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The Behaviour of Inverse Voltage on Thyratron's Anode Versus Operational Parameters in Gold Vapour Laser

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ABSTRACT

Two gold vapor laser tubes with different lengths of 60 and 75 cm and identical diameter of 16 mm were used to investigate the behavior of inverse voltage on thyratron's anode in the excitation circuit, versus operationl parameters such as buffer gas pressure and electrical input voltage. It was shown that, the inverse voltage on thyratron's anode decreases with increasing of the buffer gas pressure and so electrical input voltage, individually. By optimization of these operational parameters, the lifetime of thyratron will be increased.

Key words: Thyratron, Inverse voltage, breakdown voltage, gold vapour laser
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INTRODUCTION

The successful metal vapour lasers (MVLs) that survive today have done so because they have desirable characteristics that are either not available or difficult to attain using other technologies. The gold vapour laser (GVL) has a high average and peak power in the red (627.8nm) spectral region, and is attractive due to its possible application to photodynamic tumor destruction and hyperthermia Huang, Shan, Huo, and Wang (1987); (Nezhad, Sajad, Behrouzinia, Salehinia, & Khorasani, 2010),(Behrouzinia, Namdar, Zand, Barry, & Hojabri, 2006).

The design of the modulator is of great importance to MVL and so GVL efficiency and performance. The modulator must deliver pulses of the energy, pulse repetition frequency and rise-time appropriate to efficient laser generation. Excitation circuits for self-heated pulse MVLs require fast, efficient and reliable switches capable of holding off voltage of 20-30kV, of commutating peak currents of up to ~1kA at pulse repetition frequency of 10s of kHz and average current of ≥ 1A. The switch must also contend with the strongly non-linear impedance of the laser discharge. The hydrogen thyratron remains the most commonly used switch as it can achieve all the parameters simultaneously (Little, 1999). Thyratron is a discharge tube with its internal chamber filled with hydrogen at low pressures. It consists of three electrodes named anode, cathode and the network between them. An external pulse triggers the network. The hydrogen thyratron acts as a switch. The required time for recombination of electrons and ions through the thyratron is approximately equal to 10 µS. This is the time that thyratron needs to return to its primary conditions and hence store the high voltage in itself. The return of a fraction of the energy to the storage capacitor leads to the appearance of the negative voltage over swing on the thyratron anode, which promotes recovery of the thyratron. The optimum negative voltage for recovery is generally 500-1000V. Thyratrons that are used for pulsed MVL applications are commonly rated to anode voltage of ≥ 25kV, peak current of ≥ 1kA and the average currents of ≥1A. One of the factors that affects laser downtime and hence service life of the system as a whole is the lifetime of the thyratron, which is usually specified as ~ 10^{11} shots. If the thyratron anode voltage present at the end of each excitation pulse routinely exceeds -2-3kV, then metal ions sputtered from the anode lengthen the recovery time and eventually cause failure of the thyratron to recover (Le Gal La Salle, 1988). Damage to the cathode and anode also occur due to internal heating at the beginning of commutation, when the thyratron anode voltage is still high, and the current is substantial. The most successful means of reducing thyratron stresses is by using non-linear magnetic field (Behrouzinia et al., 2006). The laser tube is a non-linear load, whose impedance depends on its plasma (tube capacitance and inductance) and plasma conductivity, each of which is time dependent. The rise time and strength of the longitudinal electric field in GVL and the form of the current pulse depend on the tube impedance. Matching of the laser tube to the external circuit is important to attain high laser efficiency. The overall laser tube impedance can be represented by a transmission line of resistance, inductance and capacitance. The resistance of a GVL increases linearly with its length and buffer gas pressure, and inversely with its gas temperature and electron density (Blau, 1996), (Gilbert & Cameron, 1965). By varying the operational parameters such as buffer gas pressure and electrical input voltage, the impedance of the tube is varied and the value of inverse voltage on thyratron's anode is varied so, due to the mis-match impedance between circuit and laser tube. So by tuning these operational parameters the inverse voltage on thyratron's anode is set to the optimize value. Therefore we can control the operation of the thyratron and increased its lifetime. However, with more inverse voltage, it causes the device to dissipate energy and hence the thyratron is spoilt. Increasing the inverse voltage on the thyratron's anode from the specified value leads to a huge decline in its lifetime. Even in powerful thyratron, the permitted value of inverse voltage does not exceed 5 kV. In this work, the dependence of inverse voltage of the thyratron's anode on the input voltage and pressure of He-Ne buffer gas have been investigated, individually and, the amount of breakdown voltage versus excited tube's length and buffer gas pressure have been studied.

EXPERIMENTAL APPARATUS

In this work, two identical GVLs with an inner diameter of 16 mm and active medium length of 60 cm and 75 cm have been used. Plasma cavities are made of alumina which can tolerate the temperature greater than 1700°C which is surrounded with Alumina Fiber. Two cylindrical electrodes made of molybdenum are employed for discharging. The Laser system consists of two coaxial tubes. The internal tube is ceramic named the plasma tube (the place of producing plasma) and external tube is water jacket. Self- inductance of the two coaxial tubes is produced by the transition of magnetic flux across the space between the two tubes. The capacitive property is generated when the electric field is implemented between the conductor and insulator tubes. The resistance value has a direct relation with the length of the laser and buffer gas pressure whereas changes with electron density reversely. Each of laser tube has been coupled to a standard driven circuit, separately, as shown in Fig.1. The gas in the tube is excited by the discharge of main capacitor C_s through the TGI1-1000/25 thyratron as a switching device which is cooled with air. A peaking capacitor C_p is connected between the tube electrodes. In order to determine the inverse voltage on thyratron's anode, an oscilloscope and the NTG3015 high voltage probe have been used. The experiments were carried out at 20 kHz frequency using a mixture of Hellium and Neon gases at ~50 and 70 Torr of pressures.

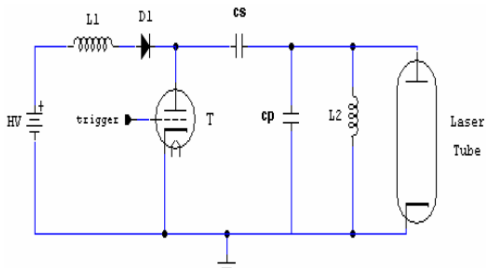

Fig.1. Schematic layout of standard modulator circuit. C_s = 1.65nF, C_p =0.68nF, L_1=100mH, L_2=1.5mH.

Air is used for cooling the system instead of water jacket which there is a new special design. The Resonance cavity includes a plane multilayer mirror with %98 reflectance and plane quartz with reflectance of 8%. The output power of about 4~7W can be generate by the lasers with the above mentioned characteristics.

RESULTS AND DISCUSSION

The variation of inverse voltage on the thyratron`s anode versus electrical input voltage at two different gas pressures in lasers with the length of 60 and 75 cm are shown in Figs.2 and 3, respectively.

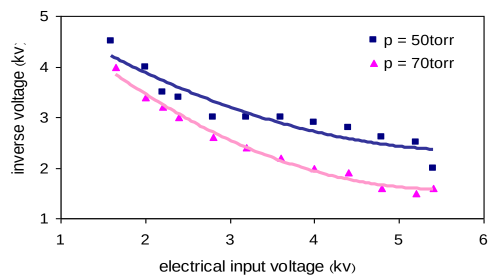

Fig.2. The inverse voltage on the thyratron's anode versus electrical input voltage in the tube length of 60 cm.

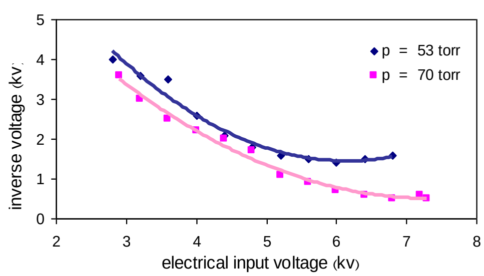

Fig.3. The inverse voltage on the thyratron's anode versus electrical input voltage in the tube length of 75 cm.

As shown in Fig.2 the value of the breakdown voltage in the gas pressures of 50 and 70 Torr are achieved at 1.60 and 1.65kV, respectively. Also, Fig.3 shows that these values for the specified gas pressures are equal to 2.80 and 2.90 kV, respectively. These figures clearly indicate that as gas pressure is increased, breakdown voltage rises. These experimental results are compatible with Paschen's equation given by:

$$V_b = f(p.d) \quad (1)$$

Where p is gas pressure, d is the distance between two electrodes which is equal to the length of discharge tube and V_b is the breakdown voltage. According to these equations, V_b has a direct relationship with the product of p and d. The breakdown voltage is corresponded to the highest value of the inverse voltage on the thyratron's anode. Moreover, a comparison of Figs 2 and 3 shows that the inverse voltage on the thyratron for the longer tube laser is more than the shorter one. So when the electrical input voltage increases, the inverse voltage on the thyratron's anode decreases. In fact, as electrical input voltage grows, the temperature of tube's wall T_w (°k) rises. The density of metal vapour atoms n(cm^{-3}) is a function of T_w according to the following relation (Hogan & Webb, 1995).

$$n = 1.233 \times 10^7 \, exp(0.0124Tw) \quad (2)$$

The dependence of n on the T_w shows that with increasing of T_w, n also increases; hence the number of atoms which are employed in the laser process increases exponentially. The number of atoms in the laser process strongly affects the electron temperature T_e(°K) in a way that with growing n, the electrons loses their energy due to inelastic collisions with atoms and then causes T_e to be reduced. Decreasing T_e leads to diminish in the number of metal vapour atoms which can obtain the required energy for ionization. Therefore, the number of secondary electrons reduces. Owing to the fact that the tube resistance has inverse relationship with T_e, the resistance rises with declining electron density. Consequently, more impedance matching between laser's tube and its charged circuit is obtained using higher electrical input voltage, the rate of reversing energy from the tube and inverse voltage on the thyratron's anode is reduced. Also, it has been observed that at higher gas pressures, the inverse voltage on thyratrons's anode has been reduced.

CONCLUSIONS

Based on the experimental results, more impedance matching between laser's tube and discharge circuit occur with the increasing of gas pressure, because of the increasing in the impedance of the laser's tube. Therefore, dissipation of energy on the circuit and the thyratron decrease. Consequently, the amount of inverse voltage on the thyratron's anode is decreased by the increasing of gas pressure. Also it was found that, the inverse voltage on thyratron's anode is decreased when electrical input voltage is increased. Increasing the electrical input voltage leads to an enormous diminish in electron density. Meanwhile, the tube's resistance goes up, and more impedance matching is achieved, so, the amount of breakdown voltage has been increased with rising gas buffer pressures, for lasers. Moreover, the breakdown voltage in the longer tube is more than the smaller one. So the inverse voltage on thyratron's anode is decreased with increasing the electrical input voltage. But, however, these are technical limitations for increasing of electrical input power and so, for obtaining the highest output power in any laser; there is an optimum value of the electrical input power. Longer life time of the thyratron has been obtained by declining of inverse voltage on thyratron's anode.

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