Chapter 11

Automation and Exploration of Jitter in Pulse Power Supply of CVL

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11.1 Introduction

This chapter presents the various improvements obtained in the performance of the copper vapor laser (CVL). The operation of the CVL has been automated using PLC and proper feedback thereby ensuring optimum performance of laser. A novel approach has been proposed to reduce the pre-discharge electron density in the elemental copper vapor laser thereby obtaining dramatic improvement in the performance of CVL. A theoretically and experimentally validated mathematical model of the pulse power supply (PPS) is presented to explore the parameters contributing to jitter in the CVL. The same model is used to highlight the dynamics of the magnetic pulse compression circuit of the CVL.

11.2 Automation Work

When a high voltage pulse is applied across the laser head (copper vapor laser), due to impurities present in the discharge, a smooth glow discharge is not able to develop throughout the laser. Concurrently it offers a high impedance to power supply and large amount of energy is reflected back into the power supply, which harshly affect power supply in long run. To dodge this situation, during initial period of laser operation, proper suction of impurities inside the laser head is done by activating vacuum fast switch (high flow) and purging of Neon gas into laser head by activating the gas fast switch (high flow). This process is repeated until laser discharge attains a stable condition (no rolling in discharge). When the discharge becomes smooth Neon gas is purged at low flow rate (1 mbar/min) by activating Gas Slow switch with desired inflow rate and vacuum slow switch is simultaneously activated at lower suction rate. The normal operation condition for the CVL is a fixed operation pressure maintained by the slow gas inflow rate and slow suction rate. Conventionally the conditioning of the CVL discharge is done by applying high voltage to the laser head and manipulating the gas slow / fast and vacuum slow / fast switches by visually observing the discharge, which requires a lot of man power and time if many lasers are simultaneously operated. Further additional activities like monitoring critical parameters such as bypass inductor temperature, resistance (R) temperature, pressure in laser head also requires manual effort. While manual operation of laser, during conditioning phase, a lot of neon gas is wasted. By visual examination of laser head discharge condition, one can't evaluate the exact condition of laser plasma discharge and thus to ensure its smooth operation, it is necessary to continuously operate Vacuum fast and Gas Fast switches, which consumes time and excess neon gas. The difficulties in the conditioning as well as operational phases of the CVLs are minimized by operating the laser in automation mode through PLC by taking reflected voltage from laser as feedback. The circuit diagram of the CVL power supply is shown in Fig. 11.1. When a high voltage is applied at the Laser head terminal, a high voltage discharge take place in between the anode and cathode. The impedance offered to this discharge depends on the constituent gases present in the laser tube at that time and the pressure inside the tube. The magnitude of the reflected voltage pulse depends upon the impedance encountered by the laser head. It has been observed that laser impedance increases due to contamination in the laser gas which increases laser breakdown voltage and breakdown time. During such abnormal condition, discharge energy provided by power supply is dumped into bypass inductor and the remaining is reflected back into power supply. If gas impurity in the laser head persist for long time, than a higher magnitude of pulse power is reflected back into the power supply and bypass inductor and it can damage the bypass inductor and the power supply. Therefore to determine laser condition, reflected voltage is taken as a feedback and monitored. It is difficult to sense the reflected voltage directly at laser head due to high voltage and EMI. The reflected voltage across resistor R was sensed, as shown in Fig. 11.1. During normal operation of laser the reflected voltage across resistor is a few volts (20-30 V pulse) but if laser condition deteriorates then reflected voltage increases to higher value (100-200 V pulse) as shown in Fig. 11.2. Programmable Logic Control (PLC) can't read at high frequency, so this reflected pulse voltage at 9 kHz was converted into DC voltage and the laser head condition was calibrated with this DC voltage. On the basis of this DC voltage the laser head parameters like – Gas flow rate, SMPS voltage are changed. Figure 11.3 shows the circuit for converting pulse reflected voltage to DC voltage. Measured reflected voltage across resistor 'R' is reduced using voltage divider followed by rectification and signal smoothening. This DC voltage is fed into PLC through an isolator. If the laser condition deteriorates then reflected voltage increases and this increases reflected voltage propagates through power supply and reaches across resistor 'R', shown in Fig. 11.1. During normal condition of laser DC voltage varies between 3.5 V to 4 V (Can be changed by varying resistor value in potential divider) but if laser condition is bad DC voltage can be up to ∼25 V. During initial phase of operation of laser until fluorescence has been obtained inside the laser head, continuous conditioning cycles for the laser head is done to remove the

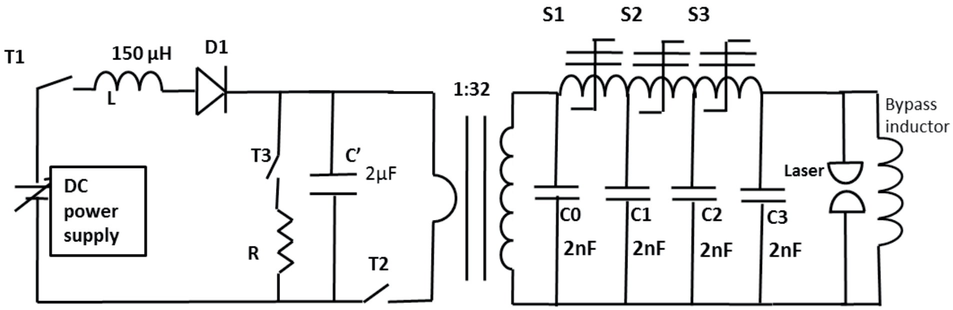
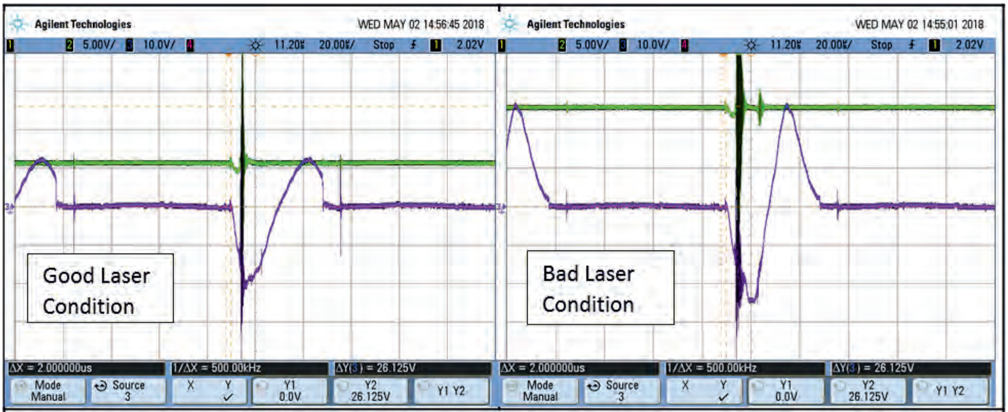


Figure 11.1: Pulse generating unit of copper vapor laser.



Green Line :- Equivalent Dc voltage of reflected positive pulse

Purple Line: - Voltage across resistor. The positive pulse of voltage depends on laser condition and negative pulse depends on operating voltage

Figure 11.2: Waveform across resistor R.

impurity and thereby decreasing reflected voltage below 4 V. After fluorescence inside the laser head, reflected voltage is monitored and if goes beyond a normal (6 V) range, an alarm is generated and if it becomes critical level (9 V) laser is shut down. The reflected pulse across the resistor and converted DC voltage level is shown in Fig. 11.2. The magnitude of the negative pulse in the Fig. 11.2 is depends on the operating voltage while the magnitude of the positive pulse shows reflected voltage across the resistor.

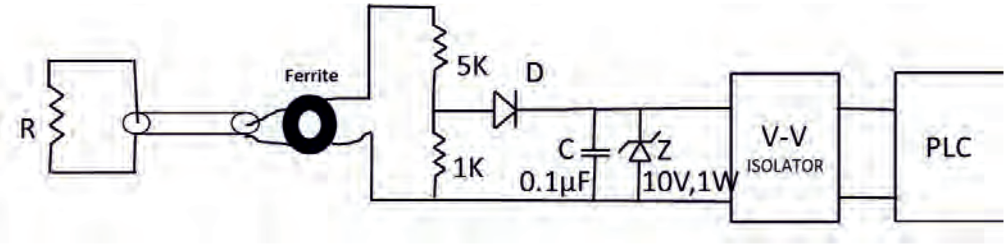


Figure 11.3: Variation in DC voltage with laser condition.

11.3 Phantom Current and Electrode Geometry – a Correlation

It has been found that the current in the elemental copper vapor laser appears before the voltage breakdown. The appearance of the current is nearly 50 ns prior to the breakdown and constitutes roughly 70% of the peak current. This current is referred as phantom current or pre-discharge electron density. This has been reported that reduction in the phantom current leads to dramatic improvement in the performance of the metal vapor laser (MVL). The pins in the high voltage electrode are used to facilitate discharge. It has been presented that along with augmenting the discharge, it also impacts the laser performance. A correlation has been established between the electrode pin geometry and the phantom current thereafter the electrode geometry with optimum laser performance has been proposed. The electrode pins manipulates the electric field in the nearby localized region thereby effecting the amount of phantom current in the MVL. Three different electrode pin configuration of 0, 8 and 36 pins are tested and compared and it was found that the electrode with zero pin offers the minimum phantom current and the 8 pins electrode offers the highest quantum of the phantom current.

[*"Dependence of phantom current in a metal vapor laser on electrode geometry", Dheeraj K Singh, et al., Laser Phys. Vol -30, Issue 11, 2020* [132]].

11.4 Analysis of Temporal Jitter in PPS of CVL

The CVL offers widespread application owing to its unique features like high power and high efficiency. In order to increase the optical output power from CVL with requisite beam qualities, CVL is operated in the master oscillator power amplifier (MOPA) configuration. MOPA operation imposes a stringent requirement of jitter in the system to ensure proper temporal synchronization of the optical pulses. High jitter in the system deteriorates the optical output power along with power stability. Jitter in the CVL is due to simultaneous contribution of several parameters. This paper presents the experimentally validated MATLAB model of the pulse power supply and highlights the parameters that contribute to jitter in the optical output of CVL. It has been found that the impedance variation in the laser load has dominant contribution to the jitter in the CVL system. Various methods has been demonstrated to reduce the impact of impedance variation on the CVL performance, particularly jitter.

[*"Exploration of Jitter in Solid State Switch Based Pulse Power Supply of Copper Vapor Laser", Dheeraj Kumar Singh, et al, JRLR, Vol. 41, Issue 6, 2020* [133]].

11.5 Comprehensive Analysis of Voltage Compression

With advancement of the solid state switches, the pulse power supply now employs the solid state high voltage switches i.e. magnetic switches. These magnetic switches are utilized to fasten the rise time of the voltage pulse applied across the CVL. These magnetic switches offers varying inductance and behave as a switch due to nonlinear ferromagnetic characteristics of its core. The magnetic switch offers negligible inductance and acts as a closed switch when it gets saturated on the application of desired voltage. Similarly during unsaturated state, these switches act like an open switch and offer huge inductance. The magnetic switch along with capacitor forms a voltage compression circuit also referred as a magnetic pulse compression circuit (MPC). It is important to fix the B-H curve operating point (i.e., reset of magnetic switch) for desirable and smooth MPC functioning. This is ensured by application of DC current to the magnetic switch to reposition the operating point in the B-H curve from positive to negative saturation flux before the next pulse. The resetting of magnetic switch becomes crucial in the applications having stringent jitter requirement like MOPA operation. The resetting of the magnetic switch becomes cumbersome with increase in the repetition rate of the magnetic switches as there is hardly any time for oscillation to die out on its own. This paper presents comprehensive analysis of high repetition rate magnetic pulse compression circuit. Jiles-Atherton equation along with current and voltage waveform is used to derive the hysteresis curve of the magnetic switch. The impact of the oscillation in the MPC on the hysteresis curve of the magnetic switch have been highlighted. A theoretical and experimentally validated simulation model is developed for comprehensive analysis of MPC operation at high repetition rate.

[*"Dynamics of magnetic pulse compression circuit of metal vapor laser", D K Singh, et al., Journal of Physics: Conference Series. Vol. 1921. No. 1. IOP Publishing, 2021* [134]].

Frequently Asked Questions

Q1. What is the feedback point for automation and why is it chosen?
Q2. Why is the pulse feedback voltage converted into DC voltage?
Q3. What advantages does automation offer over manual operation?
Q4. What is phantom current and how does it impact the performance of metal vapor laser?
Q5. What is the correlation of output power with number of discharge pins in electrode?
Q6. What is the correlation of phantom current with number of discharge pins?
Q7. What is the electric field enhancement and on which factors does it depend?
Q8. What is jitter and why are jitter requirement stringent in Copper Vapor Laser?
Q9. What are the parameters in pulse power supply that contribute to jitter in laser optical pulse?
Q10. Which method is employed to draw B-H curve (Hysteresis) of magnetic switches in MPC?
Q11. How does load variation affect the oscillation in MPC stages?
Q12. What is the purpose of MPC stages in pulse power supply of CVL?
Q13. Why is resonant charging circuit used before pulse transformer in pulse power supply of CVL?
Q14. With increase in the number of pins in electrode, what happens to the jitter in the pulse power supply?
Q15. During impurity inside laser head, what happens to its impedance offered to supply?
Q16. Due to laser load variation, what happens to the jitter in pulse power supply?
Q17. Which pin configuration in electrode will have lowest phantom current?
Q18. Current pulse in laser originates during, before or after voltage breakdown?