

Characterization of Variable High Voltage D. C. Power Supply Designed and Constructed for Low Pressure Gas Discharge

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Abstract: In this work we characterized a variable high voltage DC power supply, designed and constructed for low pressure gas discharge, suitable for laser pumping and plasma production. A homemade transformer was performed to obtain maximum output voltage of 30 KV and current variation of 100 mA which is required for laser production and plasma creation. A mixture of CO₂, N₂ and He was tested with different pressures and variable flow rates for discharge evaluation and parameters validation. The peaks intensities of the discharge emission spectrum were linearly related to current variation, which showed homogenous peaks rising up as a good indication of the system power stability. On the same manner, the system efficiency was evaluated from the input electrical power and the electrical energy dissipated inside a discharge cavity, which was approximately equal 20%.

Keywords: DC power supply, gas discharge, plasma emission.

1. INTRODUCTION

Most of modern physics has some understanding or explanation of one phenomenon or another associated with a gas discharge which is the essential process in plasma and gas lasers physics. Injecting large amounts of electrical power into a gas can generate optical power. High voltage D.C. power supply stores the energy in the power capacitors and then supplies it to the discharge gap in short time. The excitation of the gas can be carried out at relatively high voltage and low current. The atmosphere filling the space between two electrodes in the discharge gap is excited and emits lights at the beginning of the electrical discharge [1].

Looking more closely at the regions of discharge, the terminal characteristic appears. Distinct of discharge is specified due to some physical facts. The potential between the cathode and the anode, as function of the distance, rises very sharply near

the cathode and remains constant for short distance and throughout the rest of the distance rises more or less uniformly [2, 3].

Usually the discharge region is surrounded by water coolant jacket to remove the waste energy from the gases mixture inside the discharge tube. The waste heat is dissipating away by two basic techniques. The gas heat conductive properties carry off the heat conductive in the active medium to the tube wall, but it is ineffective due to the low thermal conductivity of the gas. Force convection is sending away to remove heat waste by replacing the hot gas with cool gas. The heat leave the active region through the tube wall by conduction is less compared with the amount of heat carried out of the active region by the gas flow in the flow cooled gases [4].

Applying an electrical field to a gas in a tube, a number of interesting phenomena is observed at low pressure when the current density through the gas is increased [5]. Electric field strength (E) in this region is proportional to the gas pressure, and to the current flowing through the column and weekly dependent on the tube diameter. The current density at the tube center in the column region has maximum value and drops to zero at the wall surface. Continuous increasing of the current density (J) causes break-down of gases to occur at about $J=10^{-4}$ A/cm² and the voltage decrease at this point [6]. Low current distribution on the cathode area is proportional to the total current which varies due to the current increase [7]. In CO₂ laser, as example, normal current density in the laser tube is proportional to the pressure square in the range of 20 – 70 torr for N₂ and CO₂ gases [8]. Thermal conductivity of gases at high pressure is essentially independent of pressure. Thermal conductivity at low pressure is pressure dependent, where the container dimension determines the mean free path of the molecules. Specific heat and viscosity, at high pressure, are increased with pressure at constant volume [9].

The average electron energy is a function of the E/N ratio, where E is the electric field and N is the molecule density. Gas pressure (P) at constant temperature is directly proportional to the N, so E/N is often replaced as a ratio by E/P. The mobile electrons carry most of the current, the rest is carried by the massive positively charged ions, and their sum must be constant. The electrons and ions in gas discharge must be created at exactly the same rate, as they are lost. This is necessary for the existence of a discharge, which is called the ionization balance condition given by [10]:

$$\frac{dn_r}{dt} = v_i n_r - \frac{n_r}{t} \quad (1)$$

where n_r is the number of new electrons, v_i is the speed of new electron, and t is the time required. From this relation, the sum of production of new electrons and ions present in a discharge and new electrons by an externally controlled source and the losses of electrons by various processes in the discharge tube produce the ionization balance. The electrons are emitting through thermo-ionic emission from the cathode, and these electrons gained kinetic energy corresponding to a significant fraction of the cathode from the negative glow. The collision processes involving excitation in gas

molecules, two types such as first kind and second kind collision are occurring. The first kind collision is the conversion of the kinetic energy of one species into potential energy of another species. Collisions of the second kind is conversion of the potential energy into other form of energy such as kinetic energy, or transferred as potential energy in the form of electronic, vibrational, or rotational energy to another unlike or like species.

The D.C. electrical power is entered to the molecules of the gas and transferred to neutrals atoms, exciting the quantum levels of interest. The neutral gas molecules are excited by absorbing energy from electrons during collision process. The various excited states of gas molecules, needed for laser production in gases, are obtained by collisions of secondary electrons produced in the gas flow. Stored energy within the molecules can be increased or released by absorbing or radiating energy. Sufficient kinetic energy of the molecules by collision can cause change in the molecules energy state [11]. The large energy quanta that can be released in the molecular collisions at high temperature of the gas are measurable quantities. The bulk of radiation is connected with changes in the rotational or vibrational energy of the molecules at temperature in the range of up to 3000 oC [12]. This radiation has wavelengths in the range of 1 to 30 μm [13].

2. THE EXPERIMENTAL PART

A high voltage (D.C.) power supply was designed and constructed due to input power capacity of variac, which was designed to obtain maximum output of 30 KV D.C and maximum current of 100 mA. However, the main (A.C.) input of the transformer was 220 Volt that providing maximum output power of 1.5 KVA. The main electrical power source was controlled by a variac, rectified by diodes and smoothed with electrical high voltage capacitors. Voltage double circuit was designed according to the output transformer, and the capacitors available, which was used to raise the high voltage from 15 KV to 30 KV. Thermal resistances of 300 K Ω and 350 Watt were connected in series as ballast resistance while resistance of 80 M Ω was connected in parallel as bleeder resistance to protect the circuit from high voltage, current leakage, and electrical damage. Full-wave rectifier circuit, composed of four diodes of 30 KV and current of 100 mA, was connected in series with the transformer to remove the ripple of A.C. voltage for rectification. Capacitor of 1.5 μF , connected in parallel to the load of 30 KV, was used to smooth the D.C. high voltage.

The design and construction of the transformer involves a ferromagnetic iron core in order to ensure high values of magnetic flux linkage. Two iron sheets, with widths of 10 cm, 16 cm and 20 cm length and 0.2 mm thickness, were arranged to form a geometrical rectangular shape of 24 X 24 x 5 cm and used as iron core. The input voltage source of 220 V and 50 Hz frequency was connected to variac device, of 8 Amperes and output voltage range from 0 to 250 V, in order to control the output

(A.C.) voltage of the transformer. The transformer turn ratio of 1:137 was connected in parallel to the output variac, which raise the output voltage from 220 V to 15 KV. The design parameters were determined through the following equations:

$$\text{Rate of flux} = 4 f \Phi_m$$

$$\text{Maximum of induced e.m.f. / turn} = 2\pi f \Phi_m \text{ volts}$$

$$\text{Root main square of induced e.m.f. / turn} = 1.11 X 4f \Phi_m$$

$$\text{Root main square of e.m.f. in primary and secondary coils} =$$

$$E_{1,2} = 4.44 N_{1,2} f \Phi_m \text{ volts,}$$

where Φ_m is maximum value of the flux in Weber, f is frequency, and N is number of turn.

The secondary coil was separated from the primary coil by two papers glowed on the oil bath jacket, which was used for passing the hot oil from the bottom to the upper region. The primary coil was insulated from the iron core by PVC tube cover with two insulation papers to obtain good insulation. Mild steel oil container was designed and constructed to contain the transformer and 8 gallons of oil to produce optimum cooling environment. Radiator of three channels was attached at both sides of the container for oil circulation cooling system. Oil was used as cooling medium to convey heat to the container wall, which dissipate heat through mild steel container and create electrical insulation medium around the transformer. Temperature differences around the transformer circulate oil from hot region to cold region, which flow through radiator channels. The tank cover was insulated from the case by rubber strip to prevent oil leakage and insulate the electro-static voltage from the outside region. The efficiency of the transformer was obtained from the ratio between input and output powers losses during full load power. The losses which occur in a transformer on load can be classified into: power losses in primary and secondary coils, and core losses due to hysteresis and eddy currents. Core loss was constant at all loads due to the maximum value of the flux dose, not vary by more than 2% between no load and full load. Figure 1 shows the electrical circuit of the high voltage power supply of 30 KV provides the electrical power needed. Copper metal was used as a cathode rod in the discharge tube which was filled with mixture of CO₂, N₂ and He gases. The anode was made from tungsten rod of high melting point. NGN rotary vacuum pump was used to evacuate the system to the required low pressure via adjustable valve and high-pressure hose. Different values of pressure inside the tube can be controlled via the vacuum pump. To get rid of the heat generated in the discharge cavity, since effective heat absorption is needed, water pump was used to ensure forced water-cooling. The electrical power was supplied to the system until stream of pink light along the electrode was observed. The high voltage ground stick has

to be connected to the earth to release the electric static charges from the D.C. high voltage power supply. The data from the multi-meter were recorded due to the high voltage regulation current variation.

3. RESULTS AND DISCUSSION

The air break-down was produced at pressure of 100 mbar and 15 KV, while the space charge was developed between the anode and the cathode. At this stage, the potential gradient was decreased to 4.14 KV and discharge regime was established, as shown in Figure 2. The balance of the discharge was obtained under stable circuit conditions, while the glow was observed between the two electrodes. The inlet of the gases through the cathode was sensitive to discharge stability rather than through the anode. It is believed that the high electric field at the electrodes can be affected by the roughness of the surface and that may cause additional charge generation which disturb the stability of the discharge. The electrical input power was controlled to displace the axial location of gas discharge in the cavity. Figure 3 shows the high voltage applied to the discharge cavity versus current variation. From the graph, it can be seen that the high voltage is decreased more rapidly than the increment in the current values. The fall of discharge was occurred at high temperature due to thermal loading on the gas. Electrical power and gases flow rate were controlled carefully to get continuous discharge output power required to create a constant intensity. Figure 4 shows the current as a function of gases pressure in the discharge region. The relation between gases flow rate and current is displayed graphically in Figure 5. The atoms and molecules excitations are proportional to gas velocity, relative to the mass of the gas moving into the discharge tube per second. The quantities effect on the discharge regime is plotted in Figure 6 for different excitation electrical powers with a mixture of 10% CO₂, 10% N₂ and 80% He at different pressures. The optical efficiency was increased with the medium saturation resulting from discharge stability and higher cooling efficiency. On the same manner, the system efficiency was calculated from the input electrical power and electrical energy generated inside a discharge cavity, which was approximately equal 20%.

In order to examine the effect of electrical field on the emission of the excited gases, series of spectra were recorded as shown in Figure 7. The spectrometer was used to detect a side light of the discharge tube, which directly viewed the gases excitation through a sensitive detector. Furthermore, the spectra showed the discharge stability of the high voltage discharge and current variation inside a discharge cavity. It is clear from this figure that the intensity of the emission is increased with the current increment to a certain value. In the spectra some peaks are appeared in the visible region due to the N₂ and He transitions in the discharge medium. It can be seen that the intensities are linearly related to current variation, which showed homogenous peaks rising up. Furthermore, the spectra showed the discharge stability of different current

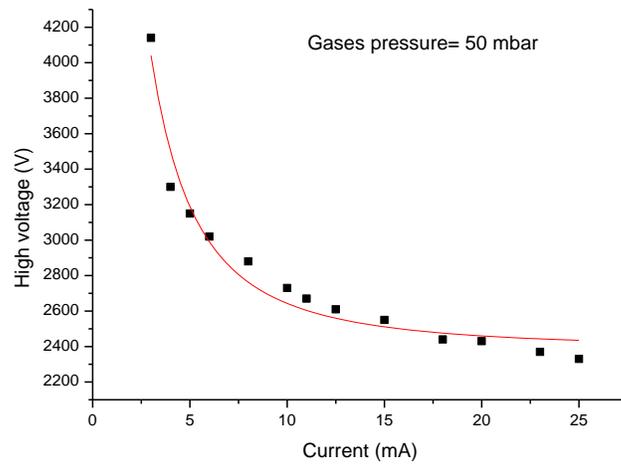


Figure 3: The voltage versus current variation

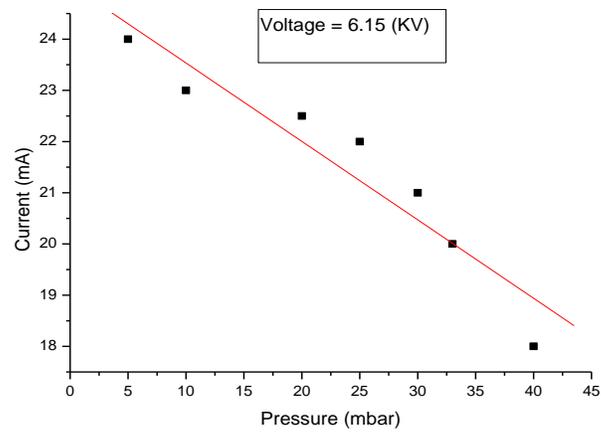


Figure 4: Current versus gas pressure

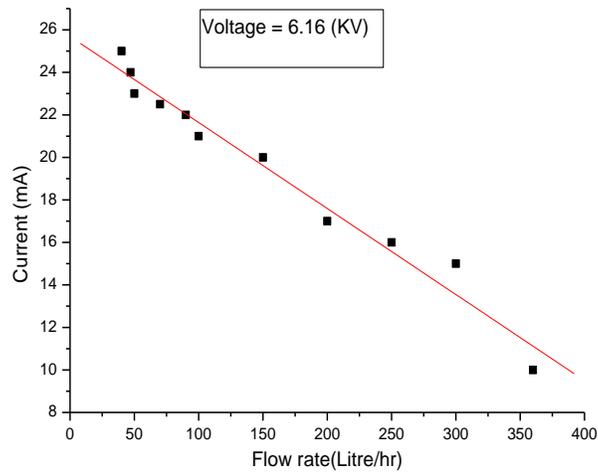


Figure 5: The relation between current and gas flow rate

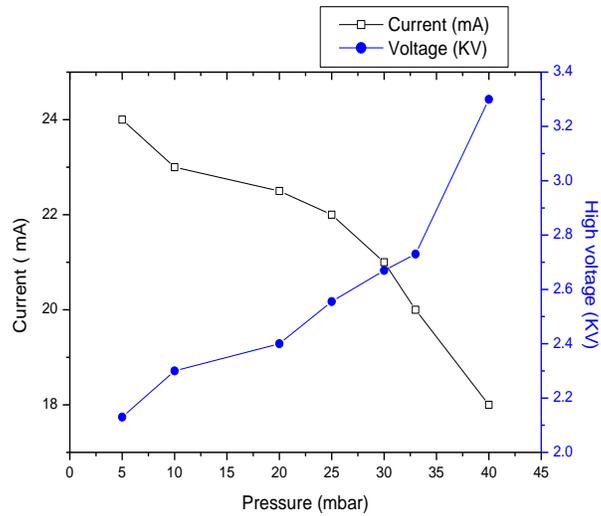


Figure 6: The relation between gas pressure, current and Voltage in the discharge tube.

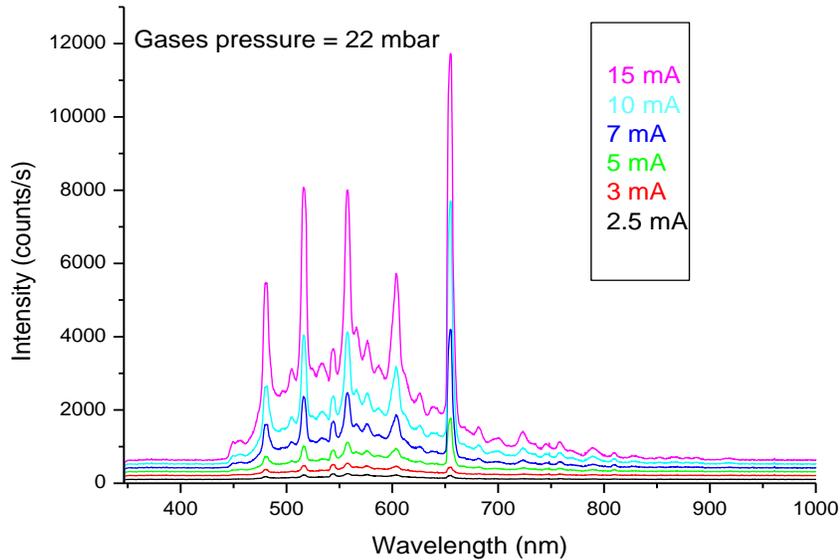


Figure 7: Spectra of discharge inside laser cavity with different values of current

4. CONCLUSIONS

In this work, a D.C. high voltage power supply designed and constructed for low pressure discharge was characterized successfully. The spectra of the glow discharge showed intensity variations against currents values, which indicates discharge regime stability. The constancy of the power supply output reveal a steady of high voltage and current variation with appropriate value of gases pressures and flow rates that is a sign of reliability of the system.

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