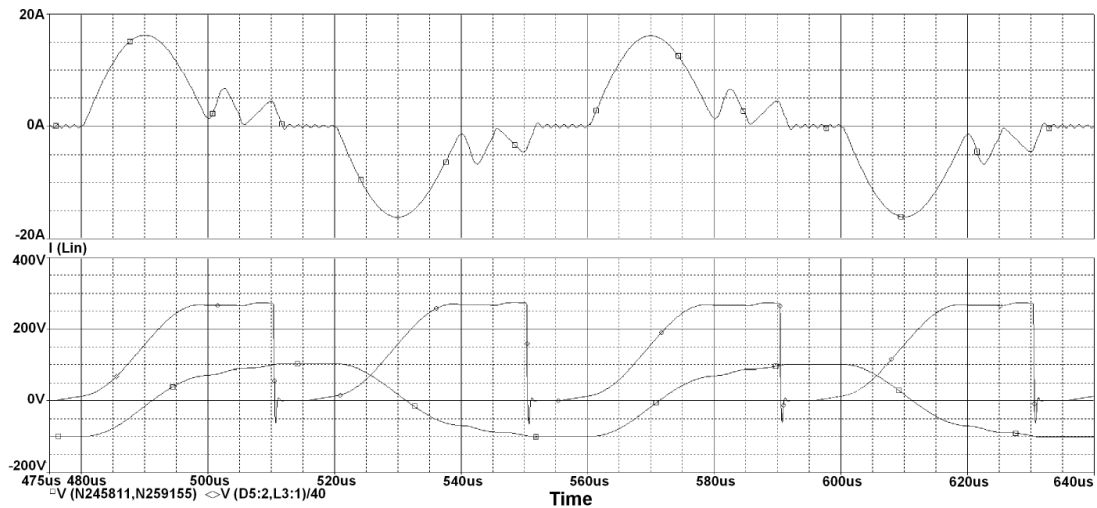


Figure 4. Current and voltage waveforms, capacitance ratio $a = 3$.

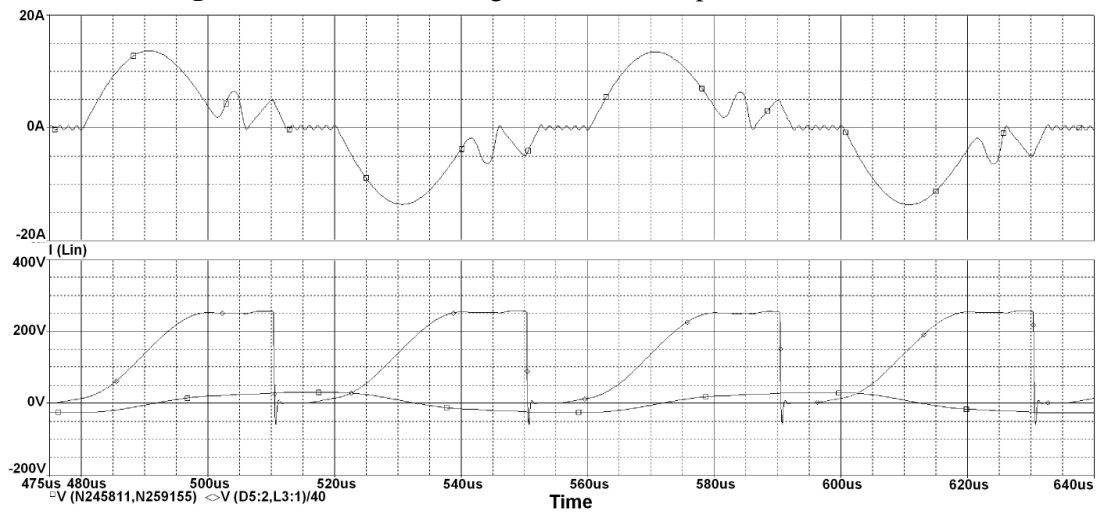


Figure 5. Current and voltage waveforms, capacitance ratio $a = 10$.

The control circuit is based on an Atmega8 microcontroller; it has the ability to change the width of pulses and pauses between them for driving the power switches of the inverter. The power supply includes a soft start circuit.

The simulation results are experimentally verified. The power supply inverter operates at a frequency of 42 kHz. The results are shown in Figure 6. Waveforms show that the thyatron recovery time is about 8 μ s.

A maximal average output power of 2.5 W has been obtained at a maximum pumping power and a frequency of 42 kHz. The practical efficiency is about 0.6 %.

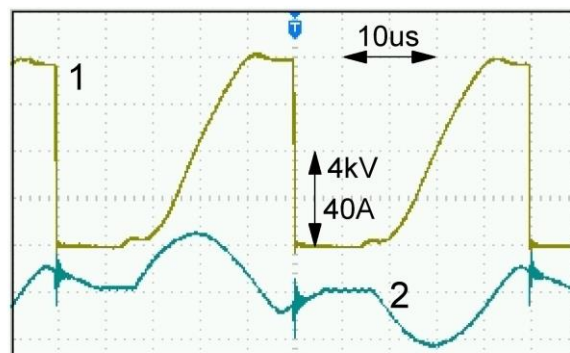


Figure 6. Current and voltage waveforms: 1 – the thyatron anode voltage; 2 – the inductor current (an inverter operates at a frequency of 42 kHz).

5. Conclusion

To sum it up, the results of OrCAD simulation of the processes that occur in the power supply based on an H-bridge inverter are presented. Compared to the half-bridge inverter we can see that the H-bridge topology circuit allows one to reduce the pulse transformer size. The H-bridge circuit is more preferable for CuBr lasers with a multistage charging of the storage capacitor.

The results of development of the high pulse repetition frequency of the CuBr laser are presented. For the half-bridge circuit power supply, an average output power of 2.5 W has been obtained at a frequency of 42 kHz.

Acknowledgment

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