THE SIMULATOR OF POWER SUPPLY OPTIMIZATION FOR PULSED TEA CO2 LASER

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ABSTRAK

SIMULATOR UNTUK OPTIMISASI SUMBER DAYA LASER PULSA JENIS TEA CO_2. Cahaya laser CO2 telah digunakan untuk banyak aplikasi, terutama laser tipe TEA (Transverse Excited Atmospheric). Makalah ini membahas simulator untuk menoptimalkan sumber daya LASER tipe TEA CO2 sehingga keluaran LASER optimal. Metode optimisasi dengan men-simulasikan dan menganalisis rangkaian listrik sumber daya dengan menggunakan tool Simulink. Hasil penelitian merekomendasikan penggunaan konfigurasi yang sesuai untuk mencapai pulsa arus yang stabil dan maksimum, yaitu tegangan masukan pemicu 15 kV, tegangan breakdown spark gap (SG1) 22,8 kV, tegangan SG2 19,5 kV, tegangan SG3 134 kV, dan tegangan pemicu 8 kV. Periode pemicuan 0,05 s dan kapasitansi kapasitor C1 = C2 = (0,1 – 1) μF. Optimisasi sumber daya dimaksudkan untuk mendapatkan lebar pulsa lebih tinggi dari waktu hidup pulsa, yaitu pada rentang (109-106) detik, dan lebar pulsa arus laser diperoleh (0,7-1) μs.

Keyword: sumber daya, simulator, kapasitansi kapasitor, lebar pulsa laser

ABSTRACT

THE SIMULATOR FOR POWER SUPPLY OPTIMIZATION OF PULSED TEA CO_2 LASER. The CO2 laser light has been widely used for many applications, especially for TEA (Transverse Excited Atmospheric) modes. This paper aims to optimize the simulator which generates the power supply of pulsed TEA CO2 laser so that can provide the optimum laser output. The method study was done by simulating and analyzing the electrical circuit from the power supply of TEA pulsed CO2 laser into a dynamic mathematical form, by making the power supply simulator using Simulink. The results obtained, recommend the use of appropriate configuration to achieve the pulse of current is stable and maximum, namely 15 kV input voltage, breakdown voltage of spark gap (SG1) of 22.8 kV, SG2 = 19.5 kV, SG3 = 134 kV, and 8 kV trigger voltage, trigger period of 0.05 s, and capacitance values of capacitors C1 = C2 = (0.1–1) μF. Optimization of power supply is intended to get the laser pulse width is higher than the laser level life time at the order of (109 – 106) seconds, and laser currents pulse width obtained from (0.7- 1) μs.

Keyword : power supply simulator, capacitance of capacitor, laser pulse width.

INTRODUCTION

Laser is an acronym stands for "Light amplification by stimulated Emission of Radiation", which means that strengthening the stimulation of light emission of radiation[1]. In contrast to the light source in general, the laser has unique characteristics which are monochromatic, coherent, and high power.

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Laser has been widely used in various fields, both in the field of science, medical, or industrial field. In the field of science, laser may be used in many applications such as for spectroscopy. Spectroscopy is often used in laser ionization experiments and isotope shifts. In the medical field, laser can be used among others for the treatment of nerve and tissue dissection. In industry, among others, the laser can be used for materials processing, communications, army weapons, steel cutting, and drilling.

This research used laser gas with amplification medium with a gas mixture of CO2, N2, and He, and the energy pumping was done electrically or electrical discharge. For generating an electrical pulse was done by using Mark-Bank generator where it is effective as laser power supply. The quality of electrical pulse is determined by the condition of capacitor circuit in the Mark Banks generator. For settings the excitation of laser medium is determined by an electrical pulse which is produced by Marx Banks generator on spark-gap. With the optimization of electronic circuits in generator that includes input voltage, voltage trigger, and capacitance of capacitor, can be obtained the optimal laser action.

This research will provide a simulation optimization of electronic circuits on power supply to obtain the optimum laser output. The indicators of success is obtained by optimizing the laser output and the pulse shape with a Gaussian spectrum with a short and high bandwidth. The optimized variables are voltage input, voltage trigger, and capacitance of capacitor circuits from laser power supply. Simulation was done by using Matlab 7.0.1. This program provide adequate computing facilities which are able to visualize the results of programming.

THEORY

The occurrence of laser discharging process depends on voltage, capacitance, electrode spacing and gas composition. So it can be found the best conditions for laser operation using a particular specification of voltage and capacitance.

Laser delay time is needed by the electrons at the excitation level to decay by emitting a photon into deexcitation level. Lasers delay time indicated when the interval between the time series began to be operated until the appearance of the laser pulse.

Laser time delay occurs because the excitation is due to three factors:

1. A diffraction loss in the cavity, mainly due to fluctuations in the refractive index, from the heat would be generated from the discharge.
2. A life time each variation at each level of vibration excitation.
3. Density of molecules at each excitation level.

These three factors are influenced by the gas mixture when used and parameters of circuit [2].

A series of CO2 laser that is used in the research is a pulsed TEA CO2 laser which can be operated at atmospheric pressure. TEA is an abbreviation for Transversely Excited Atmosperic which can be interpreted as an excitation that occurs in the direction perpendicular to the optical axis at atmospheric pressure[3].

A scheme of a series of pulse TEA CO2 laser can be simplified (Widdi Usada, 2010) to explain the process that occurred in the laser action as Figure 1.

High voltage source through a resistance R provids limiting currents fill the capacitor C. When the spark-gap is flown by a negative voltage pulse, then the capacitor energy C will be conveyed to the laser tube. Thus, corona discharge occurs between the electrodes in the laser tube (marked in blue color on laser tube), and due to the resonator it will be obtained a CO2 laser light pulses.

Gas discharge (corona discharge) will occur if the voltage provided on pin helical electrode. A high voltage consists of two main parts, namely the voltage rectifier and spark-gap discharge in Marx-Bank circuit.

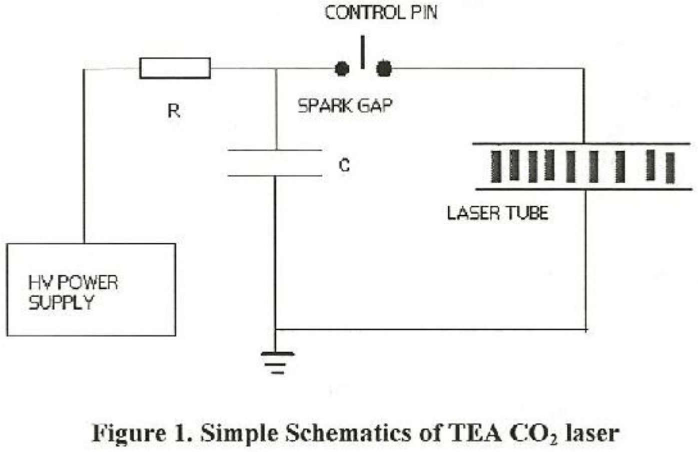

Figure 1. Simple Schematics of TEA CO_2 laser

Marx-Bank circuit voltage has been given by turning the dial potensio until the spark-gap on Marx-Bank circuit discharge and drain the voltage into electrode helical pin.

There are six factors to ensure the process of corona discharge in the laser tube and produce the laser light are taken place, those are: (1) gas pressure, (2) the distance between the pin electrode, (3) the occurrence of breakdown voltage which means it has fulfilled the requirements Paschen, (4) it is required electrode spacing and pin at spark gap, (5) negative voltage control spark gap, and (6) capacitor voltage.

Paschen formula is formulated (for air filling and for other gases are considered almost same) by Equation (1):

$$V_{breakdown} = \frac{365.p.d}{\ln(p.d)+1.18} \qquad (1)$$

where p is the pressure (torr), and d is the distance (cm).

Therefore if it is known about distance between the pin electrodes in the laser tube and gas pressure can be estimated the breakdown voltage. If the breakdown voltage of spark gap is exceeded, it will lead to a discharge in the laser tube and it is marked by the appearance of blue color.

The mechanism principle of power supply circuit at part of focusing and multiplier voltage are shown in Figure 2.[4] The capacitors C1 and C2 is filled from the source voltage Vin through ballast resistance R1 and R2. Because of the charging process the voltage at point A and B will be equal to the voltage Vin, while points C and D are voltage grounding. Between points B and C mounted a spark gap (SG1) the value of its voltage below the voltage of Vin (VSG1≤Vin). When the value of B greater than the value of breakdown voltage of spark gap (SG1), then the capacitor C2 will loose its cargo so that the SG1 will discharge. The capacitor C2 will discard its cargo to earth through the SG1 and resistor R3, so the voltage to earth voltage (VB≤0V). Discharge time value = R3C2. Because of discharging process SG1, then the voltage at point C is equal to Vin, so the voltage at A becomes 2 Vin, when it measured against the ground. Between point A and the laser tube there is spark gap (SG2) and large voltage is 2 Vin . When the voltage exceeds in A breakdown voltage greater than SG2 will discharge and charge on C1 will be released through SG2 to laser tube as value = 2 Vin . The output voltage is almost twice the voltage Vin. Output voltage will be pulsed, because of discharge in both spark gaps do not occur continuously, but after the capacitor is fully charged and release the charge. Because charging capacitor depends on time, then the spark gap discharge also depends on time.

A charge released by spark gap discharge will collide gas particles and transfers the energy to gas molecules N2, so that N2 molecules will be excited to a higher level. At this level, the N2 molecule will release the energy to the CO2 molecules having molecular vibration-rotation energy state to get a stability state, and then it will be issued a number of laser light.

Simulink contains several sets of blocks for a specific purpose. Simulink blocks were useful for designing and simulating control systems, analyzing the stability, and strengthening the system. Designing systems with Simulink, have been done by dragging and dropping. Each function blocks can be drag and drop in design window. After all the blocks needed are completed, it will be connected with virtual wires.

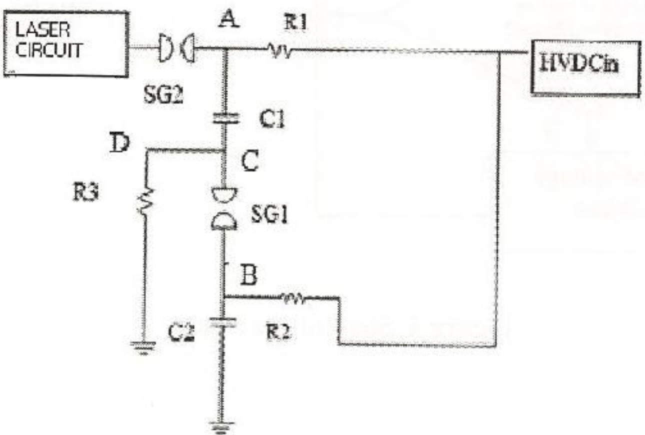

Figure 2. Part of Focusing and Multiplier Voltage for Power Supply of TEA Pulsed CO_2 Laser.

METHODOLOGY

This study was done at voltage multiplier and focusing in Figure 2 by varying the parameters of power supply, among others, the capacitance of capacitors, variations of the input trigger voltage, and trigger period. Figure 3 shows a flowchart of of research. A power supply circuit simulator is built using Simulink of Matlab 7.0.1, can be seen in Figure 4.

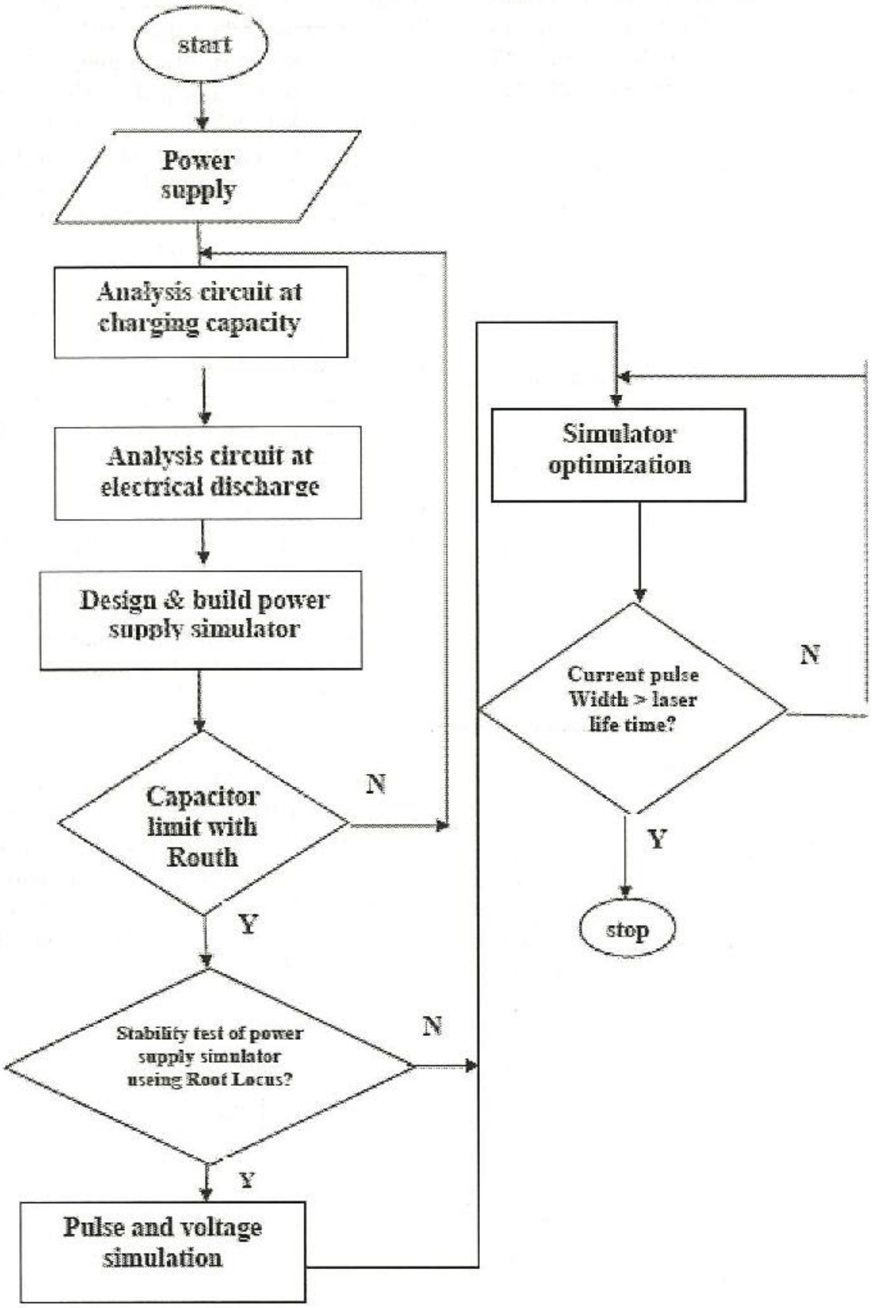

Figure 3. Steps of Research

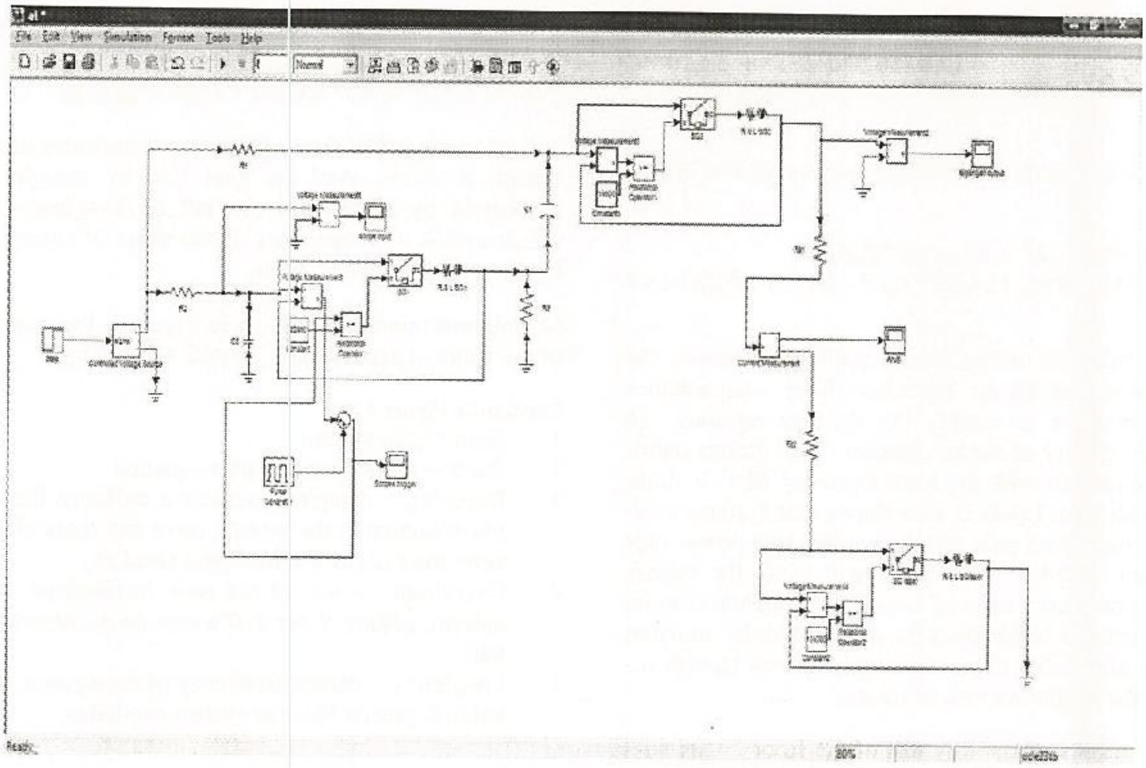

Figure 4. Chart of Power Supply Simulator

RESULTS AND DISCUSSION

Currents Analyze at Dischage on Power Supply

The discharge event occurs when the spark gap (G1) reaches its breakdown voltage, and electric field formed as a series circuit between the plasma inductance and resistance which each having around 17 nH and 0.1Ω. Circuit diagram becomes as Figure 5.

When the loop method is used to solve circuit analysis, there are two loops (I1 and I2) flowing in the circuit, such as Figure 5. At the time of discharge, the impedance at the SG1 is seen as a combination of series connections between L1 and Rs1, the impedance at the SG2 is seen as a combination of series connections between the L2 and Rs2, and the impedance at the SG2 is seen as a combination of series connections between L3 and Rs3, plus the resistance of Rk1 and Rk2, which is derived from the cable resistance.

With the circuit parameters as follows :

$R_3 = 10^5\ \Omega$
$L_1 = L_2 = L_3 = 17.10^{-9}\ H$
$Rs_1 = Rs_2 = Rs_3 = 0{,}1\ \Omega$
$Rk_1 = 5\ \Omega$
$Rk_2 = 0{,}001\ \Omega$

and the current flowing in the laser output circuit is I2. We propose a Dirac function and constant □. The Dirac (t) is an impulse function with high in infinity and pulse width is close to zero, while □ is a constant whose the value can be known if the count by changing the variable capacitor (C) on the output voltage. by comparison of output voltage against input voltage is :

$$\frac{V_{out}(t)}{V_{in}(t)} = 0.5\,dirac(t) + f(\alpha)$$

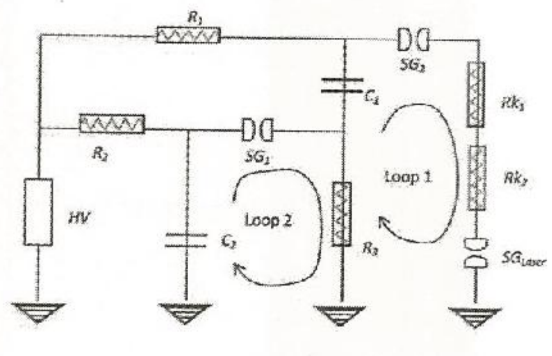

Figure 5. Loop I_1 and I_2 in a series of power supply of pulsed TEA CO_2 laser during discharge

Stability Test of Simulator Laser Power Supply

It is necessary in determining the appropriate limits the values of capacitance of capacitors used in power supply circuit in order to obtain a stable circuit. Limitation capacitance capacitors were completed using the Routh method.

Transfer function of power supply simulator :

$$G(s)=\frac{(2{,}89.10^{-16}C^1C^2s^4+3{,}4.10^{-3}C^1C^2s^3+(10^6C^1C^2+1{,}7.10^{-8}C^1)s^2+5C^1s)}{(5{,}78.10^{-16}C^1C^2s^4+5{,}1.10^{-3}C^1C^2s^3+(3{,}4.10^{-8}C^1+1{,}7.10^{-8}C^2)s^2+(10^5C^1+10^5C^2)s+1)}$$

Characteristic equation for the closed-loop system with H(s)=1 is :

$$8{,}67\times10^{-16}C_1C_2\,s^4+8{,}5\times10^{-3}C_1C_2\,s^3$$
$$+(10^6C_1C_2+5{,}1\times10^{-3}C_1+1{,}7\times10^{-8}C_2)\,s^2+(10^5C_1+10^5C_2)s+1=0$$

From calculations using Routh stability criterion, the result shows that all the capacitors have a capacitance value is positive, so satisfy the stability equation. To prove the stability of the calculation of the Routh stability test conducted with the Root Locus by Matlab simulation. With Root Locus is also shown that systems analysis was done with gain control applied to a power supply system, whether these gains will make the system stable or not. Root Locus of completion method is more efficient using Matlab because of the transfer function G(s) in a high order of power supply system (fourth order), but the results are also accurate.

From the results of stability test of the Root Locus with Matlab simulation is known that all closed-loop pole is located to the left of the imaginary axis indicates that the system is stable. And the gain line by straight line movement by staying on the left of imaginary axis, which means that regardless of the value of strengthening the system remains stable.

Matlab execution can be seen in Figure 6 for examples of the value of capacitance C1 = C2 = 0.0003 μF.

Caption for Figure 6 are :

1. Gain = gain system
2. Poles = roots characteristics equation
3. Damping = damping coefficient indicates the level of oscillation in the system, more and more close to zero, the system will oscillates (broken)
4. Overshoot = size of the peak oscillations in the system, getting closer to 0% then no oscillation system
5. Frequency = natural frequency of the system, if the value is greater then the system oscillates

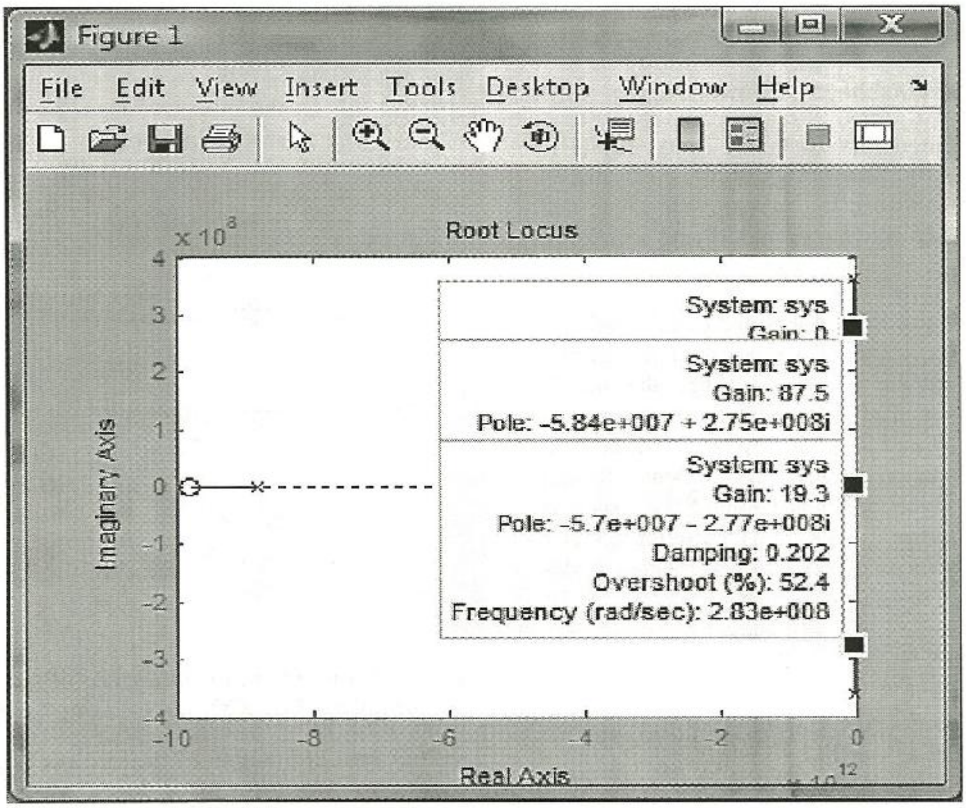

Figure 6. Root Locus for Values $C_1 = C_2 = 0.0003$ μF

Optimizing Power Supply Simulator for TEA Pulsed CO2 Laser

From the simulation data pulse of current and voltage can be concluded that:

1. The higher input into circuit make the pulse of current will be higher
2. The use of triggers, in addition useful to trigger a pulse are also to set the appearance of pulse
3. Region of stable pulses and maximum (if no trigger is used) is reached on the capacitance $C_1 = C_2 =$ (0.01-1) μF
4. Region of stable and maximum pulses (if used trigger) is reached on the capacitance ($C_1 = C_2$) greater than 0.1 μF, but the high pulse currents depending on the period used trigger
5. Appropriate capacitance value for a given value of the voltage pulse did not result in the occurrence of current oscillations
6. No occurrence of pulse current on the order of capacitance in micro-farads because input voltage only continue to fill capacitor and does not reach the full circumstances, so that the capacitor never losing its cargo.
7. Highest maximum pulse currents obtained when the maximum input voltage with a minimum trigger

So the CO2 laser simulator with the parameters as follows :

1. Step input signal with an amplitude of 15 000 volts
2. Voltage DC input voltage
3. Prisoners ballast resistor $R_1 = R_2 = 100$ kΩ
4. Capacitance $C_1 = C_2 =$ (0.1-1) μF
5. 8000 volt trigger voltage, trigger period of 0.05 s
6. Constant breaker-1 of 22800 volt, constant breaker-2 19500 volts, constant breaker-3 134000 volt
7. $R_3 = 100$ kΩ
8. Inductance and resistance of breaker-1 17 nH and 0.1 Ω
9. Breaker-2 inductance and resistance of 17 nH and 0.1 Ω
10. Cable resistance Rk_1 5 Ω, and Rk_2 0.001 Ω
11. Breaker-3 inductance and resistance of 17 nH and 0.1 Ω
12. 1 s simulation

Below is a capacitance simulation using the simulator for data of C1 = C2 = 0.1μF : Results:

1. Input voltage rises from 15 000 volts, and discharge at 0.15 s (Figure 7)
2. Trigger pulse triggers the input voltage to achieve Constant of *breaker*$_1$, a trigger pulse appears periodically every 0.05 s (Figure 8)
3. At the output there is a discharge voltage at 0.15 s (Figure 9)
4. It was formed with high pulse current in 2274 A ((Figure 10)
5. Pulse width of the plot pulse of current for 700 ns (Figure 11)
6. Gaussian shaped pulse of current pulses

Scope input voltage:

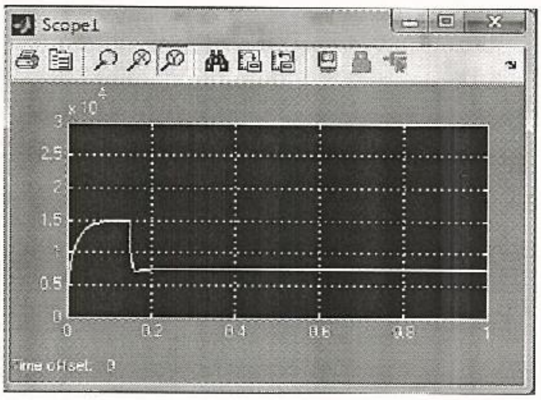

Figure 7. Voltage Input Capacitor Capacitance of 0.1 μF

Scope trigger voltage:

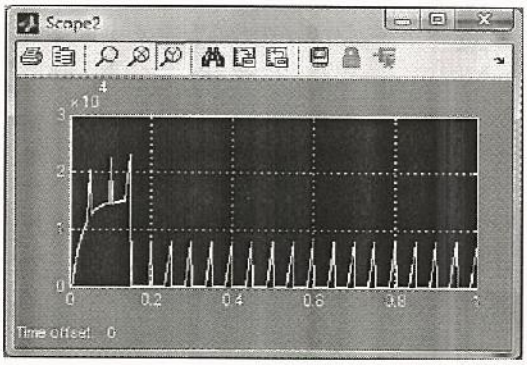

Figure 8. Trigger Voltage Capacitor Capacitance of 0.1 μF

Scope of output voltage:

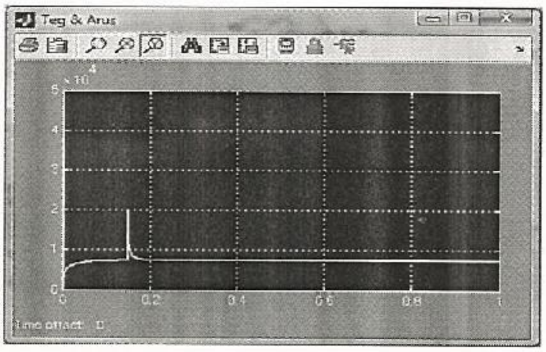

Figure 9. Voltage Output Capacitor Capacitance 0.1 μF

Scope of pulse current:

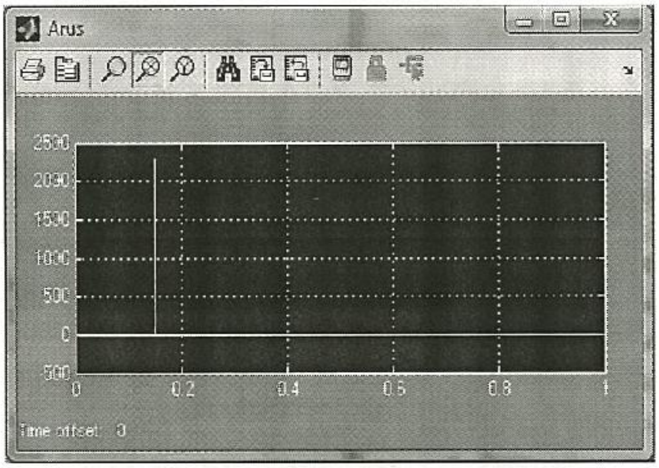

Figure 10. Current Pulses Capacitor Capacitance of 0.1 μF

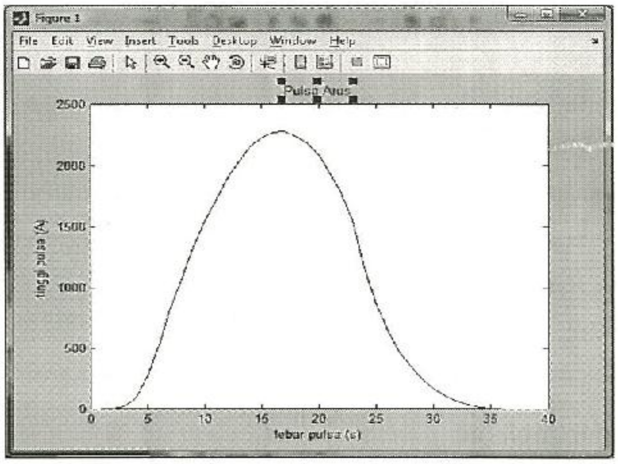

Figure 11. Currents plot of Gaussian Cistribution Capacitor Capacitance of 0.1 μF

High currents graph with current pulse width:

Figure 12 shows the relationship between capacitance capacitor and current pulse width.

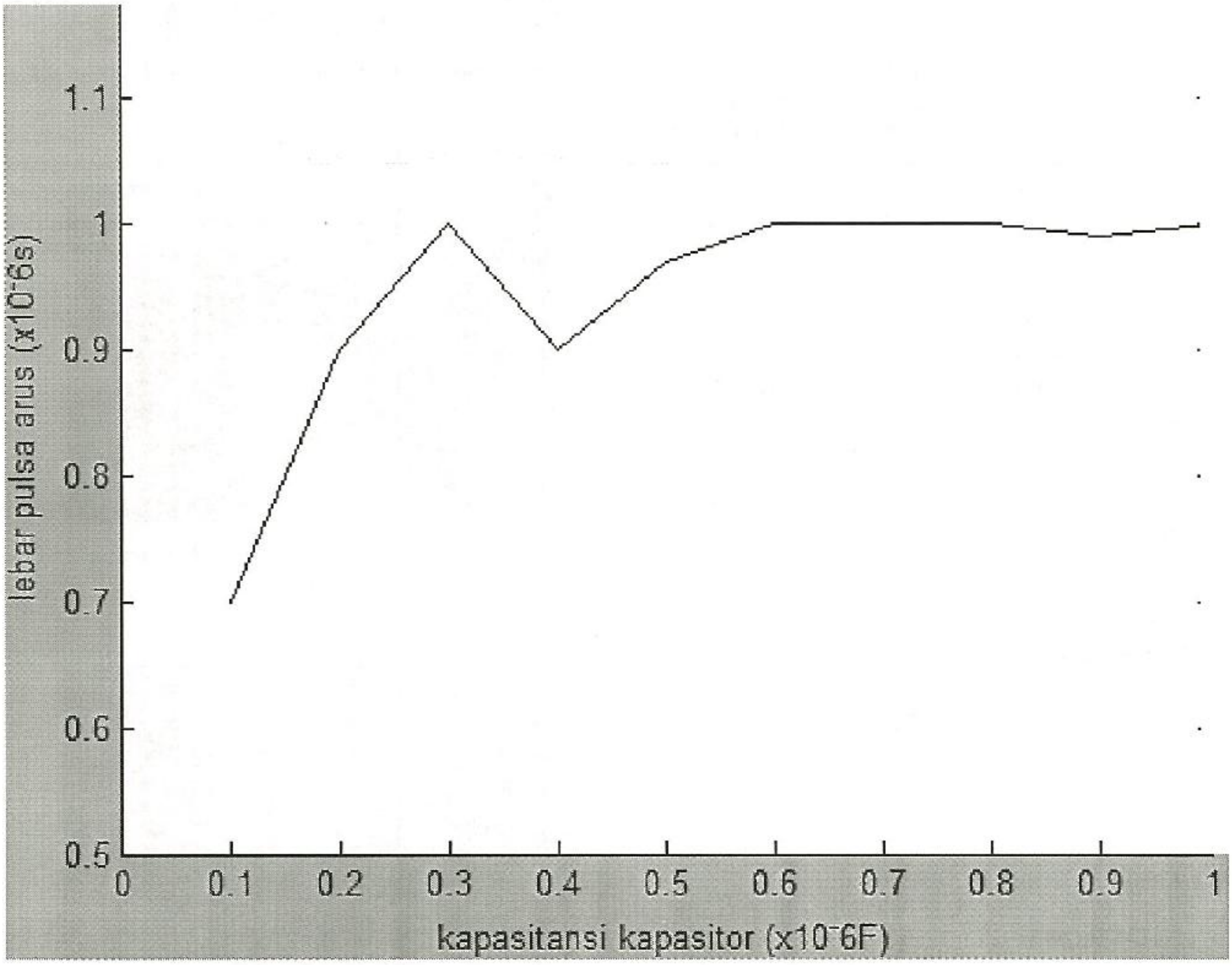

Figure 12. Relationship between capacitor capacitance and current pulse width

For improvements the research in the next, the suggestion are completetition of the simulator power supply in determining the brekdown voltage SG1, SG2, SG3 in order to be considered in gas pressure due to the gas mixture and the determination of the plasma inductance and resistance using Rogowski probe and improvements in determining the parameters of the power supply circuit in order to note the possibility of paralleled the component with another component instance capacitors with resistors, it is likely due to the wire temperature is too high because of large currents flowing in the circuit are also considered noise problems that may arise if the temperature wire is too high

CONCLUSION

Based on data from the analysis of power supply simulator about characteristics and optimization of pulse current, it can be concluded that :

1. Appropriate configuration to achieve maximum pulse currents are stable and maximum, from the research data obtained 15000 volt input voltage, breakdown voltage SG_1 = 28800 volts, SG_2 = 19500 volts, SG_3 = 134000 volts, 8000 volts trigger voltage, trigger period 0.05 s, and the capacitance of capacitor $C_1 = C_2 = 0{,}1$ to 1 μF
2. Optimization of power supply is intended to get the laser pulse width is higher than the life time of laser of the order of nano to the micro second. And the current and laser pulse width obtained from 700 ns to 1 μs

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