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A PC–Based Controller for the Computer Numerically-Controlled (CNC) LASER Machine

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***Abstract*—This study presents the development of a PC-based controller for the 3-axis computer numerically-controlled (CNC) LASER machine. This includes the use of an MK-II motion controller board in controlling the three (3) Ezi-Servo stepper motors and in enabling the LASER output from the Synrad firestar f201. The LASER power output is controlled using a developed PWM controller. The machine was tested both in functional and performance testing. In terms of performance, it can cut mild steel and stainless steel with thickness of 2 mm and 1 mm, respectively. PLT extension file was used for the g-code toolpath of the CNC LASER machine system.**

***Index Terms*—Arduino, computer numerically-controlled (CNC), computer-aided manufacturing (CAM), g-code, LASER**

I. Introduction

The first LASER (Light Amplification by Stimulated Emission of Radiation) was successfully operated by Theodore H. Maiman in the Hughes Research Laboratories on May 1960. It was in 1965 when the first LASER machine was used for production. The use of LASER-assisted oxygen jet cutting in metals began in 1967. From there, LASER cutting application began to flourish. In aerospace industries, LASER has been a useful tool in cutting titanium for their structural airframes.

To produce high accuracy cut, computer numerical control (CNC) technology was employed to LASER systems. CNC LASER machine involves a motion control system to follow a g-code pattern or toolpath, created from the computer, to be cut onto the material [1, 2]. It is an industrial technology that uses a LASER to cut ferrous and non-ferrous materials. It works by directing the output of a high-power LASER beam, through a PC controller, at the material or workpiece to be cut [3].

The controller is considered to be the heart of any CNC systems. It serves as the medium for the hardware (motors) and the computer. The challenge in creating a CNC controller, especially for CNC LASER, is not only in the precision and power, but also the process speed and its repeatability [3]. Moreover, the controller must be user-friendly in terms of usage since there are commercially-available digital signal processor (DSP) based controllers that don't have viewing monitor for toolpath simulation. With that, PC-based provide the solution in terms of flexibility, usage and openness [4]. Moreover, user can take control the settings of the CNC machine using a desktop or laptop computer.

Therefore, this study aims to develop a PC-based controller system for the 3-axis CNC LASER machine. The controller developed will be utilizing a user-friendly interface design for the motion and LASER power control. Real-time simulation will be performed while the LASER is in operation.

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II. CNC LASER System

Just like any CNC systems available in the market, CNC LASER machine behaves and operates the same mechatronics principle. Figure 1 displays the CNC LASER machine locally-designed and developed in the Metals Industry Research and Development Center (MIRDC). This machine is intended to cut metal and non-metal materials using the 200-W carbon dioxide (CO_2) LASER generator from Synrad. CO_2 LASER is commonly used in industrial cutting for mild and stainless steel, aluminum, titanium and non-ferrous applications. The machine has three (3) axes (X, Y and Z) of motion driven by stepper motors. It also has a conveyorized-delivery system to transfer the material to the CNC bed.

Fig. 1. MIRDC's CNC LASER machine.

Figure 2 illustrates the signal flow that occurs during transformation of the drawing file to a machine code that will be read by the controller. This can be characterized in terms of three (3) parts: CAD, CAM and CNC control [5].

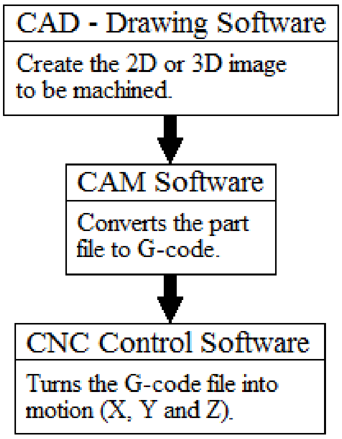

Fig. 2. Signal flow for CNC position control.

First, the computer play an integral part of the control system. Modern CNC systems nowadays are highly equipped with computers that can run computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. As seen in Figure 3 the operation parameters of the CNC LASER system. The input to the process is the LASER beam produced by the LASER generator, the 2D CAD drawings and other devices like the chiller and air-assist system during cutting. After the inputs, the process of the system involves the CAM system and the CNC motion controller to drive the stepper or servo motors.

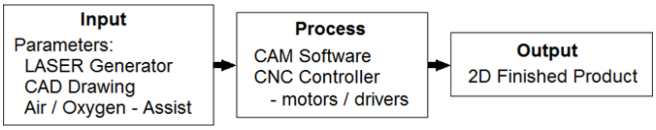

Fig. 3. CNC LASER machine operation parameters.

The generation of LASER beam involves simulating a material by electrical discharges within a closed container. Then, the beam is internally reflected by means of a partial mirror or fiber optics. These reflective mirrors are used to direct the path of the coherent light to a focus lens at the material to be cut.

III. Methodology

In this study, the controller block diagram of the CNC LASER system is shown in Figure 4. The controller used is PC-based and it is used to communicate with the board through a USB interface. Using this port, the CNC machine can be link with all modern computers even with a laptop.

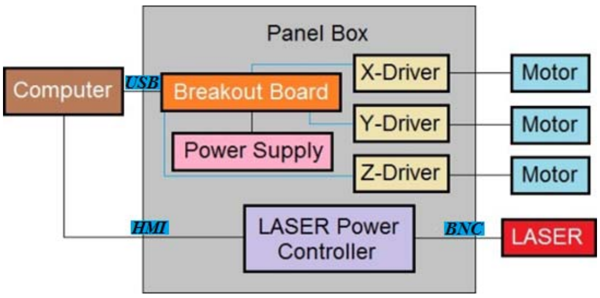

Fig. 4. CNC LASER controller block diagram.

The interface used to link the power controller and the Synrad's Firestar f201 CO_2 LASER generator is a Bayonet Neill–Concelman or Baby N Connector (BNC) Control Cable (see Fig. 5). This is a type of coaxial cable that carries the PWM command signal from the controller to the LASER's quick start plug controller.

Fig. 5. BNC control cable.

The controller operations for the LASER power is built with a simple graphical-user interface (GUI) as seen in Figure 6. The GUI was created in Microsoft Visual Studio. Moreover, other functions of the LASER generator, including the error and safety indicators, were also incorporated.

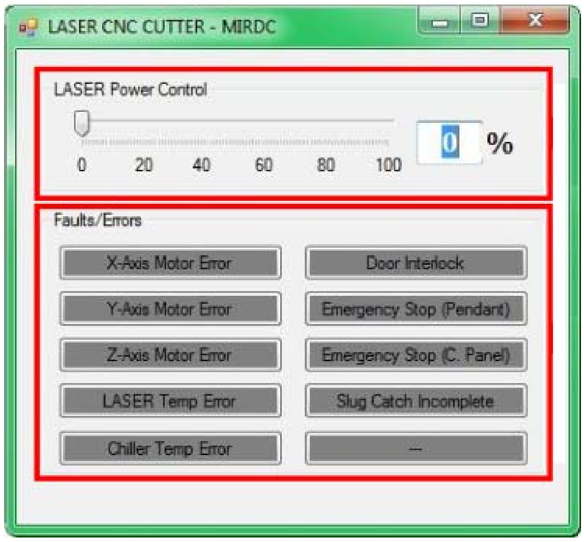

Fig. 6. GUI for the LASER power controller.

A. *CNC LASER System Components*

As shown in Figure 7, the developed CNC LASER machine, just like any CNC systems, consists of three (3) major components: mechanical, electronics and the software.

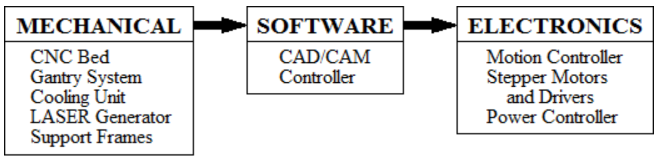

Fig. 7. LASER power control.

The mechanical or the hardware consists of the CNC bed, gantry system, cooling system or chiller, the LASER generator and the support frames. The software component consists of the computer-aided design (CAD), computer-aided manufacturing (CAM) and the controller software. The electronics part serves to be the heart of the CNC system. It consists of the motion controller, LASER power controller, the stepper or servo motors and their drivers.

1) CNC Cutting Bed – The cutting bed is made up of cutting grates that are fixed-in place with the bed. They are used to hold the material as depicted in Figure 8. The system is designed to support the material being cut. Also, the system is also connected to a transport bed used for loading and unloading the material.

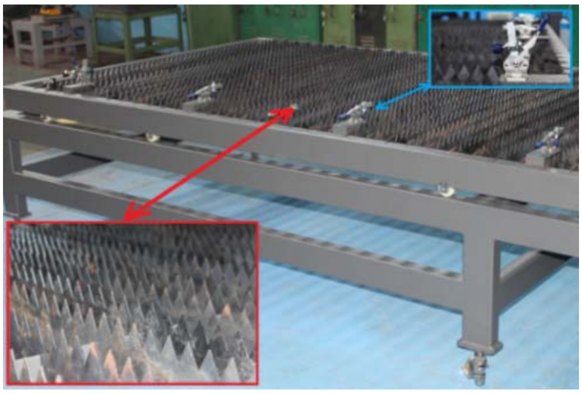

Fig. 8. CNC LASER cutting bed.

2) Gantry System – Most CNC machines employ a gantry style design (see Fig. 9). This is where the whole Y-axis assembly is suspended above the cutting bed. The whole gantry assembly glides on a linear bearing assembly and moves along the X- and Y-axis.

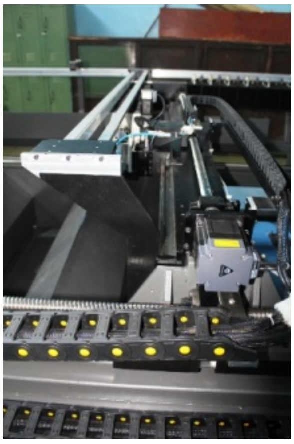

Fig. 9. Gantry system.

3) Conveyorized–Bed System – The CNC bed is driven by a single-phase 0.5-hp induction motor (see Fig. 10) through a chain-type conveyor. The speed of the motor is controlled by a speed controller.

Fig. 10. Induction motor used for the conveyorized–bed system.

4) LASER Generator – The 200-watt single-tube f201 from Synrad's firestar (see Fig. 11) is used as the LASER generator. This generator produces a near-perfect LASER beam quality, fully integrated RF drive and has an excellent power stability due to its longer resonator design. It has a gas purge to maintain internal optic integrity and uses water cooling for higher electronic component efficiencies [6].

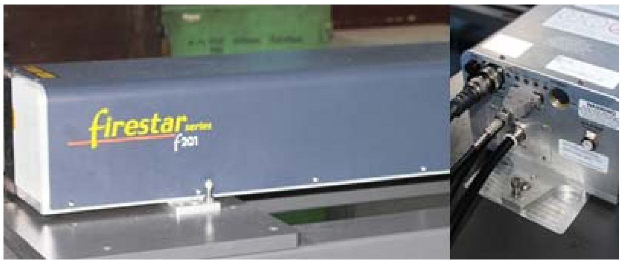

Fig. 11. Synrad firestar f201 LASER generator.

5) Cooling System – Figure 12 shows the industrial chiller used to liquid-cool the LASER generator. It is a high-precision compression refrigerant small water chiller with various setting and display functions. It has an intelligent temperature control that operates in two (2) control modes: constant temperature and intelligent temperature control. In intelligent mode, the water temperature is adjusted according to ambient temperature. It has multiple alarm functions like water-flow alarm, compressor time-delay and over-current protection, and over high and low temperature alarm.

Fig. 12. Industrial chiller.

6) Control Panel – As shown in Figure 13, the control panel is made up of an industrial panel enclosure. It consists of a human-machine interface (HMI) touchscreen monitor for viewing, exporting and editing g-code files. Safety switches are also employed like the emergency push button, control for the delivery system and LED lamp indicators for the chiller, PC, mechanical interlocks and LASER signal.

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Fig. 13. Control panel.

B. *Electrical and Electronic Components*

Situated inside the panel box are the electrical and electronic components as seen in Figure 14.

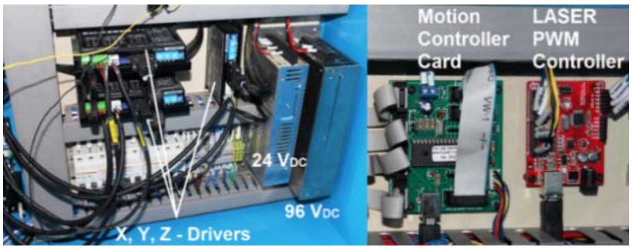

Fig. 14. Electrical and electronic components

1) Power Supply Unit (PSU) – The supply of the CNC system consists of three (3) different voltage supply. The 24-V_{DC} is used for the Y and Z stepper motor drivers while the 48-V_{DC} is used for the X-axis. For the supply of the LASER generator, the 96-V_{DC} is used.

2) Stepper Drivers – They are used to drive the stepper motors of X, Y and Z-axes. The brand of motors and drivers used were Ezi-Servo models of Fastech Corporation.

3) Motion Controller Card – This card is responsible for the generation of g-code toolpaths that will be used by the stepper motors to move from one position to another. The card used in this study is an MK2 USB controller card (see Fig. 15) from PlanetCNC [7].

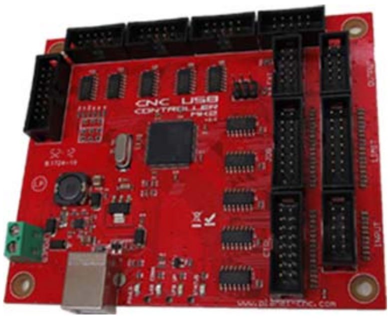

Fig. 15. MK2 CNC USB controller card.

4) LASER Power Controller Card – This card is used to control the LASER beam produced by the LASER generator using pulse-width modulation (PWM) technique. The card is a GizDuino board (see Fig. 16) and programmed through Arduino IDE [8].

Fig. 16. GizDuino controller.

IV. Testing

Testing of the controller for the CNC LASER machine is done both in functional and performance test. Simulation runs were also conducted using the Vcarve Pro [9] and the CNC USB Controller [7].

A. *Geometric and Dimensional Tolerance (GD&T)*

GD&T or Geometric and Dimensional Tolerance is a reference used to provide a clear. In this study, the logo of the company (MIRDC) was used. As seen in Figure 17, the logo has a complete geometric characteristics starting from straightness and flatness to curvature and circularity [10].

Type of Tolerance	Geometric Characteristics	Symbol
Form	STRAIGHTNESS	—
	FLATNESS	▱
	CIRCULARITY	○
	CYLINDRICITY	⌭
Profile	PROFILE OF A LINE	⌒
	PROFILE OF A SURFACE	⌓
Orientation	ANGULARITY	∠
	PERPENDICULARITY	⊥
	PARALLELISM	//
Location	POSITION	⌖
	CONCENTRICITY	◎
	SYMMETRY	⌯

Fig. 17. GD&T table and 2D design used for testing.

B. *Toolpath Generation and Simulation*

Before the 2D drawing was run in actual simulation, the file was first exported to the VCarve Pro (see Fig. 18) and CNC USB Controller (see Fig. 19). The VCarve Pro uses the *.plt* file to transport the g-code to the controller. This extension file is a graphics plot file or a printer control

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language created by Hewlett-Packard. The two figures illustrated the simulation of the generated toolpath transferred from a *.dxf* file created in AutoCAD. Prior to actual LASER cutting, drawing offset (tolerance of LASER kerf width) was also considered to ensure the accuracy of the system.

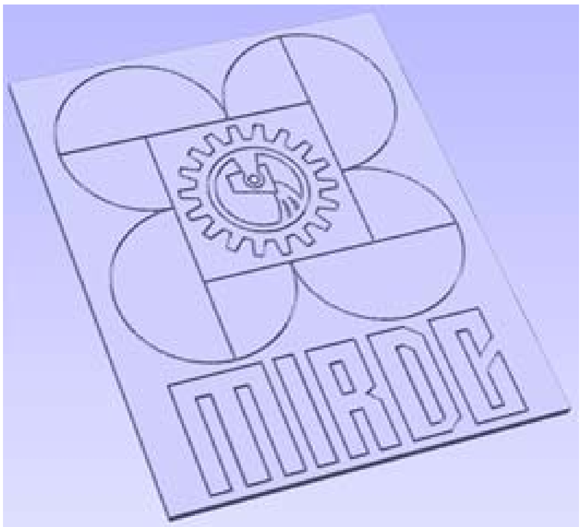

Fig. 18. Toolpath produced in VCarve Pro in .plt.

Fig. 19. Toolpath produced in CNC USB Controller.

C. *Actual Testing*

The actual CNC LASER operation, with a process speed of 2000 mm/min and duty cycle of 30%, is shown in Figure 20. The material used was a 2 mm clear acrylic plastic.

Fig. 20. Toolpath produced in VCarve Pro in .plt.

- Straightness – Outer side (length) measuring 250 mm which is 10% the length of the CNC working area.
- Circularity – Inner circle in the middle of the logo.
- Angularity – Angled formed from letters **R**, **D** and **C**.
- Perpendicularity – Adjacent sides of the outer square.
- Parallelism – Parallel sides of the outer square.
- Position – In reference to the workpiece origin.
- Symmetry – Formation of gears.

D. *CNC LASER System Cutting Profile*

Figure 21 and 22 illustrate the different cutting profile of the CNC LASER system in terms of process or cutting speed (mm/min) and thickness (mm). In Figure 25, the 200-W CO_2 LASER can cut 1 mm of stainless steel (SS) while a maximum of 2 mm for mild steel (MS) in a single pass. For the plastic material, like acrylic and acrylonitrile butadiene styrene (ABS), the LASER can cut up to 20 mm thickness in 1000 mm/min cutting speed (see Fig. 26).

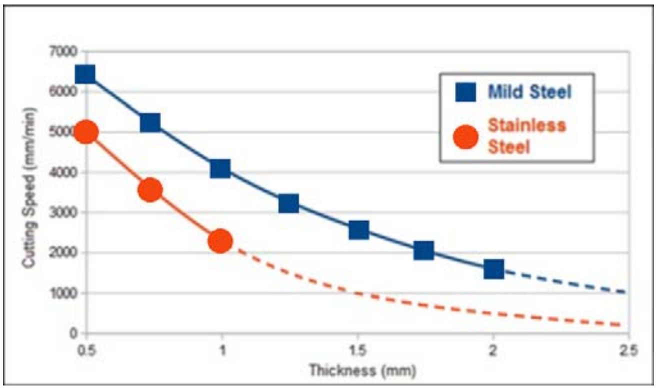

Fig. 21. Cutting profile of mild and stainless steels.

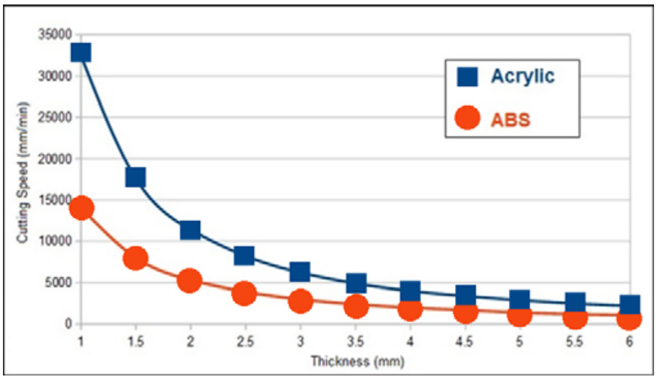

Fig. 22. Cutting profile of acrylic and ABS plastics.

V. CONCLUSION

In this study, the PC-based controller was able to demonstrate successfully the cutting operations of the CNC LASER machine developed in the MIRDC. From the results, the generated toolpath from the CAD/CAM programs, VCarve Pro and CNC USB Controller, was able to transform the drawing file (.dxf) into g-codes that will be read by the controller. In this study, the post-processor used to transfer the g-code to the PC-based controller is a file with *.plt* extension.

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Moreover, with the USB interface, actual toolpath simulation can be done. Monitoring of the g-code toolpath trace and actual results were displayed both in real-time using the graphical 3D software from CNC USB Controller.

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