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Development of insulated gate bipolar transistor-based power supply for elemental copper vapour laser

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Abstract. The elemental copper vapour laser is a widely used laser from a family of metal vapour lasers for applications such as dye laser pumping, micromachining etc. In this paper, we report the development and performance of IGBT-based pulsed power supply that replaced conventional thyratron-based power supply for 4.7 cm diameter, 150 cm long copper vapour laser. The laser tube delivered an average power of 51 W, which with conventional power supply was giving 40 W. The IGBT-based power supply offers considerable reduction in the running cost of the laser. It is more user-friendly when compared with the conventional power supply.

Keywords. Copper vapour laser; solid-state pulsed power supply; magnetic pulse compressor; thyratron; insulated gate bipolar transistor; pulse repetition rate.

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1. Introduction

Copper vapour laser (CVL) is an inherently pulsed gas discharge laser with output at two wavelengths, green (510.6 nm) and yellow (578.2 nm). CVLs are used in many applications like dye laser pumping, micromachining, high-speed photography etc. Technology of CVL is quite matured and is well reported in [1]. The CVL is pumped by high-voltage high repetition rate pulse power supply. Conventional power supply design uses thyratron as the switch in capacitor-to-capacitor charge transfer circuit. The lifetime of thyratron in the power supply is typically 1000 h. By adding magnetic pulse compressor (MPC), the thyratron life is increased by a factor of 3–4. Designs of CVL power supplies using semiconductor switches replacing thyratron are reported [2,3]. Among the various semiconductor switches, insulated gate bipolar transistor (IGBT) is very well suited for CVL pulse power supplies. In CVL power supplies, semiconductor switches are used with step-up pulse transformer and multistage magnetic pulse compressors and all these components are oil immersed. This calls for special lay-outs and replacement

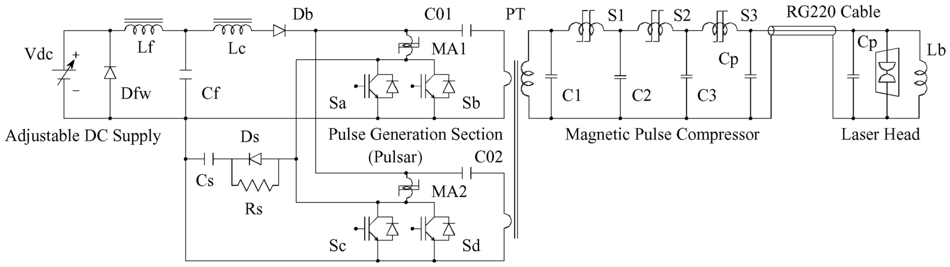

Figure 1. Circuit diagram of the solid-state pulsed power supply.

of thyratron-based power supply with semiconductor switches in the same packaging becomes a tricky task. This paper describes IGBT-based pulse power supply for CVL developed using modular units and comparison of its performance with thyratron-based power supply.

2. Power supply topology

The power supply is based on the capacitor-to-capacitor charge transfer using step-up pulse transformer and three-stage magnetic pulse compressors in the high voltage side. The electrical circuit diagram of IGBT-based solid-state pulse power supply (SSPPS) is shown in figure 1. It consists of (a) a switch mode power supply (SMPS) rated for 550 V, 20 A reported earlier [4] with filter, (b) pulse generator section consisting of IGBT switches with associated control and protection circuits and (c) pulse transformer and three-stage magnetic pulse compressors, connected to the laser head by RG 220 cable.

The SMPS acts as a regulated DC voltage source with adjustable voltage from 325 V to 550 V with a maximum current rating of 20 A. The storage capacitor is realized using two capacitor banks C01 and C02. These capacitor banks are resonantly charged through the charging inductor Lc, blocking diode Db and primary of the pulse transformer by the DC source to approximately twice its value. Pulse transformer has two primary windings of one turn each connected independently to a bank of two IGBTs and storage capacitor bank as shown in figure 1. Considering ready availability of IGBTs of different ratings and the power supply requirements, parallel operation of IGBTs offers optimum design considering cost, performance and availability and hence the design is based on parallel operation of four IGBT devices rated for 1200 V, 400 A. The stored energy across the storage capacitor is discharged by turning ON the two banks of IGBTs simultaneously and the charge is transferred from the primary side storage capacitor to the secondary side high voltage storage capacitor C1. All the IGBTs are turned ON simultaneously for a pulse duration of 5 μs at a pulse repetition rate (PRR) of 6.5 kHz. Magnetic assist (MA) is connected in the discharge loop of storage capacitor to reduce the turn ON losses in the IGBTs [5]. The step-up pulse transformer gives the flexibility to design and select primary side components with convenient voltage rating. Energy transferred to storage capacitor C1 connected in the secondary side of the pulse transformer is at the desired voltage magnitude but the rise time of the pulse is slow around 2 μs. This 2 μs voltage pulse is successively compressed in the three-stage MPC and voltage pulse of around 20 kV with a rise time of 90 ns is obtained across the laser head. The voltage pulse shape depends on the operating conditions of the laser.

3. Design details for the power supply

Optimum pulse repetition rate for the operation of elemental CVL is governed by its tube diameter and pulse voltage amplitude is governed by the tube length. The SSPPS is designed to replace the existing thyratron-based power supply for the elemental CVL having a laser tube of 4.7 cm diameter and 150 cm length.

Based on electrical power requirement and pulse repetition rate, the output storage capacitor C3 is chosen to be 2 nF. All storage capacitors of MPC stages are chosen to be of the same value, i.e. C1 = C2 = C3 = 2 nF for maximum efficiency. The peaking capacitor consists of 2 units of 1 nF (shown as Cp) in figure 1. Industry standard IGBTs rated for 1200 V and 400 A rating (Eupec-make BSM 400 GA 120 DLC) are selected as the main pulse power switch. The nominal switching voltage level for the IGBTs is designed at 825 V to keep adequate safety margin. Pulse transformer with step-up ratio of 1 : 41 is developed to achieve the desired voltage level across the laser head. Storage capacitor C0 is evaluated to be 3.3 μF based on impedance matching of pulse transformer on the primary and secondary sides of storage capacitors.

Each bank consisting of two IGBTs conducts peak current of 900 A for a duration of 2 μs, thus the total peak current through IGBTs is 1800 A. Matched gate drive pulses, matched components and symmetrical lay-out are used to ensure equal sharing of the current in the IGBTs. This is required for reliable operation. The maximum voltage across C0 will be 825 V as per the design thus energy stored across each storage capacitor bank is 560 mJ, thus the total stored energy is 1.12 J.

Pulse transformer and MPC stages are designed as per the guidelines given in [6,7] and details of the designed pulse transformer and MPC are given in table 1. Indigenously developed Ni–Zn–Co toroidal ferrite cores of 152 mm outer diameter, 102 mm inner diameter, and 15 mm height are used for pulse transformer and MPC stages. The electrical design parameters of magnetic components are listed in table 1.

The pulse transformer, storage capacitor, MA, IGBT, Snubber and MPC components are immersed in transformer oil and contained in mild steel tank. The heat in the oil is removed by circulating the oil in an oil-to-water heat exchanger. Gate driver circuit for IGBTs is designed based on Mitsubishi driver IC M57962L and current booster circuit [8]. The trigger control circuit that drives the gate driver circuit, is designed using CMOS ICs and has the facility for external trigger by signal on optical fibre.

The IGBT-based power supply is housed in a 19″/32U, 800 mm depth, standard rack identical to the earlier thyratron-based power supply for the CVL. The photograph of power supply with laser head is shown in figure 2. The SMPS unit,

Table 1. Electrical design parameters of magnetic components.

Pulse transformer		Magnetic pulse compressor: Parameter	Ist stage	IInd stage	IIIrd stage
Primary inductance	25 μH	Input storage capacitor	2 nF	2 nF	2 nF
Primary winding turn	1 T	Hold-off voltage	32 kV	32 kV	32 kV
Number of primary windings	2	Hold-off time	2 μs	400 ns	120 ns
Secondary inductance	40 mH	Saturated inductance	16 μH	1 μH	160 nH
Secondary winding turn	41 T	Number of cores	5	5	4
Number of cores	12	Number of turns	37	8	3

Figure 2. Photograph of CVL with SSPPS.

charging and control circuits for pulse generator, and laser control unit are packaged in 19″ standard plug-in units.

4. Experimental results and discussions

The CVL is operated with the SSPPS at a PRR of 6.5 kHz using neon as the buffer gas at pressure of 32 mbar in the laser tube. Waveform monitoring is carried out using Tektronix make DSO (TDS 540C). Measurements are carried out using high voltage probe (P6015A), differential probe (P5210), Pearson make current transformer (model no 2878 and 6610), Gentec make laser power meter (TPM-300).

The voltage across IGBT and current through IGBT bank are shown in figure 3. For a charging voltage of 750 V on C0, the current in the two banks is 730 and 735 A, thus the variation of current between the IGBT banks is within 1%. The voltage waveform across the input of each MPC stage is shown in figure 4. These waveforms are monitored across the storage capacitor C1, C2 and C3 with 33, 28.5 and 29 kV magnitude respectively. Experimental results of the compression gain of various stages of MPC matches closely with designed values.

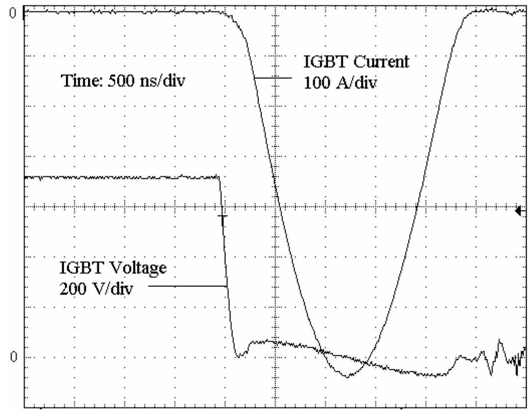

Figure 3. IGBT voltage and current waveforms.

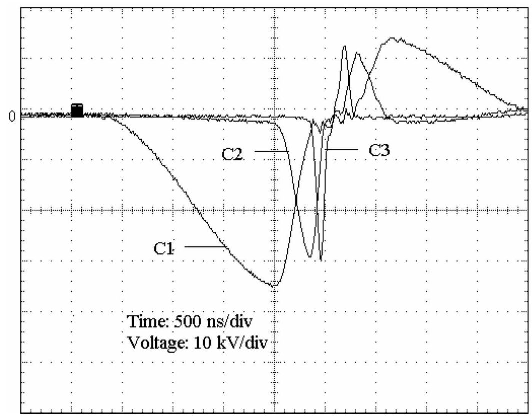

Figure 4. MPC stage voltage waveforms.

The laser head voltage and current waveform are shown in figure 5. The voltage magnitude is 18.5 kV and current magnitude is 900 A. The current is measured in one of the eight parallel paths by Pearson make current transformer and multiplied by 8 times to obtain the total current through laser tube. An average laser power of 51.6 W was obtained with plane–plane resonators. The active volume of the laser tube is 2600 cm^3 and this gives the power density of 19.85 mW/cm^3 or approximately 20 mW/cm^3. The laser power build-up is shown in figure 6. It takes about 35 min to build power within 5% of the maximum value and is observed to be within this band thereafter. The warm-up time of the laser is typically 60 min based on input power. The high average power from the CVL with IGBT-based power supply is attributed to higher voltage amplitude across the laser head and faster rise time.

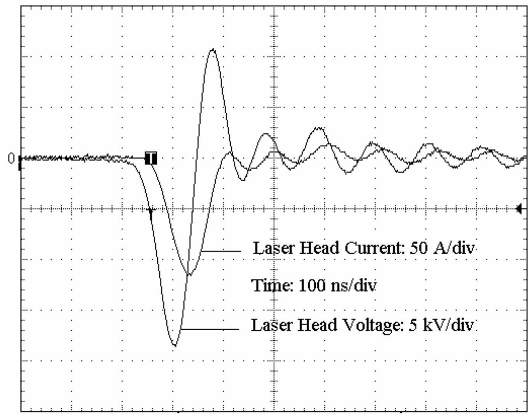

Figure 5. Laser head voltage and current waveforms.

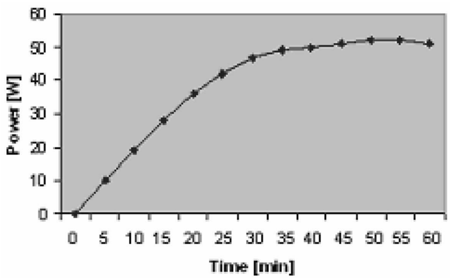

Figure 6. Laser power build-up.

5. Conclusion

IGBT-based solid-state pulse power supply is developed using modular units to replace the existing thyratron-based power supply in its standard cabinet. The average laser power obtained with IGBT-based pulsed power supply is around 51 W which is 29% more than the earlier thyratron based power supply. The mean time between failures of this power supply is expected to be several times more than thyratron-based power supply with significant reduction in operating cost.

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References

[1] C E Little, *Metal vapour laser – Physics, engineering and applications* (John Wiley & Sons Ltd, England, 1999)

[2] T Fuji *et al*, *Opt. Eng.* **31(11)**, 2481 (1992)
[3] D Chatroux and J Maury, *SPIE* **1859**, Laser Isotope Separation (1993)
[4] D V Ghodke and K Murlikrishnan, *National Laser Symposium*, 177–178 (2002)
[5] S V Nakhe *et al*, *National Laser Symposium*, 81–82 (2001)
[6] E G Cook *et al*, 8th *IEEE Pulsed Power Conference*, June 1991
[7] L Druckmann *et al*, *IEEE Power Modulator Symposium*, 213–216 (1992)
[8] Hybrid gate drivers and gate drive power supplies, M57962L datasheet from Mitsubishi Electric Corpn.