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Construction of a Tunable Repetition Rate Nd: YAG Laser System

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Abstract

The aim of this work is to study the design and construction of an Nd:YAG laser system to produce a tunable repetition rate in a laboratory scale. Electronic circuits and the resonator were both built to achieve lasing action of TEM_{00} mode, passive Q- switched and tunable repetition rate, this work also includes the construction of the cooling system which consists of heat exchanger and water pump. Laser peak power was measured to be 10 MW, with a pulse width of 10 ns and a tunable repletion rate between (0.5 - 10) Hz by steps of 0.5 Hz.

Keywords: Nd:YAG laser; Passive Q- switch; Repetition rate.

1. Introduction

In various applications of repetition pulsed Nd:YAG lasers, a lot of attention is being paid to the quality of the beam profile [1]. This is particularly true in applications which require a constant spot size during laser processing. If a laser rod is pumped homogeneously on its surface, a parabolic temperature profile, and therefore a refractive index gradient from the centre to the surface of the rod, is built up. The Nd:YAG rod works like a focusing lens, whose focal length varies at different pumping powers. The general steady-state temperature distribution in a solid is given by the three-dimensional Poisson equation. For the axisymmetric case of a rod with constant heat conductivity this equation reads in cylindrical co-ordinates as follows [2].

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$$\frac{d^2}{dr^2}T(r,z)+\frac{1}{r}\frac{d}{dr}T(r,z)+\frac{d^2}{dz^2}T(r,z)+\frac{q(r,z)}{K(T)}=0 --------(1)$$

where *q(r, z)* is the heat source density and *K(T)* is the heat conductivity in the rod. For crystals with a moderate temperature rise, such as Nd:YAG, *K(T)* is normally assumed to be constant. For crystals with lower heat conductivities and hence, higher heat loads, *K(T)* is given in the first approximation by[3].

$$K(T)=K_0\frac{T_0}{T_0+\Delta T} ------------------------(2)$$

where T_0 indicates the reference temperature of the cooling water, ΔT the difference to T_0, and K_0 the heat conductivity of the solid at T_0.With the boundary condition *T(r0)* for $r = r_0$, where $T(r_0)$ is the temperature at the surface of the rod and r_0 is the radius of the rod, it follows that

$$T(r)=T(r_o)+\left(\frac{Q}{4K}\right)\left(r_o^{\,2}-r^2\right) ---------------------(3)$$

where Q is a rate per unit volume in which heat is uniformly generated, which can simply be given by

$$Q=\frac{P_a}{\pi r_o^{\,2}L} --------------------------------(4)$$

Where the power P_a is the total heat dissipated in the rod and L is the length of the rod.

The parabolic temperature and phase error profiles by uniform heating was first studied by Koechner in uniformly pumped Nd:YAG rods. Then many researchers carried out further researches on the thermal effects. It is found that the temperature gradients generate mechanical stresses, strains, and displacements in the rod. Furthermore, the inhomogeneous distributions of temperature, strain, and displacement cause a change of the refractive index at each point of the rod. Since the refractive index in a laser rod shows a quadratic variation with radius, an optical beam propagating along the rod axis would suffer a quadratic spatial phase variation. This perturbation is equivalent to the effect of a spherical lens, called “thermal lensing effect” or “thermal lens”. Since the change of refractive index due to thermal strain is dependent on the polarisation of light, the focal lengths of the thermal lens for the radial (f_r) and tangential orientations (f_ϕ) are given, respectively by [4].

$$f_r=\frac{KA}{P_a}\left(\frac{1}{2}\frac{dn}{dT}+\alpha C_r n_o^{\,3}+\frac{\alpha r_o(n_o-1)}{L}\right)^{-1} ----------------(5)$$

$$f_\phi=\frac{KA}{P_a}\left(\frac{1}{2}\frac{dn}{dT}+\alpha C_\phi n_o^{\,3}+\frac{\alpha r_o(n_o-1)}{L}\right)^{-1} ---------------(6)$$

2. Laser system Construction:

In this work an Nd: YAG laser system has been constructed. It consists of two main parts:

2.1 Laser Cavity

The laser cavity is shown in figure (1) which consists of

Figure1: Laser Cavity

2.1.1 Laser Resonator

The optical resonator consists of two mirrors M1 and M2 with radius of curvature of R1 and R2 respectively. In the resonator, the radius W_0 of the beam waist. The spot size W1, and W2 can be expressed as a function of the equivalent resonator parameters [5, 6] .

$$W1 = \left(\frac{\lambda L}{\pi}\right)^{\frac{1}{2}} \left[\frac{g_2}{g_1(1-g_1 g_2)}\right]^{\frac{1}{4}} \text{---------------------} (3-6)$$

$$W_2 = \left(\frac{\lambda L}{\pi}\right)^{\frac{1}{2}} \left[\frac{g_1}{g_2(1-g_1 g_2)}\right]^{\frac{1}{4}} \text{-----------------------} (3-7)$$

$$W_o = \left(\frac{\lambda L}{\pi}\right)^{\frac{1}{2}} \left[\frac{g_1 g_2(1-g_1 g_2)}{(g_1+g_2-2g_1 g_2)^2}\right]^{\frac{1}{4}} \text{--------------------} (3-8)$$

The optical resonator used in this experimental work hemispherical resonator consists of these parameters:

- Convex mirror M2 : Radius of curvature ROC=0.8m & Transmittance =54% to 1064 nm, and have the dimensions is($\phi = 6mm$).
- Plan mirror M1: Radius of curvature ROC= ∞ & Reflectivity=99.9% to 1064 nm

- Cavity length (L) =100mm

A hemispherical resonator has the best alignment stability of any configuration; therefore it is often employed in low power laser. To define resonator stability on the g_1 g_2 stability .In this experimental work the beam waist equal (0.227) mm when used this parameters: $L = 100mm , \lambda = 1064nm$

2.1.2 Active medium

In this experimental work used an Nd:YAG crystal active medium. Both ends of the crystal are parallel, and AR coated for the 1064nm.The dimensions of this crystal is($5X\,50mm$)which is shown in figure (2).

Figure 2: Laser rod

2.1.3 Q- Switches

Bleachable dyes are available as thin films on glass substrates or as liquids in glass "windowed" cells. See Figure (3) . For Q-switching, a dye cell is placed in the laser cavity between the amplifier and the maximum-reflectivity mirror[7 ,8]. The dye absorbs the laser wavelength very strongly at low light intensities presenting a very high cavity loss to the laser and preventing lasing until the amplifier has been pumped to a high gain state. When the fluorescence from the active medium becomes intense enough, the energy that is absorbed by the dye optically pumps the dye material causing it to be "transparent" at the laser wavelength. Now the dye cell is "bleached" and no longer represents a high cavity loss to the laser [9]. The "bleaching" of the dye is the equivalent of Q-switching in the laser, and it can occur in a period less than a nanosecond.

Figure 3: thin film Q-switch

2.2 Laser Power Supply

A typical pulsed solid state laser power supply consists of three parts which are shown in figure (4).

2.2.1 Pulse Forming Network (PFN)

This is really the heart of the SS laser power supply and includes the main energy storage capacitor or capacitor bank, and components to control the discharge duration and peak current through the flash lamp

2.2.2 Capacitor charging unit

A mean of charging the main energy storage capacitor(s) in the PFN. These will have both a maximum voltage rating and a power rating in watts or J/second. The voltage rating is obviously critical to achieve full power but also to prevent destruction of the energy storage capacitor(s) by exceeding their voltage ratings. The power rating determines the maximum pulse repetition rate (prr) of the laser.

2.2.3 Trigger circuit

A mean of initiating the discharge of the xenon flash lamp. Three types are commonly used: external (or proximity) and series or simmer mode, in this paper used simmer mode because high stability and low jitter time.

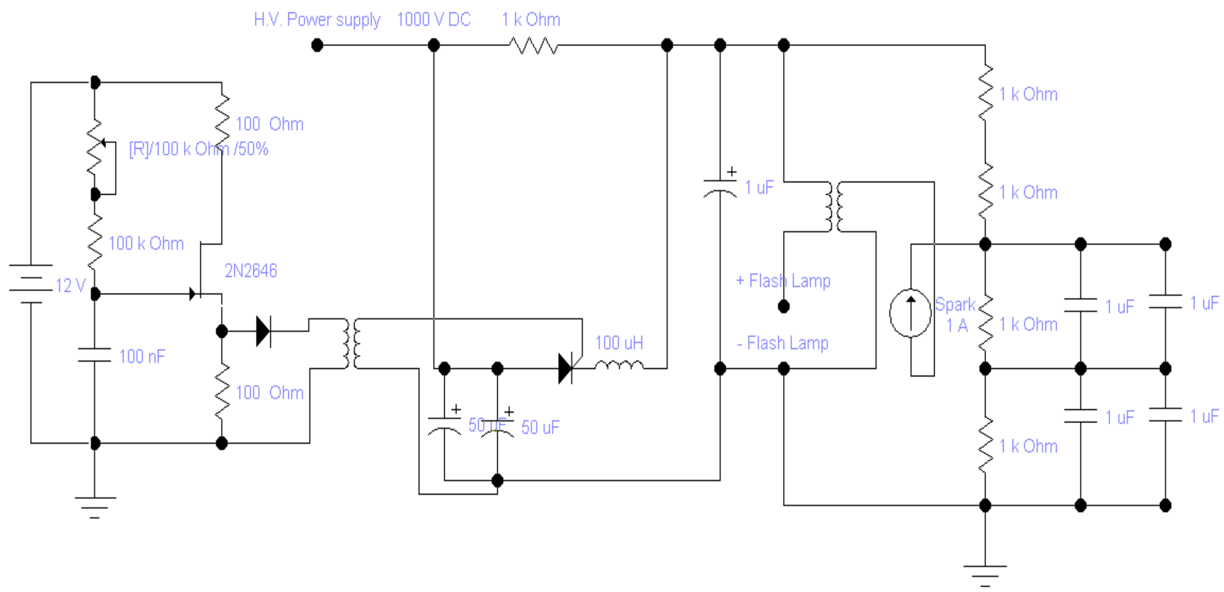

Figure 4: Laser power supply

2.3 Cooling System

The cooling system is one of the most critical subsystems in the laser. Smaller lasers may use open-loop cooling systems with tap water flowing across the rod. In such cases, the water should be filtered to remove any contamination or impurities. Larger systems use closed-loop cooling with water or a water-glycol solution. The coolant is usually refrigerated, but water-to-water or water-to-air heat exchanger may also be employed [10]. The cooling fluid circuit begins with the laser rod for maximum rod cooling. The water then flows across the lamps and the laser cavity. A flow switch is generally included to turn off the lamp power if the water flow is interrupted. Loss of cooling will quickly destroy seals, lamps, and the laser rod itself. Lasing in Nd:YAG is dependent upon rapid transitions from the lower lasing level to the ground state by radiationless transitions. These transitions occur at a high rate only if the rod temperature is low. Thus, lasting efficiency depends very highly upon the cooling efficiency. Lasing action will cease entirely before the rod temperature is high enough to damage the rod, and lower operating temperature could result in higher output powers. If the cooling water is too cold, however, condensation will form on the laser head and optical surfaces. This can lead to problems and should be avoided. Cooling systems are generally operated at temperatures just above the threshold of this effect. Figure (5) shows the cooling system constructed and used for this work.

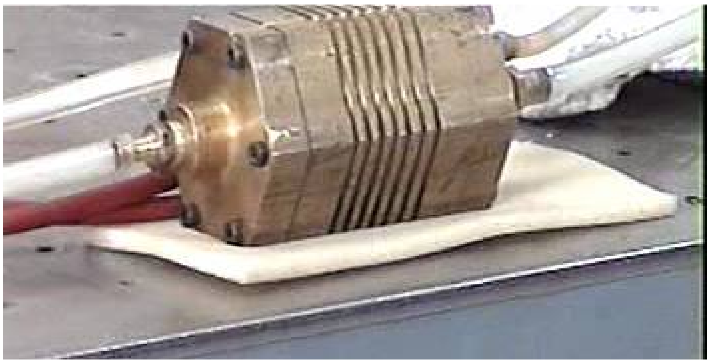

Figure 5: Cooling system

3. Experimental Results

3.1 The optical Energy of the laser output was measured using the Gentec-ED-200 meter. The meter is capable of measuring high power in the IR range of the optical wavelengths. Using the meter, the optical energy was found to be 100 mj shown in figure (6).

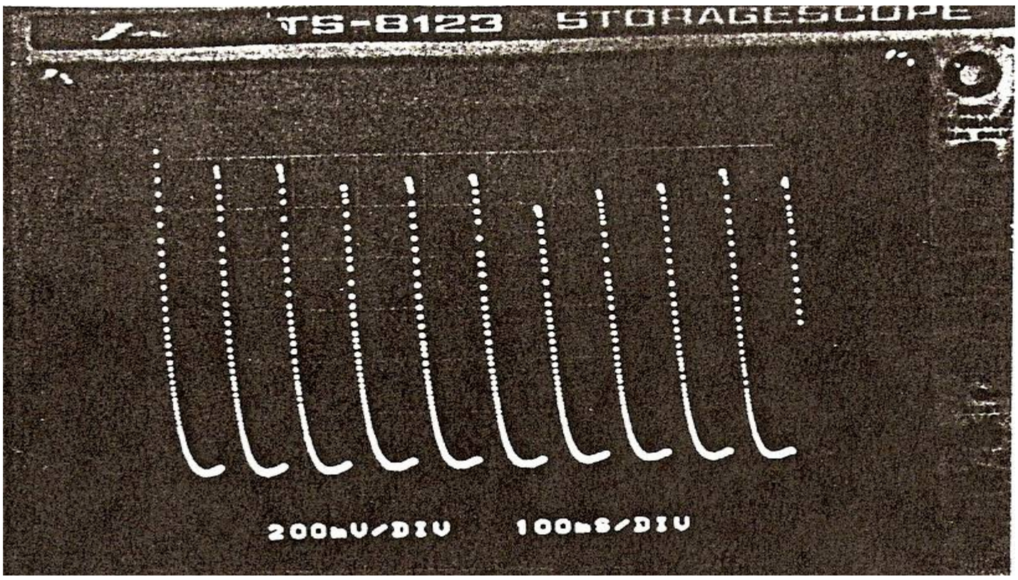

Figure 6: Repetitively Pulsed laser

3.2 A laser pulse at a low pulse repetition rate (1 PPs) was recorded in sensitive paper shown in figure (7).

Figure 7: Low Repetitively Pulsed laser

3.3 Laser pulses at a high pulse repetition rate (10 PPs) were recorded in sensitive paper shown in figure (8).

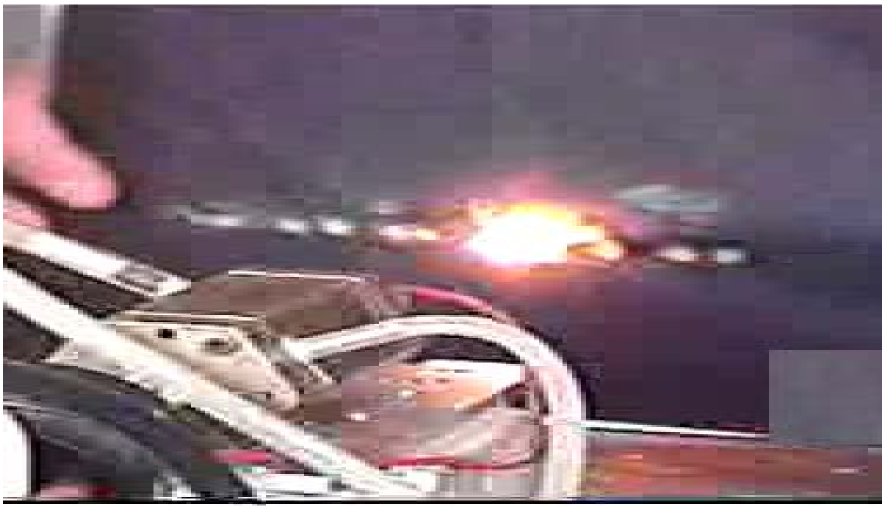

Figure 8: High Repetitively Pulsed laser

4. Conclusions

The Q-switched pulsed laser system construction in the laboratory demonstrated successfully in generated short laser pulses with low and high repetition rates and it shows a high stability output parameters.

References

[1] Brian J. , 2007, Solid-State Lasers and Applications ,by Taylor & Francis Group, LLC,New York.

[2] Breck H. ,2001, Introduction to laser technology ,Third Edition, The Institute of Electrical and Electronics Engineers, Inc., New York

[3] Tam S. ,2001 , Calculation of optical parameters in laser engraving of photomasks, School of Electrical & Electronic Engineering Nanyang Technological University Nanyang Avenue, Singapore 2263.

[4] Koechner W. , 2006, "Solid state laser engineering" Springer-Verlag, Berlin, 6th edn.

[5] Svelto O. ,1998 , Principlles of Lasers, (forth edition),Plenum Press, New York**.**

[6] Jassim M. Jassim , 2014, Performance of free-running end -pumped Nd:YAG laser system, Advances in Physics Theories and Applications, 34.

[7] French P., 1995 ,The generation of ultrashort laser pulses, Rep. Prog. Phys. 58, 169–267 9, 10, 13

[8] Liu, J., 2001, Modeling pulse shape of *Q*-switched lasers, IEEE J. Quantum Electron. 37, 888.

[9] Jassim M. Jassim , 2010 , Design and Characterization of V^{3+}:YAG Passive Q- switched end-pumped Nd: YAG Microlaser, Journal of Babylon University/ Pure and Applied Sciences,2 ,18.

[10] Mark T. 2003 , Development of a process for characterization of Nd:YAG crystals ,Degree of Master of Science in Mechanical Engineering.