

# Design and Fabrication of High-precision x-Translational and Rotational Controlled Motorized Stage (CMS)

Ahmad Hadi Ali

Science Department, Centre for Science Studies,

Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor

Phone: +607-4537980, Fax: +607-4536051, Email: [ahadi@uthm.edu.my](mailto:ahadi@uthm.edu.my)

## Abstract

*Operating high-power lasers are very hazardous to the health and safety of the workers. In addition, positioning a sample material during laser operation is very dangerous. Thus this paper will report the design and fabrication of Controlled Motorized Stages (CMS). The stages consist of two mechanical parts; an x-axis high-precision translational stage and a rotational stage. There are three main parts of CMS that are mechanical system, electronic interfacing and motor driving circuit, and control system. The mechanical systems were design and fabricated using a lightweight aluminum with high-precision resolution. They were drive by a stepper motor that can drive up to 1.0 kg sample on the stage. The electronic circuit was interfaced to microcomputer. In order to control the step-by-step motion of the stages, a program was developed with the aid of Visual Basic 6.0. The result shows that the x-axis stage can move in a range of 90.0 mm with resolution of 26  $\mu\text{m}$  in step-by-step mode, and speed exceeding 0.2 mm/s when operating continuously. In the other hand, the rotational stage can move 7.2° per step angle.*

**Keywords:** Motorized stage, control system, mechanical, electronic, precision.

## 1.0 INTRODUCTION

Since the last four decades laser beams are being used in various manufacturing process such as in machining of engineering materials. Laser beams have power density, high directionality and better focusing characteristics. These unique characteristics are very useful for machining materials in manufacturing processes such as drilling, cutting, welding and micromachining [1].

Micromachining of materials with laser beam required micrometer size spot and very fast interaction period. Specific micromachining applications of lasers include low heat-affected zone welding, precision micro-cutting, micro bending, high-security marking, and non-contact soldering. This micro-scale machining has potential applications in the field of optics, semiconductors, metals, ceramics and polymers.

In addition the drive to reduce component size in a variety of industries is bringing lasers into applications formerly addressed by older technologies. Lasers such as Q-switched Nd:YAG laser assist in this miniaturization process by providing a nanosecond and highly focused beam which can process very small submicron feature sizes [2]. This focused beam has the benefit of reducing thermal effects during material processing, which results in the ability to process thinner and more delicate materials than with other processes. Additionally, lasers allow for non-contact processing so there is no tooling wear and the beam can be quickly and precisely manipulated, resulting in high throughput processing. Contamination becomes a significant issue as component feature sizes shrink, but non-contact processing with lasers often results in a dramatic reduction in particulate accumulation in the work area.

Despite potential advantages, the practical use of lasers in non-contact micromachining of materials can become hazardous to the person. Since laser amplify and focus stimulated light onto the sample material, a slight mistaken during the machining process could turn out into a very dangerous casualty to the person as well to the system. One approach to address this situation is to control the sample material away from the machining area. Thus controlled motorized stages (CMS) were fabricated in order to micro-positioning the sample material.

Micro-positioning technology is very essential in laser micromachining of materials. Micro-positioning refers to mechanical movement with positioning resolution and accuracy in the micron or sub-micron range. Such micro-positioners are required to provide the motion in micron scales with high precision, accuracy and load capacity [3,4]. Stepper motor devices are commonly used for these applications.

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movement. It is commonly used in measurement and control applications. Several features make them ideally suited for these types of applications. Stepper motors have excellent response to starting, stopping and reversing [5]. The rotation angle of the motor is proportional to the input pulse. It's response to digital input pulses provides open-

loop control, making the motor simpler and less costly to control [6,7]. The stepper motor offers high accuracy and high precision and repeatability of movement with step angles are mostly in the range  $1.8^\circ - 90^\circ$ [8]. The holding torque is able to hold the shaft stationary [9].

In the following, the mechanical mechanism of the CMS including x-axis translational stage and rotational stage were described. The driver and interfacing circuits was explained base on the load capacity of the CMS. Control programming software used to control the movement mechanism was described. Their dynamic models were established by the shifting ability, speed, translational range, and torque as well load characteristics.

## 2.0 SYSTEM DESIGN

A schematic of the first generation CMS setup for laser micromachining is shown in Figure 1. In general the CMS consists of four main parts; a software controller, interfacing device, stepper motor driver and mechanical x-translational and rotational stage.

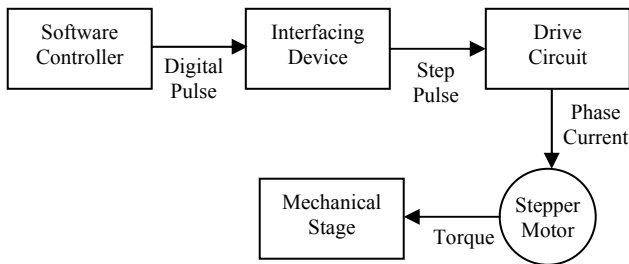


Figure 1. Schematic diagram of CMS system.

### 2.1 Mechanical Stage Fabrication

The mechanical part in CMS consists of x-axis translational stage X-CMS and a rotational stage R-CMS. The R-CMS is mounted on the X-CMS to allow the freedom of sample positioning both in x-direction as well in rotational as shown in Figure 2. The components of the setup are mounted on an aluminum base plate and the entire setup is placed on a vibration isolation optical table.

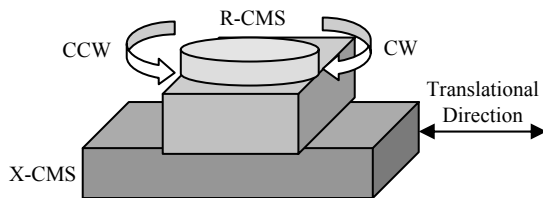


Figure 2. Schematic of R-CMS mounted on X-CMS.

The stages were design and fabricated from aluminum coated with black finishing. The properties of aluminum are suitable for the stages as it is lightweight and sturdy. Aluminum has Young's modulus of  $70 \times 10^9 \text{ Nm}^{-2}$  makes it hard to elongate or compress during the high torque translational by the stepper motor. In addition the coefficient of thermal expansion of  $25 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$  makes the stage hard to expand during the laser machining process. Besides, the thermal conductivities of  $5.0 \times 10^{-2} \text{ J/(s.m.}^\circ\text{C)}$  makes the stage resistance to the heat during the heating of material on the stage by the high intensity laser beam.

These designs are based on the frictional forces to withstand any axial input force. This makes them suitable for applications that needs long travel range, high axial force and resolution in the order of tens micrometers applications.

### 2.2 Stepper Motor

The CMS used stepper motor for the open-loop positioning system. It allows easy interfacing to microcomputer and is mechanically simple, while requiring simple maintenance. The stepper motor was manufactured by Astrosyn. It consists of unipolar winding stator and hybrid magnet rotor. It is a four phase motor with  $1.8^\circ$  resolution at full step, and operated at rated voltage 12 Vdc and current 0.16 A. The motor has holding torque of 900 gf-cm and detent torque 150 gf-cm nominal.

Figure 3. show the basic principle of stepper motor operating in full-step mode. There are two pairs of stator poles positioned perpendicularly with each others. The first stator with winding A carrying current  $I_A$  and the second stator with winding B carrying current  $I_B$ . The rotor is permanent magnet positioned at the center of the stator, and is able to pivot about its center. When the current in winding A ( $I_A$ ) is positive and the current in winding B ( $I_B$ ) is zero the rotor will line up with the vertical pole pieces as shown. When  $I_B$  is made positive its pole pieces become magnetic as shown. The rotor will now rotate  $45^\circ$  counterclockwise if  $I_A$  is equal to  $I_B$ . Making  $I_A$  equal to zero will result in a further counterclockwise rotation of  $45^\circ$ . Reversing the current  $I_A$  will result in another  $45^\circ$  rotation. Reversing the order of switching will reverse the direction of rotation.

In the open-loop control the stepper motor use only 50% of its nominal torque. A large torque is reserved to overcome any load variation. In this circuit design there is no feedback of load position to the controller. The step-by-step rotation is a feature specific to a stepping motor. The number of steps per one complete revolution features a resolution of 200 steps per revolution or an angular increment of  $1.8^\circ$  per step.

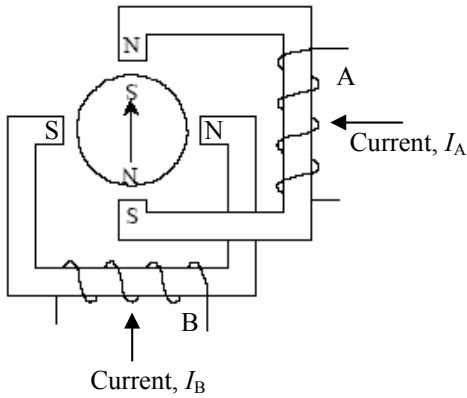


Figure 3. Stepper motor diagram.

### 2.3 Drive Circuit

The stepper motor is drive by ULN2803 darlington arrays driver as in Figure 4. The IC contains eight darlington transistors with common emitters and integral suppression diodes for inductive loads. Each darlington features a peak load current rating of 600mA (500mA continuous) and can withstand at least 50V in the off state. The driver amplifies the pulse signal from microcomputer to energized signal to drive the stepper motor.

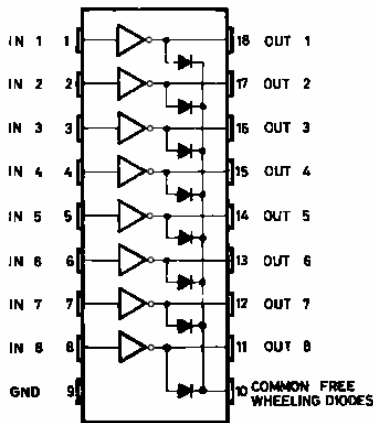


Figure 4. Stepper motor driver

### 2.4 Interfacing Device

The X-CMS and R-CMS drive by stepper motor operating under the command of a microcomputer via the parallel port. The parallel port interface circuit was designed using the DB-25 parallel port connector shown in Figure 5. The parallel port contains the data lines  $D_0$ - $D_7$ , 5 status lines, and 4 bi-directional control lines. The data lines of the parallel port outputs an 8 bit control word. The pulses from microcomputer is sent to stepper motor driver through the

parallel port data point  $D_0$ - $D_3$ . As a safety for the communication between the microcomputer with the external circuit, TLP621 optocoupler was employed. The optocoupler acts as a circuit breaker from current surge from the external circuit.

### 2.5 Software Controller

Visual Basic 6.0 was chosen for the software development because of simplicity and windows environment friendly. Menu driven VB program was developed for the stepper control application. The program menu contains options to control the position of the x-translational and rotational motion of the CMS. The friendly menu allows users to control the movement of the CMS by a simple click on the menu button as shown in Figure 5. The control menu has two parts; X-CMS control menu and R-CMS control menu. The X-CMS control menu allows user to control the stage to move forward or reverse continuously, or move step-by-step in forward or reverse direction. The R-CMS in the other hand allows user to control the rotational motion in clockwise or counter clockwise either in continuous or step-by-step mode. The moving CMS also can be interrupts by using the stop button. The menu also allow user to control the movement of both CMS at same time.

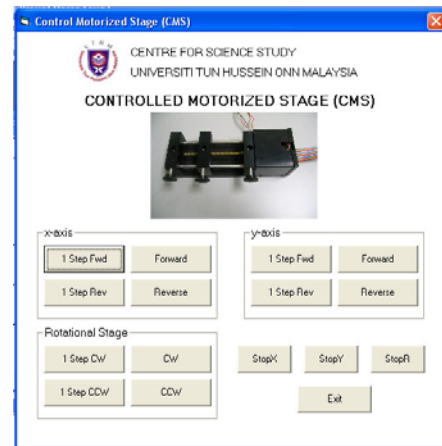


Figure 5. Control menu program.

### 3.0 RESULT AND DISCUSSION

The CMS were test in term resolution, translation range, speed and load. . The test on the X-CMS shows that the stage can move in a range of 90.0 mm with resolution of 26  $\mu$ m in step-by-step mode, and speed exceeding 0.2 mm/s when operating continuously. The stage also can withstand load of up to 1.0 kg during the operation. In the

other hand, the rotational stage can move  $7.2^\circ$  per step angle or 52 steps per revolution.

## CONCLUSION

As a conclusion, both X-CMS and R-CMS stage were successfully construct and fabricated. They can move either in step-by step or continuous mode. The x-axis stage can move in a range of 90.0 mm with resolution of  $26\ \mu\text{m}$  in step-by-step mode, and speed exceeding 0.2 mm/s when operating continuously. The rotational stage can move  $7.2^\circ$  per step angle or 52 steps per revolution.

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