Development of a Low-Cost Controller for the 3-Axis Computer Numerically-Controlled (CNC) Plasma Cutting Machine

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***Abstract*—The Metals Industry Research and Development Center (MIRDC) designed and developed a 3-axis computer numerically-controlled (CNC) plasma cutting machine for the local metalworking industry. This CNC machine was dubbed as 'Plasmanoy' – short for 'Plasma ng Pinoy'. The said equipment is capable of cutting steel and other metals with a plasma torch. It uses high-temperature plasma to melt the metal being cut. To produce precise and clean sharp cuts, computer control was introduced. However, the automation cost is quite expensive. With that, this study presents the development of a low-cost controller for the 3-axis CNC plasma cutting machine. The developed controller is capable of digitally-controlling the mechanical motion of the three (3) axes (X, Y and Z) and the plasma generator. For the toolpath generation and post-processing, TAP extension file format was used.**

***Index Terms*— computer numerical control (CNC), computer-aided manufacturing (CAM), digital signal processing (DSP), plasma cutting**

I. Introduction

FOR the past years, computer numerical control (CNC) machines became widely in-demand technologies in almost modern manufacturing industry setup unlike before where these machines were only applied in the automobile and aviation industries.

At present, CNC machines are continually and increasingly upgrading in terms of process speed, precision, efficiency and specific application. One good example of a specific application is metal plate cutting. There are many ways to cut metal plates. The following technologies available are oxy-fuel, plasma, LASER and waterjet cutting. Their differences depend on the type and thickness of the material being cut. Among these four (4) mentioned, plasma cutting technology plays in the middle in terms of speed, cost of operation and work quality. It was only in the late 1980s where CNC technology was applied to plasma cutting machines. Making this machine to cut elaborate and intricate design patterns, based on a set of instructions, with greater flexibility and accuracy and this can only be done with the help of an electronic controller. The controller is said to be the heart and brain of any CNC system. It serves as a communication medium for the computer and the actuators [1]. The only problem in developing a CNC controller is the process of integrating the system's software to its hardware components. With that, this study aims to develop a low-cost controller for the 3-axis CNC plasma cutting machine using digital signal processing (DSP) system. It will be capable of reading g-code instructions created from a CAD/CAM software. VCarve Pro software [2, 3] will be the program used to create 2D drawings and toolpath generation.

Manuscript received July 10, 2015; revised July 28, 2015. This work, was supported by the Department of Science and Technology (DOST) under the 'Makinarya para sa Bayan' or 'MakiBayan' program.

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II. The PLASMANOY Machine

The Department of Science and Technology (DOST) developed the 'Makinarya para sa Bayan' or MakiBayan program. This program aims to strengthen and promote the research and development (R&D) sector of the local metalworking industry by addressing the problems in metals engineering, furniture and equipment fabrication. To answer the country's problem in equipment building deficiency, the MakiBayan program initiated two (2) research projects: the CNC router dubbed as the 'Super Lilok' and the CNC plasma cutting machine as 'Plasmanoy' (see Fig. 1). These projects were locally designed and developed in the Metals Industry Research and Development Center (MIRDC) [1, 4].

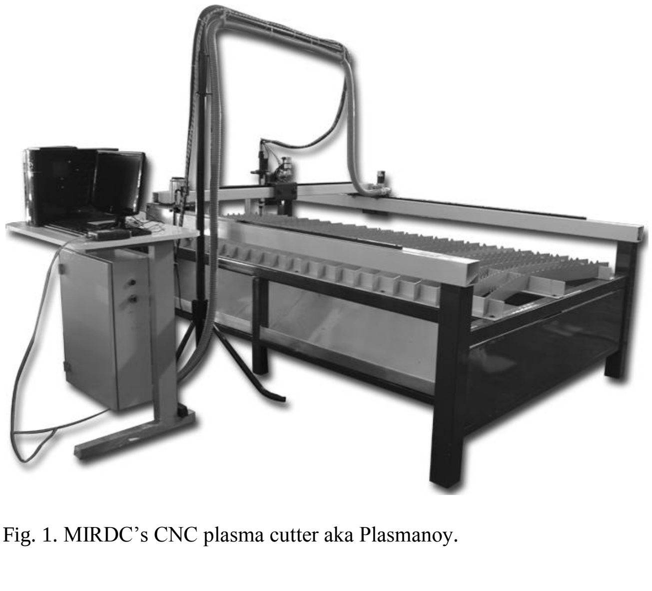

Fig. 1. MIRDC's CNC plasma cutter aka Plasmanoy.

ISBN: 978-988-19253-6-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Plasmanoy, just like any CNC plasma cutting systems, is capable of cutting all types of metal based from a given set of toolpath instructions.

A. *CNC Machine Operations*

As shown in Figure 2, the mechanical motion of the CNC plasma cutting machine moves in three (3) axes: X, Y and Z.

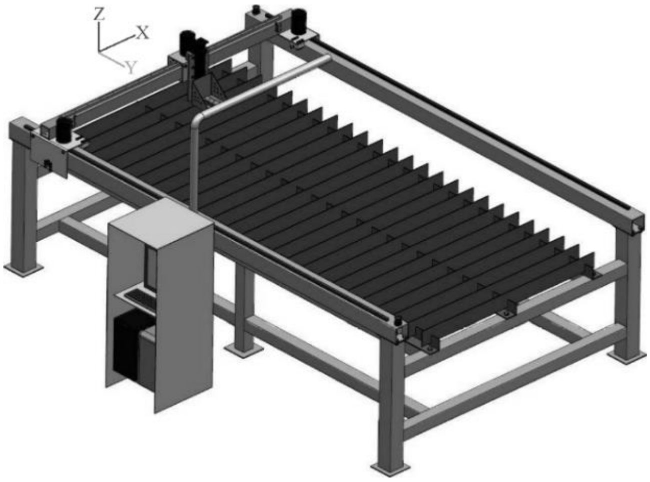

Fig. 2. Mechanical motion of the CNC plasma cutting system

The X-axis traverses horizontally from left to right. The Y-axis runs back and forth using two (2) servo motors and the Z-axis goes vertically up and down controlled by a torch height compensator (THC) system. Both X and Y axes move linearly using rack and pinion gear while the Z-axis uses high-precision ball screw transmission.

B. *Technical Specifications*

Table 1 provides the technical specifications of the Plasmanoy machine.

TABLE I
PLASMANOY SPECIFICATIONS

Item	Specifications
Maximum Working Area	1300 mm x 2500 mm
Z-Axis Travel	460 mm
Z-Axis Clearance	200 mm
Maximum Travel Speed	30 m/min
XYZ-Transmission System	20 m/min
Accuracy	0.10 mm
Power Supply	220-Vac, single-phase
XYZ-Motors	Servo motors
Main Actuation	Plasma Torch

From the machine specifications, servo motors were used to drive the three (3) axes: X, Y and Z. Only the Y-axis utilizes two (2) servo motors attached at the gantry’s both ends to keep and maintain its balance when traversing. For gantry to operate, the other servo motor is rotating opposite, or in reverse, with the direction of the first one.

C. *Controller Operations*

The signal flow in Figure 3 shows a drawing file from a workstation transformed to a machine code (g-code) that will be read by the controller [5, 6].

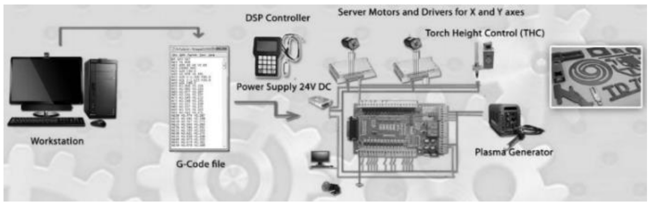

Fig. 3. CNC plasma cutting system design flowchart

Modern CNC system nowadays acquire an adaptive control for the vertical movement. This is called the torch height control (THC) that maintain proper pierce in improving the cut quality and consumable life. THC senses the arc voltage from the plasma cutter and adjusts the cutting height accordingly.

III. PLASMA CUTTING TECHNOLOGY

Plasma cutting technology is the process of using plasma, from a superheated air, to cut metal. Normally, this technology uses a compressed air supply and electricity.

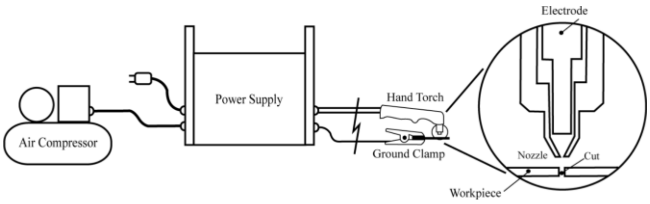

Fig. 4. Plasma arc process

In this process, as seen in Figure 4, the air from the compressor is blown at a very high speed drawn out to the nozzle. During that time, a voltage arc is also created converting some air into plasma. This plasma is very hot enough to pierce and cut the metal.

A. *CNC Plasma Cutting Process*

CNC systems involves three (3) basic steps: input, process and output. Figure 5 describes the process operations and elements used in CNC plasma cutting technology.

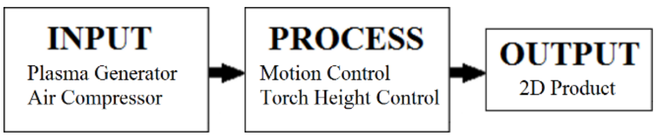

Fig. 5. Parameters of CNC plasma cutting machine operation

The process of the CNC plasma cutting system involves the interaction between the motion control and the torch height control (THC) in driving the stepper or servo motors in producing high quality 2D cut. These actuators provide the X, Y and Z motions [7].

B. *CAD/CAM Operation*

Figure 6 illustrates the process flow in the transformation of a drawing file to machine code. It can be characterized in terms of three (3) components: CAD, CAM and CNC [8, 9]. These items refer to computer software that is used both in designing and manufacturing products.

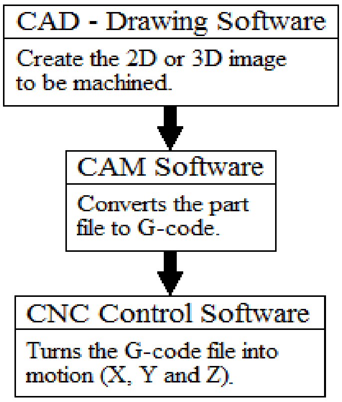

Fig. 6. Signal flow for CNC position control process

The first part is the creation of 2D layout in a computer-aided drawing (CAD) software. Then, the drawing file will undergo computer-aided manufacturing (CAM) post-processing for the generation of the toolpath or the g-codes. Lastly, the CNC control will be responsible in transforming these g-codes into X, Y and Z motions [10].

IV. Methodology

In Figure 7, the controller block diagram of Plasmanoy where it uses the computing software and the controller to drive its mechanical system.

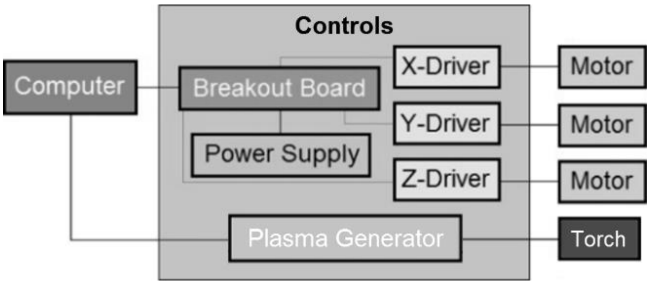

Fig. 7. CNC plasma cutting machine block diagram

Figure 8 shows the complete schematic layout of the motion control board and its pin assignment.

A. *Motion Control*

Figure 8 shows the actual motion controller board used in this study. It is used to communicate with the servo drivers (X and Y) and interact with THC.

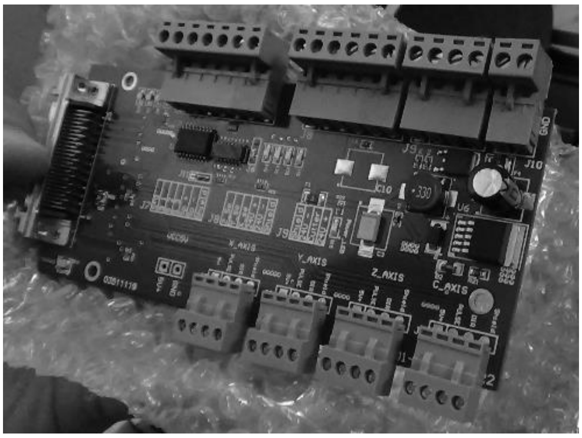

Fig. 8. Actual motion controller board used

The schematic diagram in Figure 9 shows the complete wiring setup starting from the ac power supply, plasma generator integration through THC and the servo driver connections.

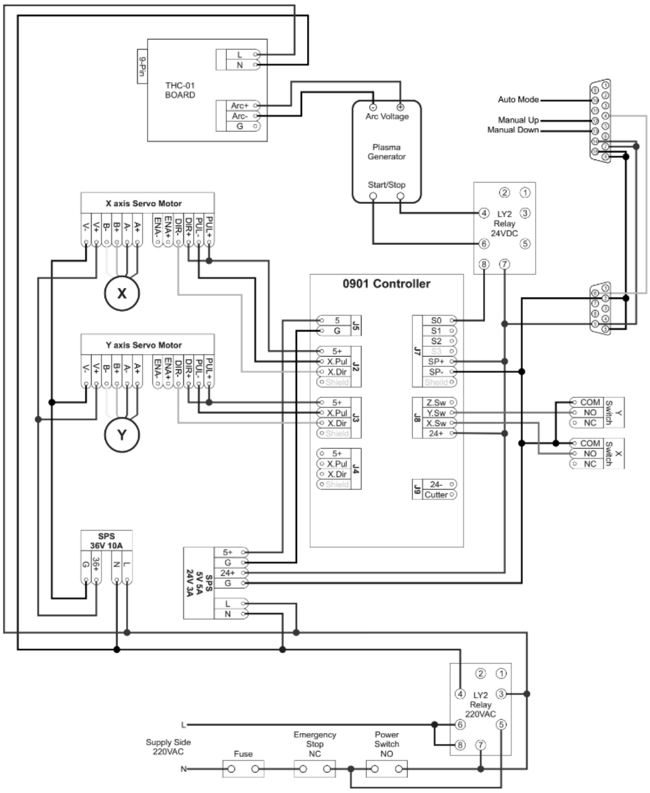

Fig. 9. CNC motion control board

B. *Torch Height Control (THC)*

The torch height control (THC) employed in this research, as seen in Figure 10, is a specialized tool used in any CNC plasma cutting system.

Fig. 10. Torch height controller (THC) process

This type of control utilizes the arc voltage that it senses in adjusting the height accordingly. Its main function is to control the z-height relative to the material being cut. This height is critical to both cut quality and consumable life. Employing this controller to any CNC plasma cutting system ensures good cut quality and helps to minimize some rework operations.

ISBN: 978-988-19253-6-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

V. Testing

The testing of the controller was performed both in terms of cutting performance and its capability to read the generated g-code toolpath from the CAD/CAM software. Figure 11 shows the drawing template used for testing.

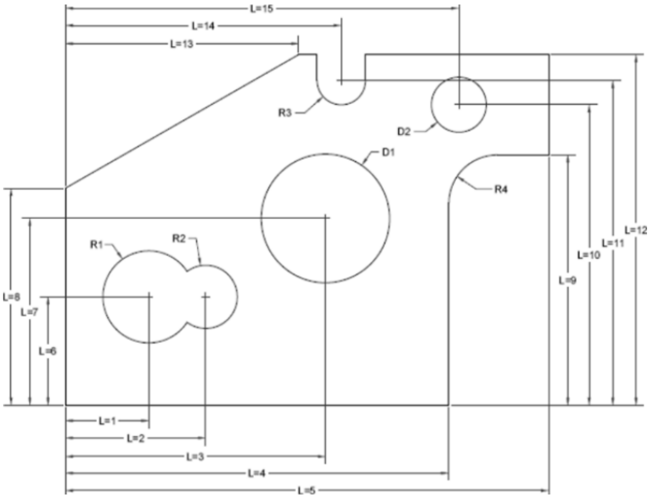

Fig. 11. Drawing template used

This drawing template, generated in VCarve Pro [2], consists of different patterns and geometric shapes. A total of 21 points (dimensional and geometric accuracy) were listed and used to test its performance.

A. *Actual Cutting Profile*

The actual testing was performed in five (5) trials using a template to a 2-mm mild steel plate (see Fig. 12).

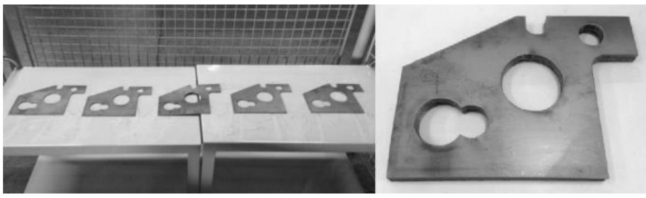

Fig. 12. Actual profiling using a 2-mm mild steel plate

Fig. 13. Coffee table – a sample plasma cut in stainless steel diagram

Also, a sample test cut using stainless steel plate was performed to produce high quality and unique metal artwork products just like the coffee table in Figure 13.

B. *Statistical Testing*

The controller's accuracy performance was calculated using the percentage error (% error) formula, as seen from Eq. 1, wherein the theoretical is the desired value and the actual is the measured or observed value.

$$\%error = \left| \frac{actual - theoretical}{theoretical} \right| x100\% \qquad (1)$$

Figure 14 shows the % error of the five (5) trials. Based from the graph, 0.34% average error was observed which is significantly good in terms of performance accuracy.

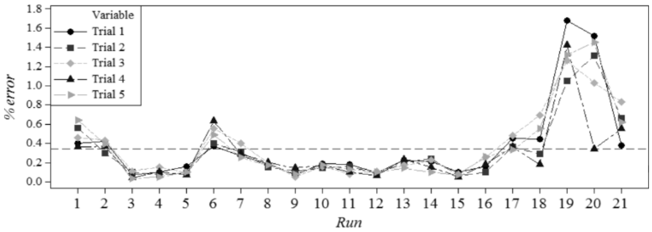

Fig. 14. % error calculation showing 99.66% accuracy (0.34% error)

Also, as depicted from the graph, runs starting from 18 to 21 show high % error values compared with the rest. Figure 15 illustrates the statistical summary of the controller performance in Minitab. To determine the accuracy and reliability, standard deviation was also calculated.

Variable	N	Mean	SE Mean	StDev	Q1	Median	Q3
Trial 1	21	0.3652	0.0939	0.4304	0.1300	0.2100	0.4100
Trial 2	21	0.3210	0.0721	0.3305	0.1000	0.2000	0.3800
Trial 3	21	0.3710	0.0738	0.3380	0.1100	0.2200	0.5150
Trial 4	21	0.2852	0.0666	0.3053	0.1000	0.1800	0.3600
Trial 5	21	0.3543	0.0856	0.3922	0.1000	0.1700	0.5200

Fig. 15. Minitab descriptive statistics

The standard deviation shows the amount of dispersion or variation. A low standard deviation denotes that the data tend to be very close to the mean while high standard deviation means more data points are spread out or dispersed over a large dataset. Statistical result depicts low standard deviation.

Acknowledgment

The authors would like to thank the Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD) of the Department of Science and Technology (DOST) for the research funding, conference publication support and travel grant.

VI. Conclusion

In this study, the controller was able to successfully demonstrate the capability of the CNC plasma cutting machine developed in MIRDC. From the results shown in the VCarve Pro drawing files, the controller was able to read its generated g-code toolpath format (.tap). For the motion, four (4) servo motor drivers (2 for Y-axis) were able to communicate with the motion control board.

Results from the performance test shows that the CNC machine was able to achieve cutting profiles of up to a 1 mm accuracy. Furthermore, a neatly made cut of any metal profiles and up to a maximum cutting thickness of 25 mm (for mild steel) were made possible with the help of the high-capacity 120-ampere plasma generator and the screw-type air compressor system.

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