DEVELOPMENT OF A WATER COOLING SYSTEM FOR Nd:YAG LASER CHAMBER

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Dedication to my beloved father and mother (Azahari Yusoff and Azizah Yaman),sisters, brother and all my friends.
Thanks for everything .....

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ABSTRACT

In solid state lasers, only a small fraction of electrical input power is converted to laser radiation. The remainder of the input power is converted to heat. Therefore, solid state lasers require cooling for the pump source and active medium. In the case of flashlamp pumping usage, a cooling system in the chamber is desirable. Without adequate cooling, the laser seals, pumping cavity, lamps and the rod itself would be damaged by overheating. Thus, the aim of this project is to develop a water cooling system such that the lowest practical operating temperature is produced, and to monitor temperatures of the laser chamber during the pumping process. In order to achieve these objectives, a refrigerated water cooling system was developed which included an internal and external water cooling system. Measurements of various parameters of this water cooling system were made in order to determine its appropriateness in solid state laser chamber. A laser chamber was set-up, which comprised of a Nd:YAG laser rod, flashlamp, chamber heat sink and stainless steel blocks. An aluminium laser house was designed inclusive with electrical and water piping system. After assembling the whole system, the circulation of water in the cooling system was tested. This is to ensure no leakage occurred during the pumping process. The flow rate of water during circulation is 9.83 ± 0.01 liter / min. The minimum temperature of the cooling system that could be achieved was $18.00 \pm 0.05\ ^{o}C$. The temperature distribution during pumping process was monitored at different points on the laser chamber. The information obtained leads to the calculation of heat dissipation from the laser chamber which operated with and without chilled distilled water. The comparison results shows that 20% improvement in heat liberated from flashlamp, whereas, 90% and 86% improvement in heat absorption in chamber heat sink and stainless steel blocks respectively. This indicated that the cooling system provided in the laser chamber was very effective in carrying out the excess heat from pumping process.

ABSTRAK

Dalam laser pepejal, hanya pecahan kecil kuasa masukan elektrik ditukarkan kepada pancaran laser. Lebihan daripada kuasa masukan ditukar kepada haba. Oleh itu, laser pepejal perlu penyejukan pada sumber pengepaman dan medium aktif. Dalam kes yang melibatkan penggunaan lampu kilat, sistem penyejukan dalam kebuk diperlukan. Tanpa penyejukan secukupnya, pelekat-pelekat dalam laser, rongga pengepaman, lampu dan rod laser sendiri akan rosak disebabkan oleh pemanasan berlebihan. Oleh itu, tujuan projek ini adalah untuk membina sistem penyejukan air supaya suhu proses terendah yang praktikal dihasilkan, dan juga untuk memantau suhu kebuk laser semasa proses pengepaman. Untuk mencapai objektif ini, sistem penyejukan air telah dibangunkan yang terdiri daripada sistem penyejukan dalaman dan luaran. Pengukuran pelbagai parameter sistem penyejukan air ini telah dilakukan dengan tujuan untuk menentukan kesesuaiannya dalam kebuk laser pepejal. Kebuk laser yang terdiri daripada rod laser Nd:YAG, lampu kilat, kebuk penebat haba dan blok keluli tahan karat telah dibina. Rumah laser aluminium juga dibangunkan yang lengkap dengan sistem saluran elektrik dan air. Selepas menggabungkan seluruh sistem, edaran air dalam sistem penyejukan diuji. Ini dilakukan untuk memastikan tiada kebocoran semasa proses pengepaman. Kadar aliran air semasa edaran diperolehi sebagai 9.83 ± 0.01 liter/ min. Suhu minimum sistem penyejukan yang dapat dicapai adalah 18.00 ± 0.05 ^{o}C. Taburan suhu semasa proses pengepaman dipantau di titik berlainan pada kebuk laser. Maklumat yang diperoleh digunakan untuk pengiraan haba dikeluarkan daripada kebuk laser dimana dikendalikan dengan dan tanpa penyejukan air suling. Keputusan yang diperolehi hasil perbandingan menunjukkan lebihan haba yang dibebaskan oleh lampu kilat dalam sistem yang disejukkan adalah 20%, sementara haba yang diserap oleh kebuk penebat haba dan keluli tahan karat masing-masing didapati bertambah sebanyak 90% dan 86% . Ini menunjukkan sistem penyejukan yang dibekalkan pada kebuk laser amat efektif untuk membawa keluar lebihan haba semasa proses pengepaman.

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LIST OF SYMBOLS

Q_o	-	Heat before
Q	-	Heat after
t_2	-	Time maximum
t_1	-	Time minimum
$\Delta\theta$	-	Temperature change
c_p	-	Specific heat
m	-	Mass
θ	-	Temperature
R	-	Water flow rate
v	-	Volume
t	-	Time
$P_{absorbed}$	-	Power absorbed
P_i	-	Power input
$\%P_{absorbed}$	-	Percentage of power absorbed

CHAPTER 1

INTRODUCTION

1.1 Overview

The first decade of solid-state laser technology has seen the development of an enormous number of lasing materials and a large variety of interesting design concepts. However, in recent years the technology has matured to a point where solid state lasers have reached a plateau in their development. To a major extent, the growth in importance of solid state lasers for industrial and military applications and as a general research tool are due to the improvement in reliability and maintainability of these systems. A wealth of applications for solid state lasers has emerged in materials processing, holography, range finding, target illumination and designation, satellite and lunar ranging, thermonuclear fusion, plasma experiments, and in general for scientific work requiring high power densities (Koechner, 1976).

A solid state laser system contains, for its lasing element, a ruby, Nd-YAG, Nd-glass or the like. Solid state lasing elements are fabricated into solid cylinders of various lengths and diameters. The rods are optically transparent and the ends are cut flat and parallel to each other. The end surfaces are polished very highly and coated with a reflective material. These laser elements are optically pumped (illuminated) by a high intensity flashlamp or krypton-arc or tungsten halogen lamp. Some of these lasers operate in the pulsed mode and others operate in both pulsed and continuous wave modes. They are cooled either by air or tap water circulating through the laser head, which includes flashlamp (Muncheryan, 1983).

In all solid state laser elements, the excitation to emission occurs in the dopant, for example the dopant is neodymium ions in the YAG lasers. The energy of radiation from the flashlamp is at least equal or greater than the energy of the photons produced in the respective dopant. The excited atoms are raised to a higher than normal quantum state (energy state) from which they return to the ground state in steps, emitting photons of wavelengths characteristics of the dopant. The greater the energy applied to the dopant from the optical pump the greater is the intensity of the emitted radiation; this stimulating energy does not alter the frequency of the radiation from the particular dopant. Because the photons in the lasing cavity are produced by equal-energy photons, any two photons in the cavity are of the same phase, frequency, amplitude and direction. When the energy from the optical pump is not sufficient to excite the dopant atoms to radiation, the energy in transition may dissipate in the form of heat or photons. This condition elevates the temperature of the laser rod; the elevated temperature in the rod tends to reduce the photon emission. So that, to prevent from overheating, the lasing rod is cooled either by circulation of air or distilled water through the laser head (Muncheryan, 1983).

Since Nd:YAG laser is the most powerful laser in this category, our study will be directed to a system containing a Nd:YAG laser rod in the laser head. Thus, it is important that during the planning stages of a laser system, careful measurement includes water temperature, quality and flow rate must be made to provide a suitable cooling system (Muncheryan, 1979).

1.2 Thermal Loading of lamp-pumped Nd:YAG Lasers

Consider a typical continuous wave (cw) Nd:YAG laser with an output power of 300 watts and input power of 12 kilowatts. Assuming a quantum efficiency of 50% (low) this means that 600 watts are absorbed in the laser. Thus 11,400 watts are not absorbed in the laser. The majority of this power is optical power from the lamps outside the pump bands of the laser. This excess power is absorbed by the cavity and by the lamps, thus dramatically increases the temperature of the laser. Roughly 10% to 20% of the electrical power will be dissipated as heat through the electrodes and 30% to 50% as heat through the envelope. In addition to causing mechanical overheating problem (seals and so on), thermal gradient will cause thermal focusing in the laser rod (Kuhn, 1998).

Typically the lamps, the cavity, and the Nd:YAG rod are cooled by water. The usual pattern is to first take the incoming cold water and confine it to the region of the laser rod with a flow tube. This will remove the heat deposited in the rod that is not converted into laser light. Next, the water is allowed to flow through the major part of the laser cavity to remove the heat deposited in the reflectors and in the cavity walls. Finally, the water can be confined to the region around the lamps with a flow tube. This removes the heat absorbed in the quartz envelope.

Many variations on this theme are possible depending on the total power dissipation in the laser. For example, in extremely high average power lasers, a water cooling loop is provided through the electrodes to avoid destroying them. In very low power lasers, water cooling may only be provided over the lamps. In some extremely low power lasers, it may even be possible to use air cooling (Kuhn, 1998).

1.3 Previous Research

Advanced Nd laser application which requires increasingly higher average output power necessitate operating near the stress-fracture limit, i.e., a regime in which output power is limited by the possibility of material fracture arising from thermally induced stresses in the laser medium (Eggleston *et al*., 1984; Emmett *et al*., 1984). Mangir and Rockwell (1986) have found large variations in the heat generation accompanying flashlamp pumping of various types of Nd-doped phosphate glass and Yittrium Aluminium Garnet (YAG). According to Chen *et al*., (1990) thermal effects in flashlamp-pumped Nd:YAG lasers arise from the fact that nearly ten percent of the flashlamp energy is converted to heat in the laser medium, while about three percent is stored in the inversion as useful gain at the time of lasing. This heating is due to the sizeable quantum defect between the pump spectrum and the lasing wavelength, and quenching mechanisms.

A new mode of laser operation is proposed by Bowman (1999) which should result in little or no heat generations within solid state laser materials. The technique utilizes balanced spontaneous and stimulated emission within the laser medium. The result would be a radiation balanced laser device in which no excess heat is generated because of the average quantum defect of the radiation process is adjusted to zero. If such a laser device can be realized, much higher average powers systems should be possible without many of the thermal and beam quality issues that limit conventional solid state laser.

From year 2000 onwards, the research on thermal heating in solid state laser was more focused on diode pumped solid state laser which was found to have many advantages over lamp-pumped solid state laser. The advantages include high system efficiency and component lifetime and also reduction of thermal load of the solid state laser material (Koechner, 1988). Usievich *et.al,* (2001) present a paper that discloses an analytical method which delivers the exact temperature distribution in a circularly cylindrical symmetrical, longitudinally, and transversely nonuniform heat source distribution and circularly symmetrical cooling means. The analytical

expressions obtained for the temperature distribution open the way to a better understanding of thermal phenomena and represent a fast tool for solid state laser design and optimization.

1.4 Problem Statement

When laser rod was pumped by flashlamp, the temperatures of the rod will increase and the rod will expand. Such expansion will result in the change of length of the laser cavity and may cause overheating on laser equipment. To prevent the laser rod from experiencing drastic changes, it needs to be controlled by developing a cooling system and monitoring the laser chamber temperatures during the pumping process.

1.5 Research Objective

The main objectives of this research are listed as follows:

1. To develop a cooling system.
2. To develop a laser chamber.
3. To measure the circulation of cooling system over the laser head.
4. To analyze dissipation of heat at different points on laser chamber during pumping process.

1.6 Research Scope

In this study, a water cooling system and laser chamber for high power Nd:YAG solid state laser are developed. The input power of the flashlamp used for pumping is 1.6 kW. The measured parameters of water cooling system are including water temperature, quality and flow rate. A laser chamber is set-up which comprised of a laser rod, flashlamp, heat sink and stainless steel blocks. A laser house is built inclusive of electric and water piping system. The water cooling system is installed in the laser chamber and the circulation is tested. The laser rod is pumped with flashlamp and the temperatures at different points which include the flashlamp, stainless steel block and chamber heat sink of the laser chamber are measured within an hour.

1.7 Thesis Outline

This thesis consists of seven chapters. The first chapter reviews some of previous research related to thermal heating in solid state laser. This chapter also contains the objectives of the research under taken.

Chapter II covers the literature review related to the research work. This includes the fundamental of solid state laser, thermal effect in solid state laser, the fundamental of heat transfer and description of several types of cooling techniques used in solid state lasers.

Chapter III describes the preparation of materials, development of water cooling system and facilities involved in the research; and also describe the technique used to measure temperature.

In chapter IV the measurement of various parameters of a water cooling system is discussed. Two parameters are tested which include water temperature and water quality in order to ensure the cooling system is appropriate for chilling of the laser rod.

The development of a laser chamber is explained in chapter V. This involves the development of the component in the laser chamber, the design of the laser house inclusive of an electric and water piping system and testing of the circulation of water cooling system in the laser chamber.

Pumping of the laser rod is discussed in chapter VI. The temperature was monitored at different part of the laser chamber. The amount of heat dissipation was estimated based on the temperature information. The measurement was carried out with and without chilling of the distilled water.

Finally, some conclusions of the project are drawn in chapter VII. These include summary of the project and discussion of the problems encountered during the work of the project; and finally last but not least, works to be carried out in the near future are suggested.

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