AC 2011-31: INTEGRATING PROJECT BASED LEARNING THROUGH MACHINE DESIGN, FABRICATION AND TESTING

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Integrating Project Based Learning through Machine Design, Fabrication and Testing

Abstract

Computer Numerical Control (CNC) machines are used in a variety of ways in supporting the development of new products and processes and can provide an excellent means to expose students to standardized control procedures as well as offer opportunities to effectively supplement the teaching of control systems and instrumentation. Using Mach3 ™ for software control and stepper motors for power transmission, a relative low cost but effective CNC Plasma machine was developed by Western Carolina University (WCU) and Asheville-Buncombe Technical Community College through a joint partnership. This paper will present a logical approach to developing such a system and describe how applications have been integrated into curricula at both the two-year and university level programs through Project Based Learning (PBL). Educational merit and approaches will be described relative to respective educational levels.

Background

Western Carolina University is committed to supporting economic development through scholarly engagement and partnerships. The university established a campus-wide mandate for engagement with regional business and industry and has provided for engagement activities that focus on sustaining economic development and boosting entrepreneurial startups through innovative and creative projects, particularly those that develop intellectual capital and technology transfer[1,2,4]. The development of products demonstrating significant potential for entering the market place at low cost coupled with technology transfer resulting in increasing employment in western North Carolina is of particular concern in light of the significant number of displaced workers in the region [3,9].

The Engineering and Technology Department has a long standing relationship with Asheville-Buncombe Technical Community College, through transfer articulation, program offerings, and applied research. A collaborative effort to develop a new CNC plasma system and provide opportunities for students to apply sound engineering principles for both mechanical power transmission and electrical control for a CNC plasma machine was initiated in the summer of 2010 and will continued through spring semester of 2011.

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Project Based Learning

The integration of project based learning is certainly not new and has been implemented across an array of varied disciplines. As suggested by Greenburg [5] and Nelson[6], the responsibility for carrying out the project is shifted to the student while the teacher serves more in a mentor role. Fink[7] further describes the PBL approach as a method that encourages creativity, independent thinking, and proactive self-directed learning. Support for PBL in Engineering Technology include realistic environments that are more similar to those students will encounter when entering the work force, project focused solutions rather that theory focused calculations, and the integration of knowledge from a variety of non-traditional classroom resources. Sheppard and Gallois[8] describe a more holistic method of implementing and integrating technology with an entrepreneurial approach to undergraduate engineering education under an umbrella term called Technogenesis™ as shown in Table 1. Under this broader curriculum approach, technology and applied engineering applications are blended with entrepreneurship and integrated through eight semesters of undergraduate study. Western Carolina University has taken a similar approach of integrating PBL both vertically through four years of study and horizontally across three different engineering and technology programs. These programs included electrical engineering, electrical and computer engineering technology, and engineering technology. Further, PBL culminates in a team approach during the senior capstone where industry sponsored projects are carried out. The sponsored projects are coordinated through the University's Rapid Center for Product Realization, and all senior project classes fall under the responsibility of the Rapid Center's director. The goals, logical progression and integration of PBL at WCU are shown in Table 2.

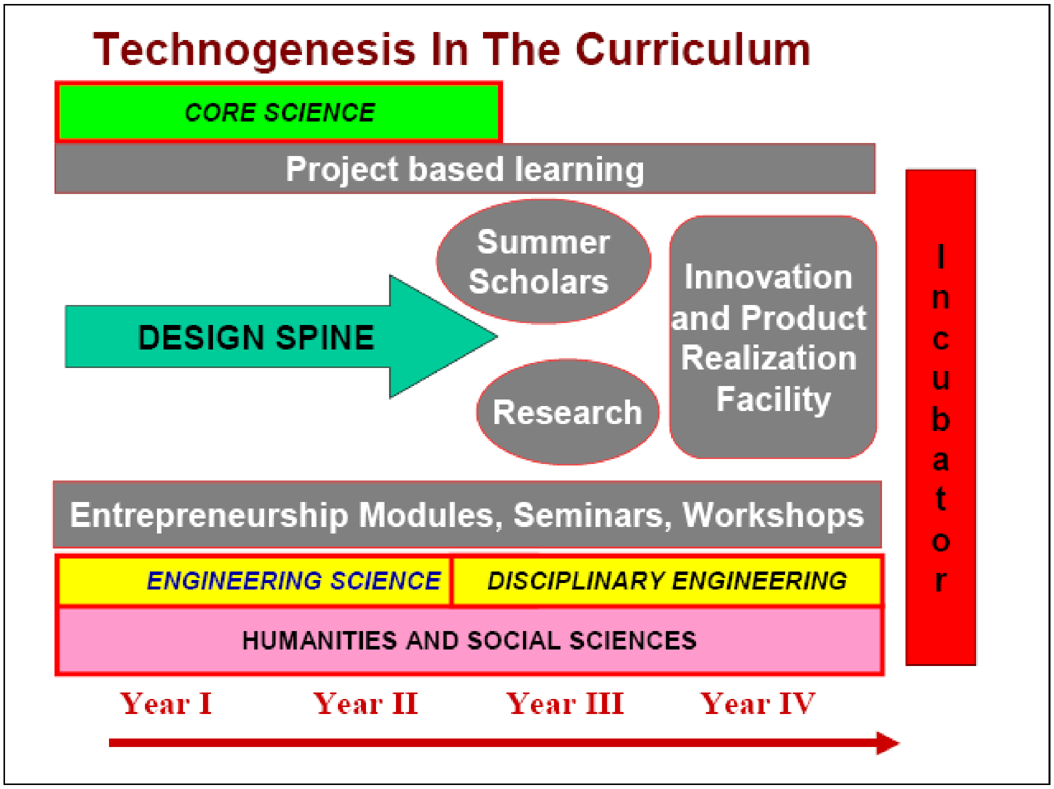
The incorporation of PBL as described in this paper focuses on the integration of mechanical and electrical engineering applications through a joint partnership between the university and a regional community college. Elements of entrepreneurship are included such that design and fabrication are developed for a Do-it-Yourself-Kit (DYK) with customer input playing a vital role in the development of the CNC system. The entrepreneurship approach consists of enabling a small business to sell units in a Ready to Assembly (RTA) package. The focus, however, is more on learning engineering principles through direct project development employing PBL as the primary instructional method.

To fulfill the goal of nurturing technical professionals with strong experiential skills, the focus is on applied scientific knowledge and engineering principles rather than traditional engineering theory and engineering design as stressed by both Kumar[10] and Grinberg[11]. Based on the foundations of PBL and the nature of the requirements for the CNC Plasma project using a design-build-test approach, a logical and compatible fit existed between the two.

CNC Plasma System Design

Companies such as Torchmate™ and PlasmaCam™ produce commercially available units with controllers that function quite adequately; however, cost and options may not be desirable for many end users. The CNC plasma system developed was done so with several factors in mind. Alternative options providing simple operation and control, relatively low cost and high quality were set forth as desirable design characteristics. Further the system was presented to the student teams for developing a Do-it-Yourself-Assembly (DYA) approach. The focus was not on new component design, but rather implementing off-the-shelf, readily available components that could lead to the development of a Ready-To-Assembly (RTA) kit with options based on the needs of the consumer.

Table 1: Technogenesis ™ Model Developed by Sheppard and Gallois.



Western Carolina University and Asheville-Buncombe Technical Community College worked collaboratively in the development of a PBL approach that could enhance learning opportunities for both two and four year engineering technology students to carryout the CNC plasma project at the community college laboratory test site. After reviewing designs for CNC plasma machines relative to cost, capacity and control system parameters of existing systems, benchmarks were identified for the PBL project. A decision was reached to implement a method for simple construction, open loop control, and provide a 4' x 4' nominal cutting area. Due to the structural integrity, availability, and ease of fabrication, extruded aluminum was selected for the structural fame. Gecko™ drives were identified as being the most cost effective, simple, and effective units for drive control, and electrical circuitry requirements were defined. Finally, Mach3 ™ software was selected due to its common use, affordability (running on a personal computer serving as the main machine controller), customer support, and cost. Rack-And-pinion (RAP) drives were also selected based on simply design, cost, and mounting options to extruded aluminum structures.

Table 2: Project Based Learning Model at Western Carolina University.

Project Based Learning Conceptual Model				
Project Control Level	Tightly Directed			Open Ended
Year	**Freshman**	**Sophomore**	**Junior**	**Senior**
	Fall class	Spring Class	Spring Class	Fall and Spring
Course Number	ENGR 199 and ENGR 200	Separate Classes: ET 362,ECET 290, EE 222	ENGR 300	ET 461/478,ECET 478/479,EE 401/402
Theme	Tools		Application	
	Introduction to Design Tools	Synthesis of Curriculum Subjects	Synthesis of ET, EE, and ECET Curriculum Subjects	Deliverable Engagement Project
Course outcomes	Introduction to Project planning	Scientific Method	Creativity	Proficiency in all introduced outcomes
	Intro. To Design Process & Impact	Problem Solving	Sustainability	
	Intro. To Teaming Training	Self Directed Learning and Research	Mixed teams	
	Communication Tools and Format	Communication, Practice, Reports and Presentations	Communication Lab Reports, Engineering Package	
Classes	Combined Classes	Separate Classes	Combined Teams of EE, ET and ECET students	EE, ET and ECET Combined
Type of Projects	Canned Projects	Canned Projects	Student designed industry projects Competitive Project	Open ended Projects

After considerable research, a fabrication company was identified that sold the mechanical components for mounting stepper motors coupled to a RAP system. In many cases, the cost of components was less than purchasing the material and fabricating custom parts. An initial conceptual design as shown in Figure 1 was developed based on the stated constraints and component resources.

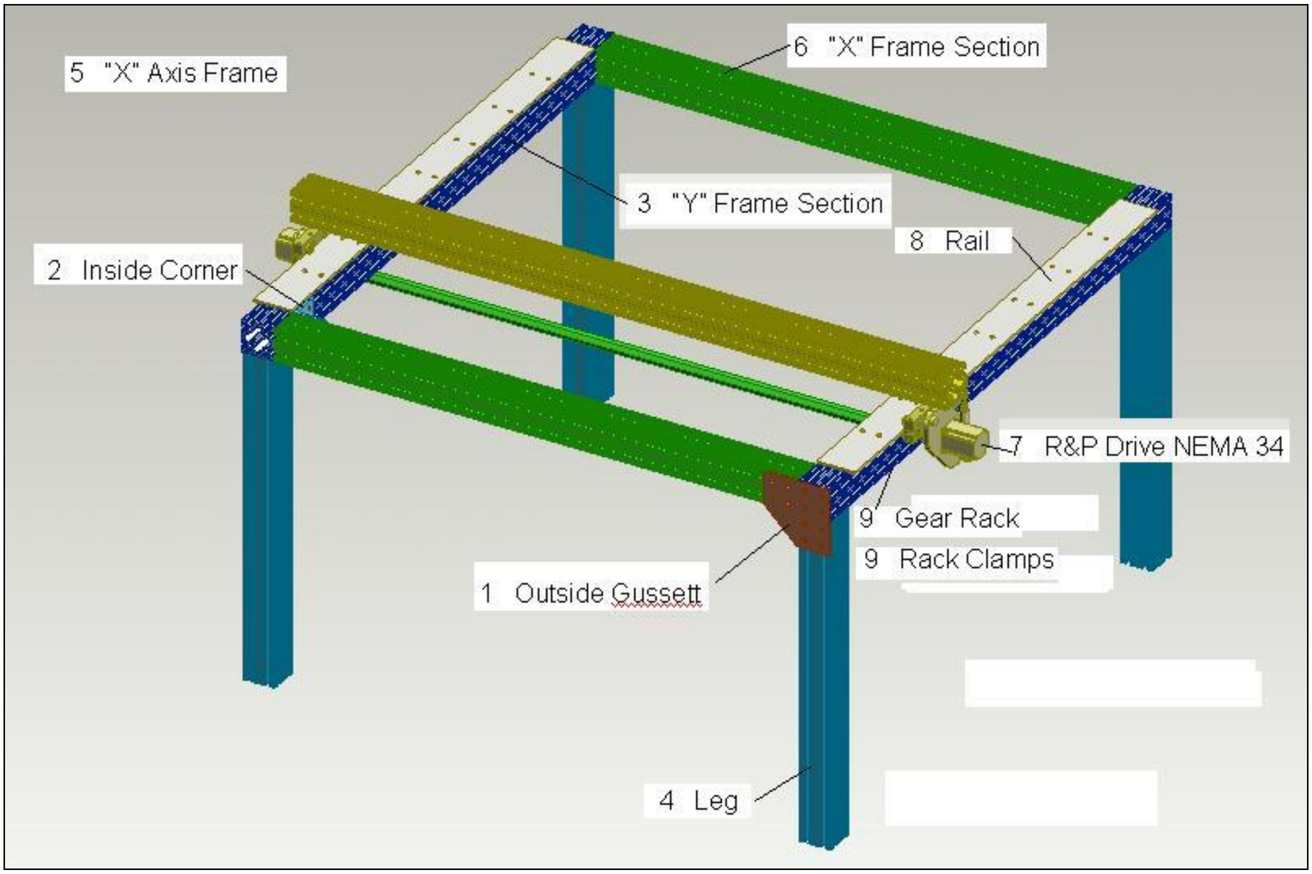


Figure 1: Initial Structural Parametric Model of the CNC Plasma Table

Controls Drives and Resolution

Current drive technology and more efficient motor development has enabled the cost of open loop, drive systems such as stepper motors to be implemented for controlling mechanical drives at a relatively low cost. While newer technology employing direct current and alternating current servos has replaced the older stepper motor technology, stepper motors still are quite practical and viable for open loop systems that require less accuracy than modern machine tools. A major advantage of such systems is the cost to implement a much more simple method of control. Further, drives are readily available and compatible with digital communication through a standard parallel printer port. Software is also readily available for both configuring and controlling such systems at low cost. Specifically, Gecko ™ drives provide the capability to micro-step yielding a resolution of 2000 pulses per revolution when controlling stepper motors, and Mach3 ™ software provides the same attractive feature since it is compatible with the Gecko drives and uses a standard parallel printer port for communication, sensing, and control. This approach not only provides a low cost and simple solution for open loop machine control, but also provides a practical means for teaching digital control and applications through actual machine control. Initial laboratory results have shown the resolution using a Gecko ™ drive configured for 10 micro-steps to interface to a 1.8 degree stepper motor coupled to a rack and pinion drive train can produce a resolution of .0008 inches per pulse when incorporating a 2:1 gear reduction. Calculations results showing resolution and frequency are shown in Table 3.

While closed loop systems provide greater accuracy and improved performance, this project focused on open loop systems that were challenging enough for students but not as complex as servo systems. In the case of plasma CNC control systems, accuracy does not need to be as high as with CNC machining. Two viable structural prototypes demonstrating proof of concept were developed in the initial phase of the project. During the second phase, electronic circuitry, a reliable and accurate drive train, and control software was integrated into the design and prior to testing.

Table 3: Summary of Drive Train Calculations.

Pinion Gear Resolution, Speed, and Frequency Calculated Results								
Driver Microsteps	Motor Steps/rev	Gear/Belt Ratio	Pinion Gear		Move Spd inch per minute	**Steps per** (inch)	Min. Freq. kHz	Resolution[inch]
			Diametral Pitch	Number of teeth				
10	**200**	**2**	**20**	**20**	**120**	**1273.240**	**2.5**	**0.0008**

Component Selection and Methods of Control

The goal of the CNC plasma project was to satisfy the design requirements and serve as a vehicle for implementing PBL into the curricula for both two and four year engineering technology programs. Based on estimated load calculations and desired range of positional control, systems were identified to meet the required specifications for the drive train, motor control and program execution. The methods of control and selected input/output components are shown in the Table 4 and Figures 3-5.

Table 4: Base Structural and Drive Components

CNC Plasma Machine Major Components			
Part	*Quantity*	*Base Price*	*Source*
Carriage	5	$34.00	CNC Router Parts
Rack-and-Pinion Drive	2	$89.00	CNC Router Parts
Rails	3	$50.00	Fine Line Automation
Gear Rack	2	$60.00	Fine Line Automation
Motor Mount and Drive	2	$139.00	CNC Router Parts
Stepper Motors	2	$104.00	Automation Direct
Frame 3x3	16 Ft.	$700.00	80/20 Corporation

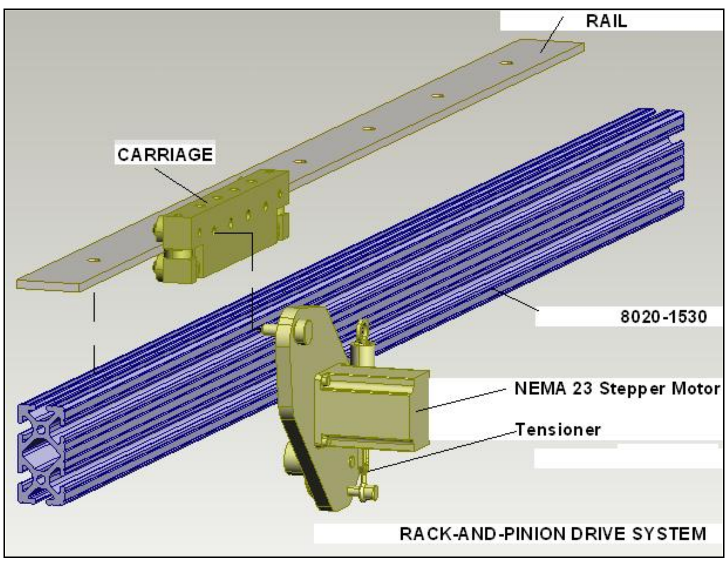


Figure 3: Drive mounted on 80/20 aluminum.

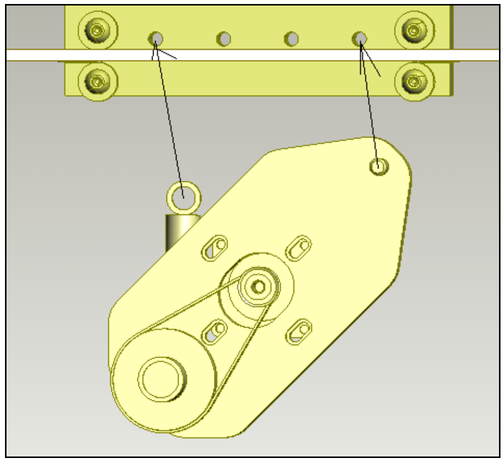


Figure 4: Motor Mount.

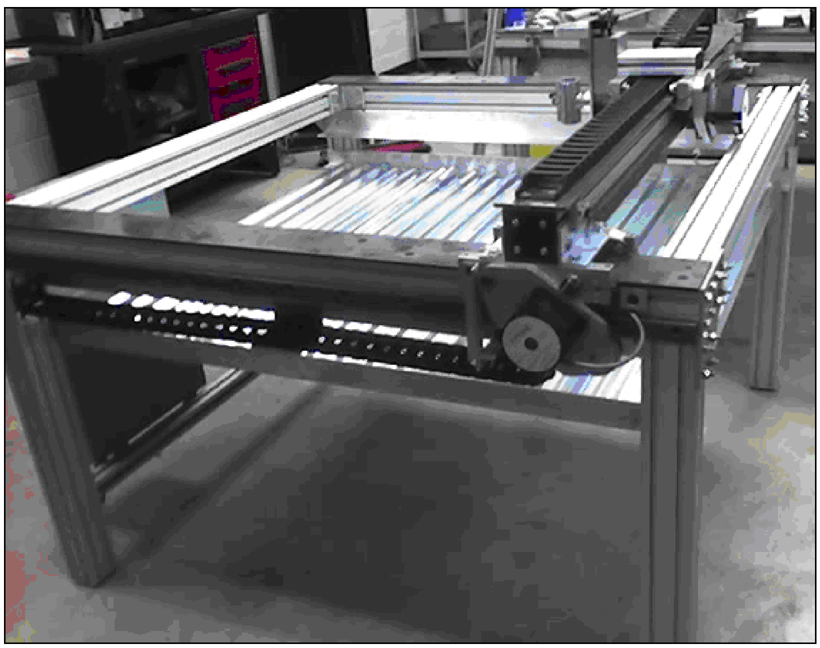


Figure 5: Completed Mechanical System

Mach3™ was selected as the primary method for variable monitoring, configuration, and control due to the capabilities for interfacing with Gecko drives and standard CAM software. Mach3™ is very suitable for CNC milling, lathe applications, and plasma cutting. Further, Mach3™ has become more popular with private users, commercial businesses, and educational institutions. Mach3™ also provides a resident CAM package included with the base package, or Numerical Control (NC) files can be imported from a variety of other commercial CAM packages with relative ease. Post processing plug-ins are also available. Mach3™ control and configuration panels are shown in Figures 6,7.

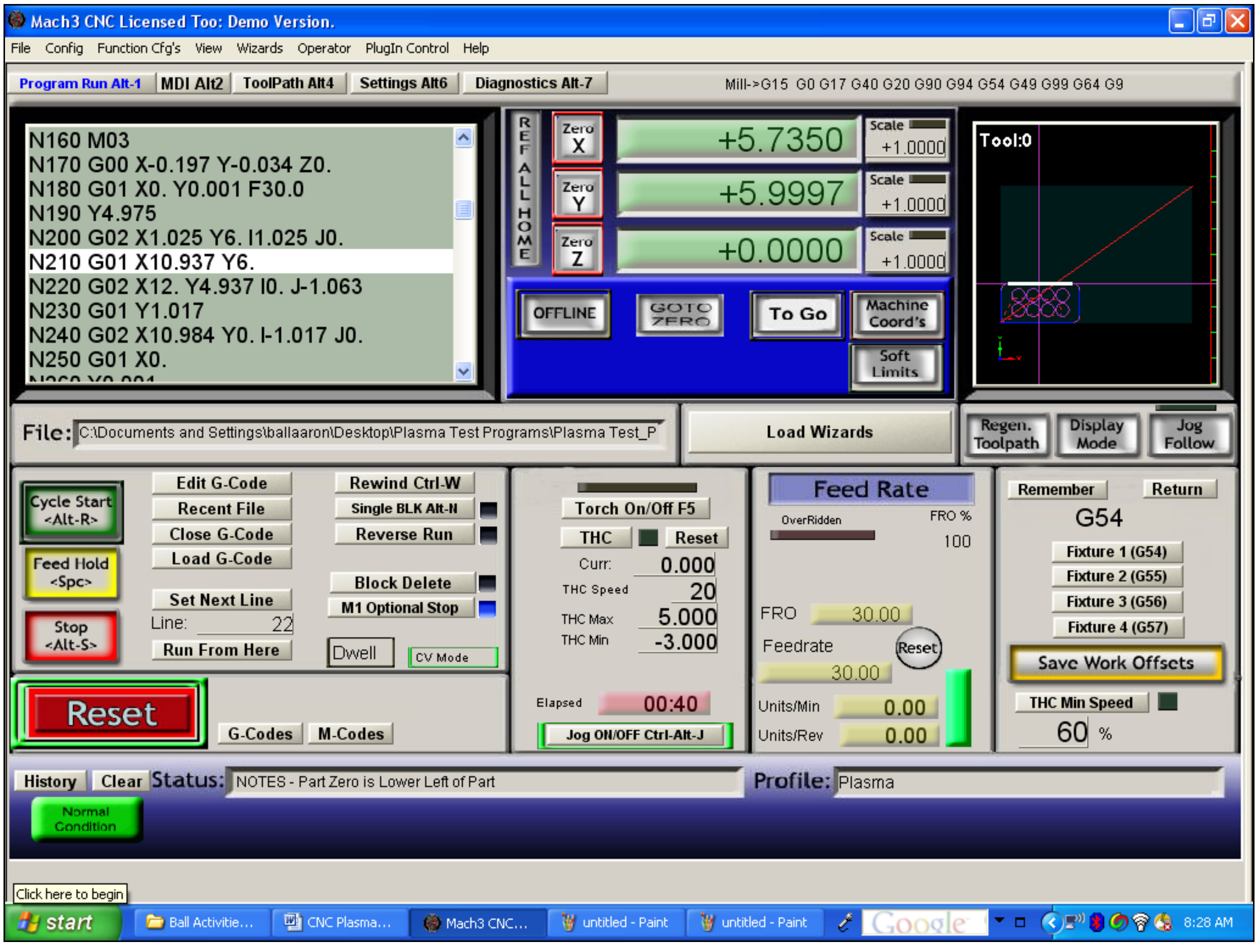


Figure 6: Mach3™ Control Panel

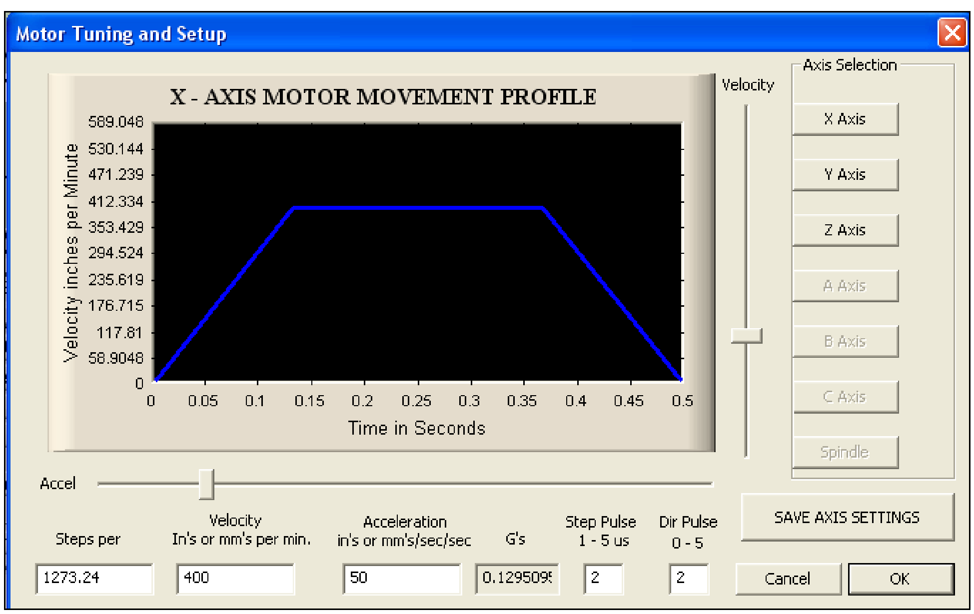


Figure 7: Mach3™ Motor Tuning Configuration

Educational Goals

The CNC plasma project presented a challenging opportunity for integrating the development and PBL application into engineering and technology courses. Specifically, the educational goals of the project were the professional and technical skill development of faculty and students, engineering project work for students, and developing laboratory equipment to support research and courses in control systems, instrumentation, and CNC. Students were involved in all phases of the project including design, fabrication, and installation under the supervision of faculty. Community college students participated in structural system fabrication and testing, electrical controls, and assembly. Students at the university were responsible for 3D modeling, custom machining, and drive train verification. Solid models were imported into OneCNC CAM package for producing required CNC programs which in turn were developed for a HAAS V3 machining center. Custom components of the plasma system were fabricated and assembled on the WCU campus then delivered to the Asheville-Buncombe test facility for installation.

Faculty Involvement

Faculty members from both the university and community college were involved in numerous activities throughout the project. This close partnership was strengthened through total team participation between the two institutions. Although the lead faculty members served as project coordinators, and community college faculty were initially charged with the responsibility for control development and testing, all faculty were committed to making the project a success. Both institutions freely exchanged support in the form of test site development, instrumentation and control, and testing. As a result of this cooperative team effort, a Plasma CNC system was developed to support both product development and PBL for both two-year and four-year institutions.

Student Involvement

Snellenberger[4] and his colleagues emphasized the need for students to attain higher technical skills and practical engineering experience to reinforce a stronger U.S. engineering workforce[4]. Aside from technical skills, practical engineering experience, and progressive professional skills from industry, advisors often urge that graduates must be made aware of skills such as planning, communications, and safety. The comments from industrial advisory board members have had a major influence on the engineering and technology programs. Under their guidance, the curricula for each of the engineering and technology programs were designed to provide flexibility and accommodate two general categories of students. For community college students seeking to transfer to a bachelor’s degree program, electives in math and science are made available. However, for those students seeking immediate employment with an associate’s degree, project classes are recommended to provide workplace experience. Project classes are the vehicles for allowing the student to integrate the technical and non-technical skills in a formal approached called PBL. The Plasma CNC project, with challenges in many disciplines, was well suited for this very type of student experience. This project was in essence the experience that ABET[12] supports and industrial advisory board members desire.

Students from both institutions made important contributions and support to the project. Western Carolina University students were primarily involved with engineering documentation and modeling, rapid prototyping, and component machining. Graduate students also modeled drive trains, verified calculations and configurations for software. Two-year college student involvement included site development work, structural assembly, instrumentation, controls, and testing.

Overall Benefits of the Project

In addition to the educational benefits, a win-win situation has been further developed through the non-competitive and collaborative efforts of each educational institution. It is widely recognized that technology transfer has the potential to enhance the competitiveness of small businesses, which in turn spurs regional economic development and job growth. As a result of this project, a CNC Plasma System was developed that could support such initiatives. Additionally the central missions of Western Carolina University and Asheville-Buncombe Technical Community College have been complimented through efforts in providing students and faculty exposure to new technology and modern engineering applications. Students gained the potential to expand the body of knowledge and demonstrate concepts of viable product development leading to a fully functional CNC Plasma cutting system. .

Conclusion

Western Carolina University and Asheville-Buncombe Technical Community College contributed resources and support for the design, fabrication, and testing of the CNC Plasma System. This creative and applied engineering project provided each institution with the opportunity to integrate applications of theoretical concepts into course and laboratory exercises as well as supporting research. The CNC project provides multiple learning and research opportunities for community college students, university undergraduate and graduate students, and faculty from both institutions. Faculty have gained and strengthened their technical knowledge of subjects that may have otherwise remained uncultivated. Further, students were provided opportunities to solve real design problems and gain experience in fabrication, system control, and testing. The knowledge and experience gained will prove to be valuable in the enhancement of engineering technology curricula and support of future engagement projects.

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