DEVELOPMENT OF LONG PULSE Nd:YAG LASER SYSTEM

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (Physics)

Faculty of Science
Universiti Teknologi Malaysia

DECEMBER 2012

To my beloved mother, family,
lecturers, and friends

ACKNOWLEDGEMENT

Thanks to Almighty ALLAH, the Most Gracious and the Most Merciful for giving me strength, *keredaanNya* and time to complete this work. With His blessing may this work be beneficial for the whole of humanity.

I was honoured to have Professor Dr. Noriah Bidin as my main supervisor, Dr. Yaacob Mat Daud and Dr. Rahman Tamuri as my co-supervisors. I would like to express my thanks and sincere gratitude for their support, guidance, patience, comments, suggestion and encouragement throughout my research. Without their suggestions and criticisms, this would have not been the same as it is presented now.

I would like to acknowledge the help and kind assistance of the following person, Pn. Norhasimah Yaacob, En. Iskandar Abdul Aziz and En. Rashdan Rani. for assisting in lab work; En. Ganesan Krishnan, En. Faizal Mansor, En. Royston Uning and Cik Atiqah Ismail for their assistance, guidance and ideas as my colleague. I am also grateful to all staff Physics Department, UTM who share their ideas, comment, and support along my research.

I would also like to take this opportunity to thank the Government of Malaysia through IRPA scholarship and Universiti Teknologi Malaysia for granting this project through vot 79389. Without this financial support, this project would not be possible.

ABSTRAK

Laser Nd:YAG yang mempunyai tempoh denyutan tinggi dapat dijana dengan teknik pengujaan yang sesuai. Matlamat kajian adalah untuk menghasilkan pembekal kuasa bervoltan tinggi untuk laser sistem. Dalam kajian ini, teknik rangkaian pembentuk denyut berganda telah dibina bagi menghasilkan bentuk denyut segi empat and laser berdenyutan panjang pada kuasa yang malar. Pemacu lampu kilat telah direka dengan mengubah-ubah tenaga masukan. Lampu kilat bergas xenon telah digunakan sebagai penguja bagi Kristal laser. Pemacu lampu kilat yang dihasilkan mempunyai lima litar elektronik utama iaitu litar pengawal isyarat, pembekal kuasa *simmer*, litar pencetus penyalaan, pembekal kuasa pengecas capasitor dan litar pembentuk denyut berganda. Pembinaan pemacu lampu kilat dimulakan dengan menghasilkan litar pengawal isyarat. Litar ini menghasilkan isyarat bervoltan rendah bagi mengaktifkan beberapa komponen elektonik seperti *silicon controlled rectified* (SCR) dan transistor. Litar pencetus penyalaan digunakan untuk mencetus nyalaan bagi gas xenon dalam lampu kilat. Arus elektrik rendah dibekalkan kepada lampu kilat oleh pembekal kuasa *simmer* supaya lampu kilat berada dalam keadaan *simmering mode*. Pembekal kuasa pengecas kapasitor digunakan untuk membekal kuasa elektrik kepada kapasitor pada tempoh tertentu. Radiasi sinaran dari lampu kilat digunakan untuk menguja kristal Nd:YAG. Hasilnya merupakan cahaya laser Nd:YAG yang mempunyai panjang gelombang 1064 nm, tempoh denyutan selama 650 mikro saat dan berkuasa 250 mili Joule.

ABSTRACT

The Nd:YAG laser with long pulse duration can be produced by using an appropriate pumping scheme. The purpose of this study is to construct a high voltage power supply for laser system. In this attempt multiple-mesh pulse forming technique was performed to obtain electrical pump pulses with a more rectangular shape and long normal-mode laser pulses at constant power. The flashlamp driver was designed with variable input energy. A linear xenon flashlamp was selected as an optical pump for Nd:YAG laser crystal. The developed flashlamp driver consists of five major electronic circuits. These are signal controller device, simmer power supply (SPS), trigger pulse ignition circuit, capacitor charging power supply (CCPS) and multiple-mesh *LC* pulse forming network (MPFN). The construction of the flashlamp driver started with the design of a signal controller. The controller generated a small voltage to activate the electronic components such as silicon controlled rectified (SCR) and transistor. The ignition circuit was used to ignite xenon gases responsible to for forming ionized spark streamer between the two electrodes of the flashlamp. A low dc current was induced by the simmer power supply to sustain the flashlamp in simmering mode. The capacitor charging power supply was used to supply electrical power to capacitor within specific time. Radiation emitted by flashlamp was used to pump the Nd:YAG crystal. As a result a powerful Nd:YAG laser beam was generated having fundamental wavelength of 1064 nm, 650 microsecond pulse duration with maximum output energy of 250 mJ.

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LIST OF SYMBOL

K_0	–	Flashlamp impedance
V_0	–	Charging voltage
V_{scnd}	–	Secondary voltage
I	–	Current
I_{pc}	–	Peak current
t_r	–	Rise time
t_f	–	Fall time
R_L	–	Flashlamp resistance
Z_0	–	Circuit impedance
l	–	Flashlamp arc length between electrodes
d	–	Internal flashlamp bore diameter
E_0	–	Electrical input energy
α	–	Damping parameter
C	–	Capacitance
L	–	Inductance
LC	–	Inductor capacitor network
PFN	–	Pulse forming network
mPFN	_	Multi-mesh pulse forming network
SCR	–	Silicon control rectifier
DC	–	Direct current
AC	–	Alternating current
CCPS	–	Capacitor Charging power supply
CW	_	Continuous wave
SPS	–	Simmer power supply
PPS	–	Pulse power supply
RM	–	Rear mirror
OC	–	Output coupler

FLD	_	Flashlamp driver
IR	_	Infra red
UV	_	Ultraviolet
t_p	_	Pulse duration
Z_n	_	Network impedance
L_T	_	Total inductance
C_T	_	Total capacitance
n	_	number of mesh

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Laser is abbreviation of light amplification of radiation by stimulate emission radiation. In 1960, Maiman was successful demonstrated the first solid state laser. He used pink ruby crystal as active medium and helical flashlamp as optical pumping source. The system invented by Maiman was able to generate laser beam with output wavelength of 694 nm. In 1964, Geusic *et al* had discovered the best host for neodymium ions called yttrium aluminum garnet (YAG). Later on, Nd:YAG become the most versatile solid-state lasers.

Nd:Yag laser pose a very important characteristic since it's active laser crystal has a good thermal, optical and mechanical properties. It also shows a great flexibility compared to other laser system. The size, shape and type of the active material can be chosen in order to achieve particular performance of laser. The active material can be chosen with different gain which will produce different output. The output power of solid state laser can be increased by introducing an amplifier.

The operation mode of laser system depends on laser application need. Laser can be operated in continuous or pulse modes. Pumping technique employed will determine the mode operation of laser. External energy is needed to excite the atoms inside the laser active materials. Many energy sources can be selected as pumping energy. However, most solid-state lasers use optical pumping source. Lasing process occur inside laser resonator and the laser output depends on the laser material properties.

Flashlamp is a good optical pumping source for solid state laser. It has output spectrum which cover wide range of wavelength. Flashlamp commonly emit both line and continuum component of light emission wavelength and highly depend on current density flow through it. For Nd: YAG laser rod, xenon flashlamp usually employed as a pumping source. Xenon flashlamp has good efficiency in converting the electrical input energy to radiation in the 0.2 to 1.0 μm regions compare to others. The radiation emitted by xenon flashlamp is matched with absorption band of Nd: YAG (Fountain, 1970).

1.2 Flashlamp Driver

Flashlamp driver is used to supply electrical energy into flashlamp. Electrical to optical energy transformation occurs inside the flashlamp. Optical energy supplied by flashlamp will be used as pumping source for laser gain medium. In optical pumping application, the flashlamp driver is coupled of a various type of flashlamp such as xenon, krypton and argon (Oliver and Barnes, 1969; Mavroyannakis, 1971; Vitel *et al.*, 1993). The choice of flashlamp is dependent on laser active medium. For generating Nd:YAG laser, flashlamp which filled with xenon gas is the right selection and showed the best performance among others (Goncz and Mitchell, 1967; Newell and O'Brien, 1968; Davies *et al.*, 1968). Xenon flashlamp is suitable for pulse mode laser pumping and high energy operation.

Markiewicz and Emmett (1966) presented a good model in designing flashlamp driver with a detail explanation and an empirical formula. They illustrated single electrical pulse shaper or single mesh Pulse Forming Network (PFN). Their model composed of energy storage capacitor and pulse shaper inductor. The flashlamp was applied as a load and a switch. No external semiconductor or other switch is presented. The energy from storage capacitor was discharged to the flashlamp and inductor was acted as electrical pulse shaper. In 1977, David and Thun-Shi presented a PFN circuits with resistive losses. Their design focus on pumping energy optimization on Nd:glass laser system.

The energy transmission in flashlamp application can be controlled by introducing semiconductor switch. The switch is electronically monitored by controller system. Several researches has been conducted to improve the application of flaslamp. In 2000, Arya *et al*. had studied the influence of simmer current on flashlamp impedance and performance of a flashlamp-pumped Nd:YAG laser operating in the quasi-CW mode. The system efficiency increases with simmer current up to a certain value and then remained nearly constant for further increases in simmer current. Later on, Hong *et al.* (2002) developed a new real time multi-discharge method. This study showed a technology which was possible to produce various pulses with the aid of a program integrated in one-chip microprocessor. In 2003, Mazzinghia and Margherib developed ultra short Nd: YAG laser pulse with less than 200 μs. flashlamp pumped pulse Nd: YAG lasers are widely used because a lamp is much more cost-effective than laser diode as a pumping source (Yagi *et al.*, 2005).

It is essential to completely understand the optical and electrical characteristic of the flashlamp source. This is important in order to design and construct the power supply for laser system based on flashlamp pumped.

1.3 Problem Statement

A suitable optical energy and pumping technique for atom excitation inside the gain medium must be applied to generate laser light especially for long pulse laser. Longer pump pulse is required and optical energy supplied must be matched with the absorption band of the gain medium. Thus, a well designed flashlamp driver or optical pump system is needed in order to provide appropriate optical energy for Nd:YAG crystal. The optical energy supplied will be used as pumping source to generate long pulse laser.

1.4 Research Objective

The main objective of this research is to develop flashlamp driver for Nd:YAG laser system which can generate relatively long pulse laser duration in range of hundred microseconds. In this attempt several power supplies and auxiliary subsystems were constructed including:

1) Construction of electrical pulse shaper based on multiple-mesh technique of pulse forming networks

2) Construction of simmer power supply.

3) Ignition circuit design to initiate the electric spark inside the flashlamp.

4) Controller device design based on microcontroller to control operation of laser system.

5) Cooling device installation to maintain the temperature of the laser.

6) Assembly of flashlamp driver and Nd:YAG laser resonator to produce laser light.

1.5 Research Scope

In this study, power supply or flashlamp driver for xenon flashlamp was constructed. Laser resonator using two plane mirrors was designed and developed. The xenon flashlamp of 4 mm bore diameter and 7 mm arc length was used as pumping source. Nd:YAG crystal rod with diameter of 4 mm and 7 mm length was applied. The PIC16F877 microchip microcontroller is used as laser system controller. The setup of microcontroller is programmed using micro basic compiler software. The controller will manage the operation of simmer power supply, ignition circuit, PFN device and capacitor charging power supply.

The driver is operated in a single and repetitive mode. The repetitive mode is adjusted corresponding to the PIC16F877 microcontroller program. The outputs of microcontroller, either in single or repetitive mode, are connected to trigger Silicon Controlled Rectified (SCR). This SCR acts as a switch which control discharging process of energy storage capacitor. A high voltage probe is used to characterize the voltage of discharging process. The optical properties of the flashlamp and Nd:YAG laser are measured by spectrum analyzer, photodiode detector, and energy meter.

1.6 Thesis Outline

This thesis composes of five chapters. The first chapter is about an introduction and overview of solid state laser. It briefly describes the history and performance of laser. Several previous related researches regarding the flashlamp driver are reviewed. Moreover, the objective and scope for this research are also addressed clearly.

Chapter II covers theories related to the study. General principle and basic arrangement in generate laser beam are included. Several methods for designing the laser oscillator are discussed. The electrical and optical properties of xenon flashlamp are also described in detail since these are important for optical pumping source. The criteria of solid state material also state briefly.

Chapter III explains the design and testing method of the flashlamp driver. The development of flashlamp driver (FLD) and alignment of laser oscillator are discussed.

Chapter IV will cover the results of the laser system construction. The output produced from each of the flashlamp driver subsystem and Nd:YAG laser system are noted.

Chapter V will review about the performance and output developed laser system. Conclusions of research finding and suggestion for future study are briefly stated.

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