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Laser marking in CNC mills.

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Laser Equipped CNC Mills

Project Number MQP-TSB-AAOZ-21968

DESIGN AND ANALYSIS OF A MECHANICAL SYSTEM TO DO AUTOMATED LASER
MARKING IN A CNC MILL.

A Major Qualifying Project Report

Submitted to the Faculty

of the

Worcester Polytechnic Institute

in partial fulfilment of the requirements for the

Degree of Bachelor of Science

In Mechanical Engineering

By

Edmund C. Resor



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Approved:

Professor Torbjorn Bergstrom

1. CNC
2. Mechanical System Design
3. Axiomatic Design

Abstract

Every year the WPI Manufacturing Laboratories manufactures medallions for Alumni weekend. The current system requires many valuable man hours to function. Creating an automated system to laser mark the medallions would improve the current medallion production system. The goal of this MQP is to use Axiomatic Design to design a mechanical system that would enable automated laser marking to be done safely inside the CNC Machine tool that finishes the medallions. Several candidate designs were evaluated based on information content and uncertainty in their integration and operation. Using a single slide and a galvo laser significantly reduced the information content of the system. This system will be adequate for marking and engraving. Thus it has the potential to serve as a starting point for integrating other manufacturing process, such as additive manufacturing, with CNC milling. This is important since process integration is becoming increasingly important in the efficient production of emerging technologies.

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1. Introduction

1.1.1 Current process

In less than two weeks, each year, the Washburn Manufacturing Laboratories manufactures at least 600 medallions for alumni weekend. Before being marked the medallions are presented to the alumni. The current process is described in Figure 1. The red steps require the presence of a student worker to perform dull, repetitive actions.

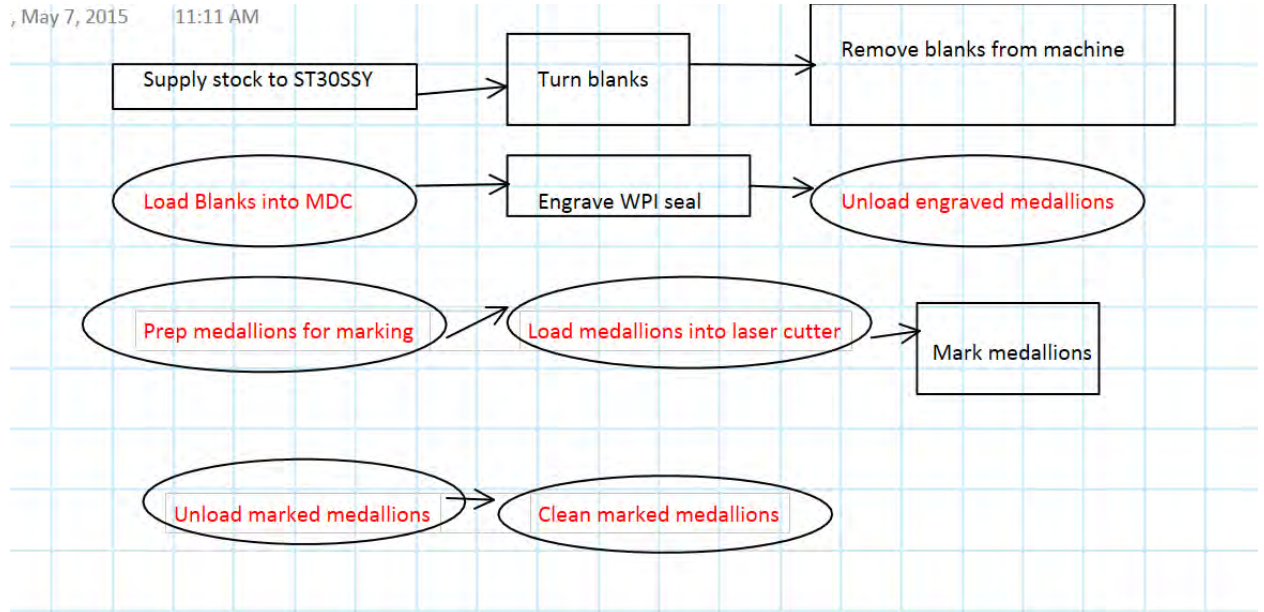


Figure 1. Current process

1.1.2 Objective

Much of the work surrounding the production of Alumni medallions involves tasks related to the laser marking of the medallions. The current machine that is used to do the laser marking is incompatible with the practical methods of automating these tasks. The objective of this Major Qualifying Project (MQP) is to design a mechanical system that will allow for the automated laser marking of Alumni medallions. This project will focus on the laser marking and the physical integration of the laser into the new automated production system. The method for automating the production system is described in Figure 2.

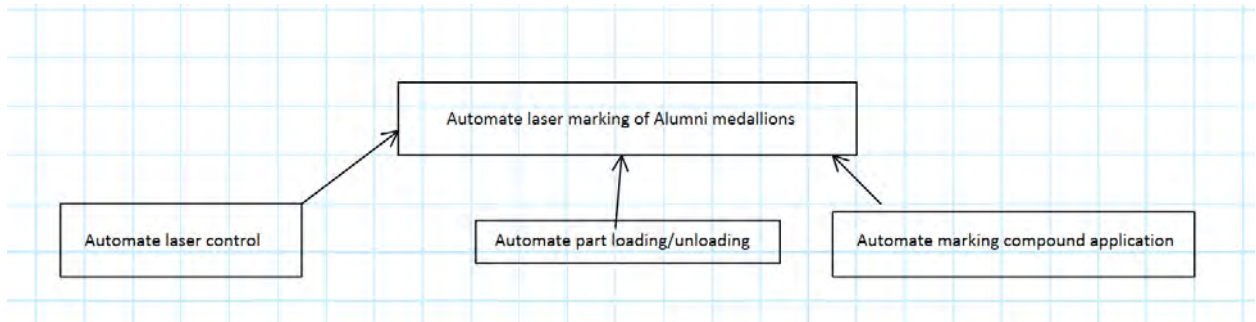


Figure 2. Automation of laser marking

1.2 Rationale

The system developed by this MQP will provide a cost effective way of increasing the quality of service available to the Worcester Polytechnic Institute community (WPI) from the Washburn Manufacturing Laboratories. The first order effects of this system will be to decrease the man hours required to manufacture alumni medallions without a decrease in quality and to provide a platform for exploring integrating different manufacturing techniques into one machine.

1.3 State of the Art vs. Current Process

The current process for laser marking the medallions starts with a student worker applying marking compound to machined medallions. In the next step the student loads the prepared medallions into the lab's laser cutter. The position of each medallion is specified for the laser printer to correctly mark each medallion. This step in the marking process is shown in Figure 3.



Figure 3. Current marking process (Bergstorm, T., 2012)

As can be seen, the current process is a batch process. Before the first marked medallion can be delivered, the entire batch must be marked. The batch size varies with the rate that the alumni arrive with their machined medallions for personalization. This leads to down time for the marking process as well as volatile waiting times for the alumni who bring their medallions to be marked.

Two commercially available systems were found that allow machining and laser marking of parts to be done in the same machine: the AMBIT™ tool changeable laser head in Figure 4 that works with milling machines and the BoXZY Desktop MakerSpace in Figure 5.

AMBIT™, developed by Hybrid Manufacturing, is a head and docking solution built for integrating manufacturing systems for flexible and lean remanufacturing {(Jones, J. 2012), (Jones, J.B. et al, 2012)}. This is a very versatile system, designed for CNC milling machines. The various heads that can be mounted allow for many different processes and the change between heads is automated and quick.

Due to space constraints inside the MDC's enclosed work area, and the fact that the MDC's spindle moves in the XY plane, not the work piece, adding the AMBIT™ tool head to the MDC is not a viable option. Its expense and versatility make it most suitable for high volume, high value manufacturing situations.



Figure 4: AMBIT™ tool changer (Jones, J., 2012)

The BoXZY Desktop MakerSpace is intended to “be a complete desktop manufacturing space” (Alec 2015). The unit is an innovative combination of functions: CNC Mill, 3D Printer and Laser Engraver, using quick change heads to create and laser engrave complex items. However, the system does not possess the performance capabilities required by Washburn Labs. The existing CNC milling needs are already met by the MDC so this function is redundant. The BoXYZ would not be able to automate the laser marking of alumni medallions in spite of its ability to do three functions. It is more of a prototype machine than a machine for the production of many personalized units. The changing of tool heads is not automated and there is no system for automatically loading and unloading parts.

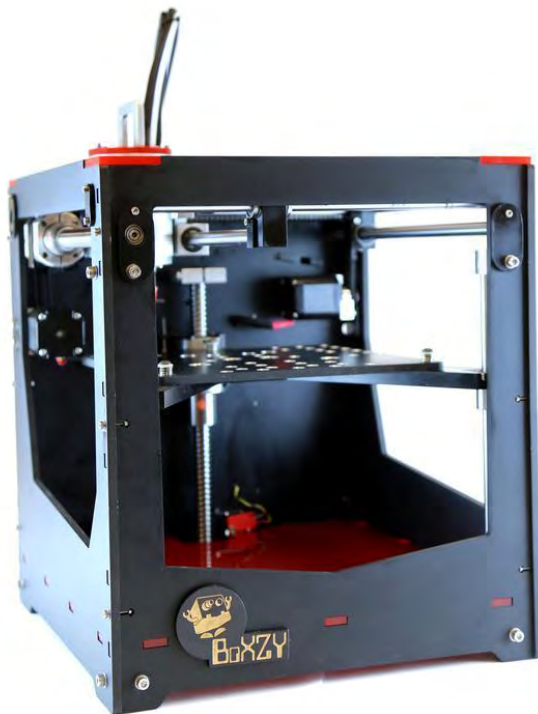


Figure 5. BoXYZ system.(Alec., 2015)

1.4 Approach

This project focusses on the laser marking and physical integration of the laser marking system with the MDC. This project is working in conjunction with other projects that deal with the electronic integration (Eberheim, R. 2015), automating the part loading/unloading (Bourque, D. et al. 2015), and automating the application of the marking compound (Cornelius, A. et al. 2015) to automate the entire laser marking process.

1.5 Method

The design method used for this MQP is Axiomatic Design which analyzes the customer needs and constraints as a way to evaluate proposed solutions. This maximizes the flexibility of the end result and minimizes iterations in the physical prototype stage.

2. Design Decomposition and Constraints

2.1 Current Process

The needs of the Washburn Manufacturing Laboratories, the customer, for the manufacture of medallions are the first inputs to the design process and are listed below as Customer Needs [CNs] beginning first with the CNs for the current process. These are followed by a description of the customer's constraints on possible solutions to these needs.

The Customer Needs [CNs] for the current process are shown in Figure 6.

#	[CN] Customer Needs
0	Customized Alumni Medallion
1	600-800 parts must be produced
2	each part must have custom design marked onto it

Figure 6. Original Process Customer Needs

Washburn Labs have certain restrictions to the manufacture of the Alumni Medallions. The constraints for the current process are detailed in Figure 7.

#	[CON] Constraints	Description
0	Parts must be made in Washburn Manufacturing Laboratories	
1	Parts must be made between the end of the school year and the end of Alumni weekend activities	
2	All personell working on project must be wpi staff or student workers.	
3	Medallions must be presented to Alumni between machining and marking	

Figure 7. Original Process Constraints

These customer needs and constraints call for Functional Requirements [FRs] and Design Parameters [DPs] in the making of the Alumni medallions at Washburn Labs. Figure 8 aligns the Functional Requirements with Design Parameters for each step of the current process.

#	[FR] Functional Requirements	[DP] Design Parameters
0	Produce customized alumni medallions	Medallion production system
1	Manufacture medallion blanks	ST30SSY
1.1	Keep machine supplied with stock	bar feeder
1.2	Turn blanks	Turning program
1.3	Remove finished parts from machine	Part catcher
2	Engrave WPI seal on medallion	Mill drill center
2.1	Load MDC with blanks form ST30SSY part catcher	Shop personnel
2.2	Engrave seal	Milling program
2.3	Unload engraved medallians	Shop personnel
3	Lasermark custom design on to medallion	Lasermarking system
3.1	Prep medallion for marking	Shop personnel
3.2	Load shop laser cutter	Shop personnel
3.3	Mark medallion	Laser cutter
3.4	Unload marked medallions	Shop personnel
3.5	Clean marked medallions	Shop personnel

Figure 8. Current process decomposition

As shown in Figure 8, the current process requires three different machines. The laser cutter is in a separate room from the CNC machines. This requires three separate setups and places limitations on the Design Parameters [DPs] that can be used to meet additional Customer Needs [CNs] and Functional Requirements [FRs] for improvements such as automation. The extra setups increase the information content of the set-up and operation instructions for the process. The task of automating the production process is decomposed in Figure 9.

#	[FR] Functional Requirements	[DP] Design Parameters
0	Automate laser marking of Alumni medallions	Automated laser marking process
1	Automate laser control	CNC controled marking laser
2	Automate part loading/ unloading	System to load and unload parts
3	Automate marking compound aplicaiton	System to apply marking compound to medallion

Figure 9. Decomposition of process automation

As previously stated, this MQP is only dealing with the marking of the medallions in the Mill Drill Center (MDC). Moving the marking process into the MDC will make it possible to use the same robot arm to do the loading and unloading for both engraving and marking and to possibly automate the entire process in one location if a solution can be found to do the preparations for the marking. Without moving the marking to the Mill Drill Center (MDC), the automation of the other processes will have a much lower impact and the other children of Functional Requirement 3[FR3], in Figure 8, cannot be changed for improved FRs.

The requirement to satisfy the Customer Needs [CNs] and Constraints [CON] of the current process in the new process is handled by the 4th Customer Need used to design the current process. The [CNs] used for this MQP are described in Figure 9.

#	[CN] Customer Needs
0	Automated laser positioning
1	Support automated part load/unloading
2	Comply with safety rules and regulations
3	Method to prevent unauthorized operation
4	Must be able to integrate with current medallion production process

Figure 10. MQP Customer Needs

Functional Requirement 0 [FR0] “Automatically position laser focal point” and Design Parameter 0 [DP0] came with several constraints. The Constraints are listed in Figure 14.

#	[CON] Constraints
0	System cannot interfere with other services offered to the WPI community
1	Must be able to function in the dry side of the MDC
2	Comply with WPI Laser safety policy
3	Must be able to integrate with MDC & ABB

Figure 11. MQP Constraints [CON]

Constraints 0 and 2 stem primarily from concerns about safety. The reasoning behind Constraint 1 is shown in Table 1 and Table 2.

<u>Laser on ABB Table</u> <u>Figure 12</u>	<u>Laser in Dry side of MDC</u> <u>Figure 13</u>	<u>Laser in Wet Side of MDC</u> <u>Figure 14</u>
Operation of laser independent of spindle	Operation of laser independent of spindle	XYZ positioning can be done by spindle
Protected from chips, coolant, tool failures	Protected from chips, coolant, tool failures	Simpler software control
Protected from tool changer operation and crashes	Protected from tool changer operation and crashes	Preserve space on ABB table
Protected from spindle operation and crashes	Protected from spindle operation and crashes	
	Preserve space on ABB table	
	Protected from day-to-day lab operations	
	ABB already set up to load/unload parts from this locations	

Table 1. Factors in favor of each location for the laser marker

<u>Laser on ABB Table</u> <u>Figure 12</u>	<u>Laser in Dry side of MDC</u> <u>Figure 13</u>	<u>Laser in Wet Side of MDC</u> <u>Figure 14</u>
Would possibly interfere with 4815 projects.	Need to design positioning system for laser focal point	Lots of coolant spray
Risk from day-to-day operations	Difficult software integration	Chips
Difficult software integration		Risk from tool failure
		Risk from spindle crash
		Risk form tool changer crashes
		Limited space
		Laser operation not independent of spindle operation

Table 2. Factors against each location for the laser marker



Figure 12. ABB table



Figure 13. MDC dry side



Figure 14. MDC wet side

2.2 Market Ready Options

Two systems are available that satisfied the customer needs while complying with the given constraints. Before designing a custom system the two commercial system AMBIT™ (Figure 15) and BoXZY (Figure 16) were evaluated to see if they could satisfy the Customer Needs [CNs] and Constraints [CONs].



Figure 15. AMBIT™ in operation (Jones, J. 2012)

The design of the Ambit System already has a method for automatically positioning a laser in the X, Y and Z axes. Since the AMBIT System functions as an add on to a CNC machine most of the necessary safety precaution are already taken care of (i.e., estop and machine lockout). If the machine that is equipped with AMBIT System supports automated part tending and being integrated into a production line, the AMBIT system will also support these functions.



Figure 16. BoXZY being loaded with its 2 watt laser (Alec. 2012)

The BoXZY design only supports the positioning of a laser in Z and in the XY plane. BoXZY is designed to be a standalone desktop machine and this is the source of the issues with using it for this application.

2.3 Custom Design Version 1

For Functional Requirement 0 [FR0] to be satisfied three requirements must be met. The laser needs to be positioned in Z [FR1], it must be positioned in the XY plane [FR2] and the system must comply with applicable safety rules and policies [FR3]. The decomposition of the Functional Requirements [FRs] in Version 1 is shown in Figure 17.

#	[FR] Functional Requirements	[DP] Design Parameters
0	Automatically position laser focal point	System to position laser focal point
1	Position laser in z	laser head deployment system
1.1	Provide safe home position	28 inch travel capacity slides
1.2	Locate home position	Home limit switch
1.3	Locate work position	Work limit switch
1.4	Set work position	Positioning bracket
1.5	Keep laser in home position when power is off	Power off shaft brake
2	Position laser focal point in XY plane	XY positioning system
2.1	Provide stable reference point in XY plane	Positioning bracket
2.2	Position focal point in X	X axis slide
2.2.1	Set X axis home position	X axis home limit switch
2.2.2	Track X axis movement	X axis rotary encoder
2.3	Position focal point in Y	Y axis slides
2.3.1	Set Y axis home position	Y axis home limit switches
2.3.2	Track Y axis position	Y axis rotary encoders
3	Comply with applicable safety rules and policies	System to ensure compliance

Figure 17. Version 1 FR-DP Decomposition

To understand the information content and uncertainty in the Functional Requirements [FRs] and Design Parameters [DPs] of Version 1, the physical structure of the system must be taken into account. As shown in Figure 18, five different slides would have to function properly for the laser focal point to be correctly positioned. The two (black) Z axis slides and two (yellow) Y axis slides would have to move in sync so that they would not bind.

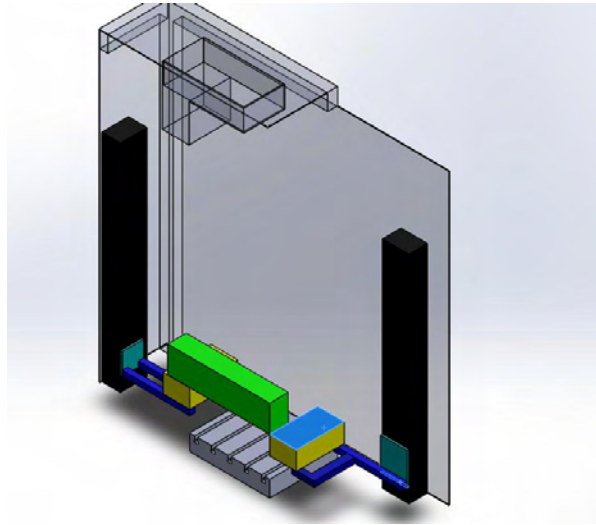


Figure 18. Version 1 model Five slides have to function to position laser focal point

In addition to this, the complex process required to install and assemble the positioning system in the dry side of the MDC increases the information content and uncertainty yet again. Finally, because of the mass of the Laser head, Y and X axis slides would have to be supported by a counter-weight system (not pictured) to reduce the moment arm on the Z axis carriages.

2.4 Custom Design Version 2

The differences between Versions 1 and 2 stem from the change in Design Parameter 2 [DP2]. [DP2] in Version 2 is an XY galvanometer scanner. The use of the scan head allows a much simpler structure as shown in Figure 19.

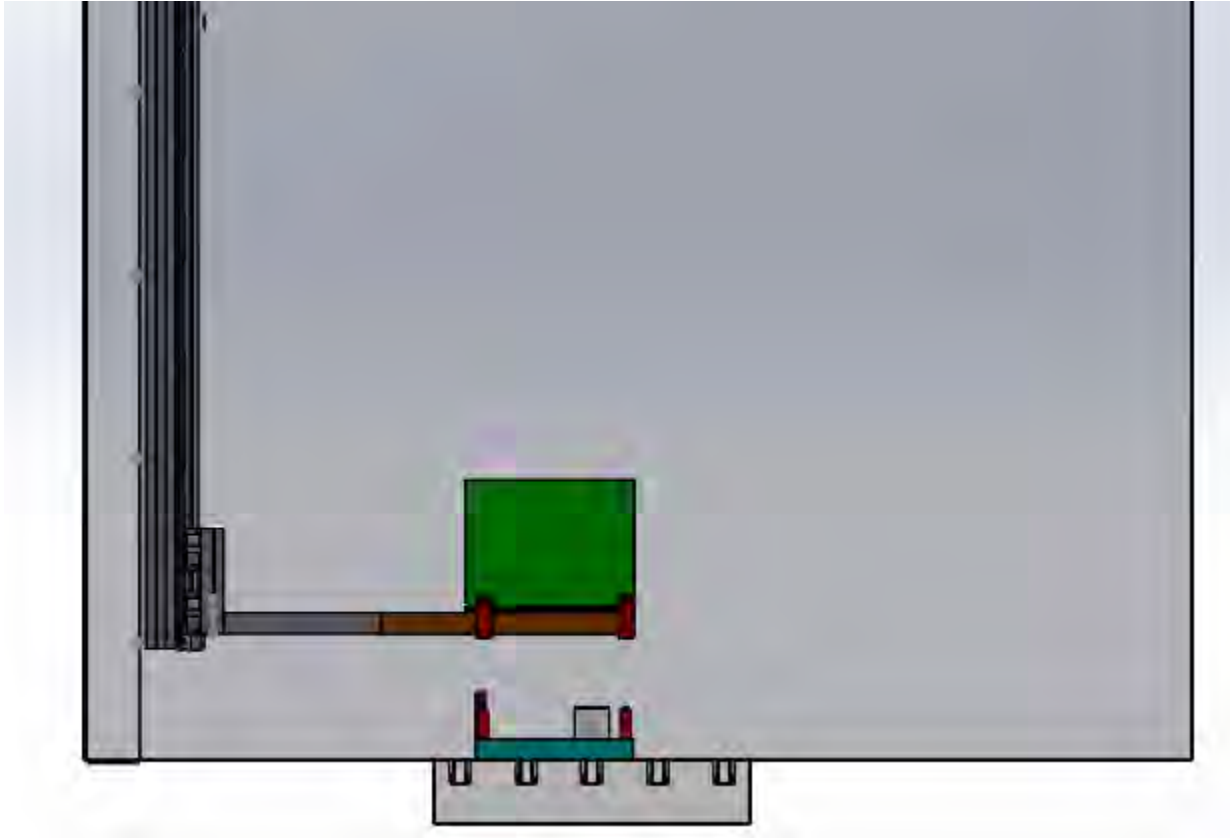


Figure 19. Version 2 as seen from the door in figure 13 (mounting spacers not shown)

The lower information content of Version 2 is also reflected in its decomposition as shown in Figure 20

#	[FR] Functional Requirements	[DP] Design Parameters
0	Automatically position laser focal point	System to position laser focal point
1	Position laser in z	Laser head deployment system
1.1	Provide safe home position	28 inch travel capability
1.2	Locate home position	Home limit switch
1.3	Locate work position	Work limit switch
1.4	Set work position	Positioning bracket.
1.5	Keep laser in home position when power is off	Power off shaft brake
2	Position laser focal point in XY plane	XY positioning system
2.1	Provide stable reference point on xy plane	Positioning bracket
2.2	Position focal point in X	X axis galvo
2.3	Position focal point in y	Y axis galvo
3	Comply with applicable safety rules and policy	System to ensure compliance
3.1	Protect shop personnel	System to protect shop personnel
3.1.1	Contain laser radiation	Light tight enclosure
3.2	Prevent unauthorized access	Access control system

Figure 20. Version 2 FR-DP Decomposition

The scanner and its bracket (see Figure 25) are light enough that the moment of inertia generated is within the performance specifications of available Z axis slides. This removes the need for a counter weight system. The scanner is composed of the X and Y axis galvos.

3. Design Parameters

3.1 Current Process

The current medallion production process uses shop personnel to satisfy most of the Functional Requirements [FRs]. The reliance on shop personnel causes uncertainty because when a human does an action multiple times, each result is not exactly the same as the others. Another source of uncertainty is the dull and repetitive nature of the tasks required of the personnel. The reliance on shop personnel and its effects causes the coupling seen in Figure 21.

	DP0: Medallion p	DP1: ST30S: DP1.1: ba	DP1.2: Tu	DP1.3: Pa	DP2: Mill drill	DP2.1: St	DP2.2: Mi	DP2.3: St	DP3: Lasermi	DP3.1: St	DP3.2: St	DP3.3: La	DP3.4: St	DP3.5: St
FR0: Produce	0													
FR1: Manu	X				0	0	0	0	0	0	0	0	0	0
FR1.1:		X			0	0	0	0	0	0	0	0	0	0
FR1.2:		0	X		0	0	0	0	0	0	0	0	0	0
FR1.3:		0	0	X	0	X	0	0	0	0	0	0	0	0
FR2: Engr		0	0	0	X				0	0	0	0	0	0
FR2.1:		0	0	0		X	0	0	0	X	X	0	X	X
FR2.2:		0	0	0		0	X	0	0	0	0	0	0	0
FR2.3:		0	0	0		X	0	X	0	0	0	0	0	0
FR3: Lase		0	0	0	0	0	0	0	X					
FR3.1:		0	0	0	0	X	0	0		X	X	0	X	X
FR3.2:		0	0	0	0	X	0	0		X	X	0	X	X
FR3.3:		0	0	0	0	0	0	0		0	0	X	0	0
FR3.4:		0	0	0	0	X	0	0		0	0	0	X	0
FR3.5:		0	0	0	0	X	0	0		0	0	0	0	X

Figure 21. Current Process Functional Requirement-Design Parameter Coupling Matrix For FRs and DPs see Figure 8.



Figure 22. ST-30 SSY



Figure 14. Dry side of the MDC in Washburn Manufacturing Laboratories



Figure 3. Laser cutter in Washburn Manufacturing Laboratories (Bergstorm, T. 2012)

The images in the above three Figures show again the equipment used in the current process of milling and marking the Alumni medallions.

3.2 Market Ready Options

AMBIT™'s use of a tool changeable laser head that uses a machine spindle to perform the positioning functions is the key to a system's ability to satisfy multiple requirements. It is also what violates Constraint 1 [CON1]. If Constraint 1 was ignored, the system would still not be a viable option since beam transport system use would not fit in the wet side of the Mill Drill Center.

Due to the role that BoXZY was designed to fill, it does not have a way to satisfy the needs of this project. BoXZY would have to be mounted on the ABB robot table, since it is designed to sit on a desk, not fixtured to a machine table. The methods of access to the BoXZY work volume are designed for manual loading and unloading of parts. Modifying the BoXZY system to work would require an excessive amount of modifications.

3.3. Custom Design Version 1

For a list of the Design Parameters [DPs] used in Version 1 see Figure 17. Powered slides by themselves can only provide axial movement. Positioning along an axis requires at least one more level of decomposition. In Version 1 the ability to do the positioning is provided by axis home position limit switches and rotary encoders. As seen in Figure 18, the two Z axes slides, which support the two Y axes slides, support the X axis slide. This arrangement is necessary to ensure that X axis slide is properly supported.

Since any error in the position of the Z axes carriages will induce error into the Y positioning system which will in turn introduce error into the X axis movements of the laser. The risk of induced error and the risk of binding if parallel slides do not move synchronously necessitates rotary encoders on each Z axis and Y axis slide. The chance of error in the function of a supporting slide increases the uncertainty of the supported slide positioning the laser focal point correctly.

The degree that any error in the installation of the Z axes slides will be compounded increases the information content and uncertainty of that process. There is also the uncertainty generated from the difficulty of precisely installing and integrating a large number of components in an environment like the dry side of the Mill Drill Center.

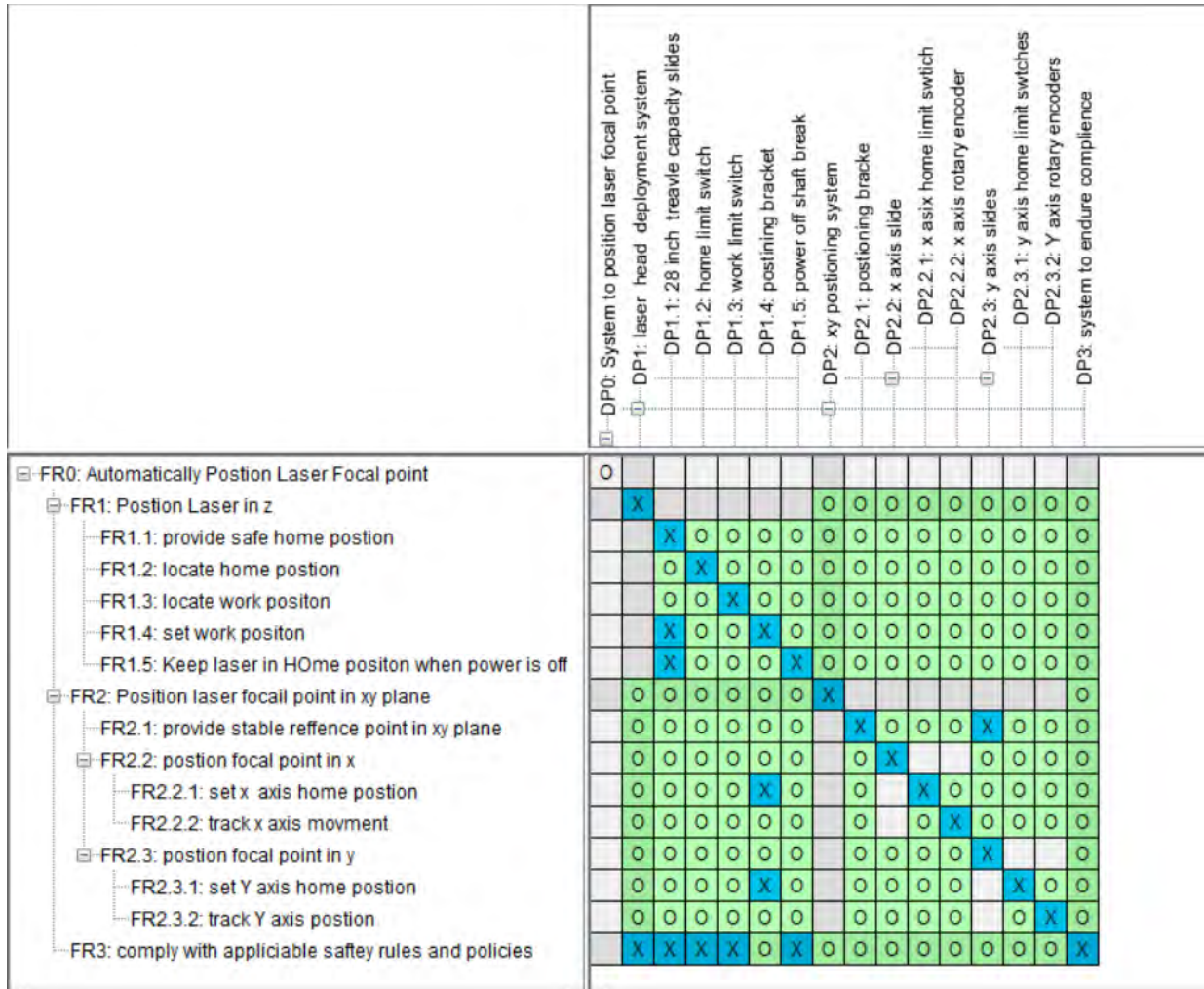


Figure 23. Version 1 Functional Requirement-Design Parameter Coupling Matrix

3.4. Custom Design Version 2

For the Design Parameters [DPs] used in Version 2 see Figure 20. The use of a Galvanometer scanner to do the positioning in the XY plane allows for [DPs] with lower information content to be used. First the [DPs] positioning the laser focal point in Z are reduced to a home position limit switch, a work position limit switch, power off shaft brake and a single Z axis slide. Thus eliminating the information content and uncertainty from the second Z axis slide and the components needed to ensure the two slides work synchronously with each other.

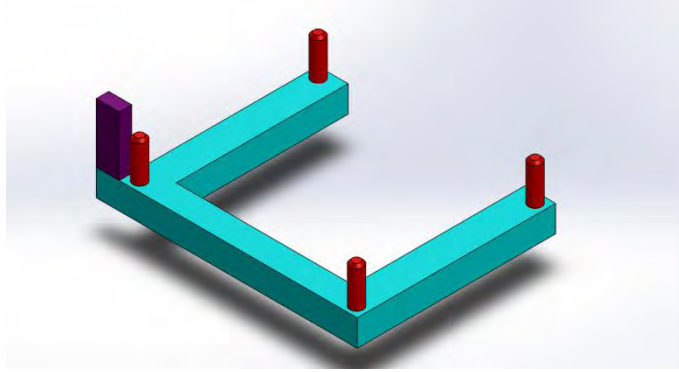


Figure 24. Positioning bracket

The positioning bracket in Figure 24 is bolted to the Mill Drill Center pallet so that the center of the four dowel pins (red) is concentric with the center of position in which the medallion will be placed. The red protrusions on the laser bracket (Figure 25) locate the scan head by engaging the dowel pins on the positioning bracket. The work position is set when the limit switch (purple) on the laser bracket is tripped by the purple block on the positioning bracket. When the switch is tripped it engages a power off shaft break on the Z axis slide (both not pictured). Section 2.4. includes a model of Version 2 in Figure 19 as well as a decomposition of Version 2 in Figure 20.

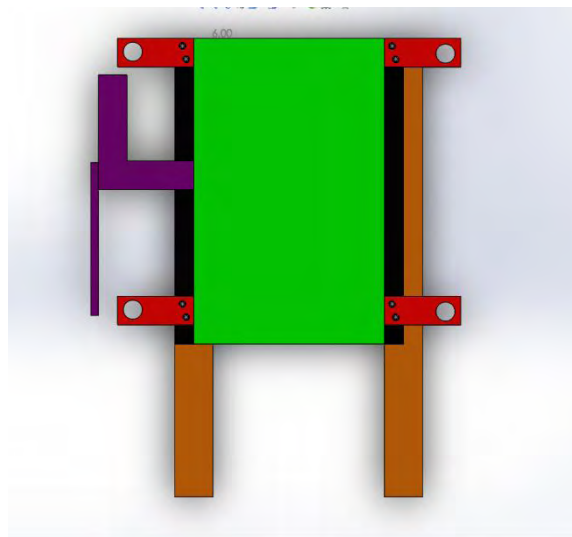


Figure 25. Laser bracket with galvo scan head (green)



Figure 26. A Galvo scanner, making a test mark at IPG Photonics

Version 2 would use a Galvanometer scanner to do the positioning in the XY plane, similar to the one pictured in Figure 26.

4. Prototype Production

4.1 Demonstration Model

A demonstration model was designed and built to perform tests to evaluate the performance of the proposed Z axis positioning system. The partial CAD model in Figure 27 was used to find the proper dimensions for the parts that were manufactured.

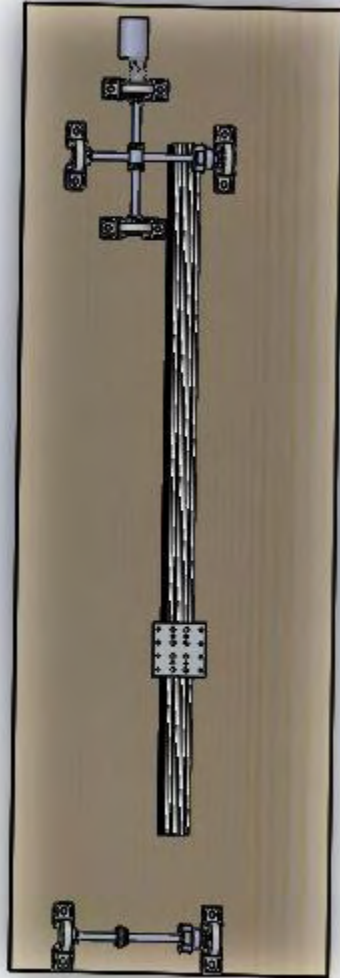


Figure 27. Partial model of the demonstration model in the orientation that the final system would be installed in.

A total of fifteen parts were made. For the purpose of describing their production the parts are divided by how they were fixtured and from what material they were made.

4.2 Demonstration Model Parts: Fixtured using a collet chuck

Twelve of the 15 parts needed were spacers, made from scrap one inch diameter 6061 bar stock. Each spacer has a 5/16-18" hole on the top and the bottom. Eight of the spacers were 3.8 inches tall, 12 pieces of bar stock were found to already be the height needed for the tall spacer, so they were just drilled and tapped on each end. The only difference in production, the 4 short spacers, was that the stock was faced down to the needed height of 2.2 inches before being drilled and tapped. 6061 Aluminum was chosen for the availability of scrap stock in a workable shape and the ease of machining it.

4.3 Demonstration Model Parts: Fixtured using a vise

The other three parts, the slide adaptor plate, the motor mount adapter and the motor mount base plate, were fixtured using a standard machining vise. Except for the motor mount base plate, the other two parts were machined from a plate of 7075 Aluminum. These parts were made from 7075 because their rough shape could be easily band sawed out of the available plate.

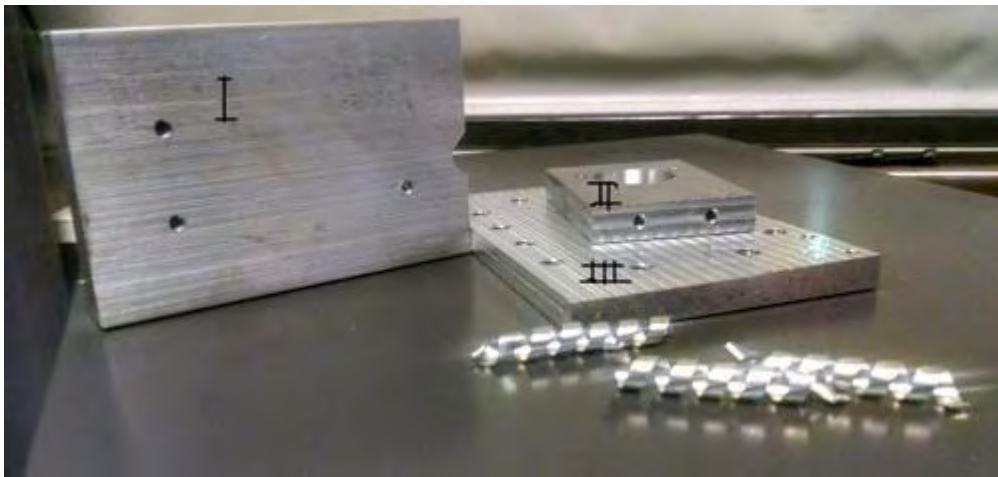


Fig 28 1Motor mount base, 2 motor mount adapter plate, 3 slide adapter plate

4.4 Demonstration Model: Tool and Fastener Selection

The tool selection was based on which tools had cutting parameters that were known to be good for 6061 Aluminum. The cutting parameters used for 6061 Aluminum can be used in 7075 Aluminum.

The slide and the belt end plate both shipped with holes that were close enough to the diameter of an F drill that they could be accept a 5/16-18" tap without intervening work. The bases of the shaft support bearings shipped with clearance holes for 5/16" bolts.

These parts and the spacers were held in place with 5/16-18” bolts. The mounting hardware for the motor was chosen to be 10-32 bolts since this was the thread size of the mounting holes on the motor face plate.

5: Testing with Demonstration Model

Tests were performed to evaluate the performance of the proposed z axis positioning system. The system was composed of the motor, worm gear speed reducer, two relays and two limit switches. It was desired to see how precisely such a system could position the slide carriage.

Component Part Number	Component Description	Notes
GM14904S012-R1	Motor \$431.60	This model comes with an encoder. The encoder output was not used for this project.
AAP2T51Z11	Limit switches \$14.50 each	
H750-3C-24d	Relays \$48.25 each, Base \$4.75 each	Base part #750-3C-SKT
57545K527 worm wheel 57545K511 worm gear	Worm gear reduction total cost \$93.02	This was added so that the demo would move at a safe speed.

Table 3. Demonstration Model Components being tested

Two tests were performed. The first test was aimed at seeing if the limit switches and relays would provide an adequate amount of control for Z axis positioning. The uncertainty in positioning mainly comes from the action of the type of limit switches used in the demonstration model. This can be controlled and is not an issue.

The second test performed was to see if the worm wheel and worm gear could replace the requirement for a power off shaft break. The test determined that a worm wheel and worm gear speed reducer would be a viable alternative to a power of shaft break. This change would decrease the information content and uncertainty over the life of the system as well as decrease the cost of the system. The demonstration model used a belt drive to reduce cost. Due to performance issues encountered with the belt drive, a ball screw slide has been selected to provide Z axis movement.

6. A Technically Feasible Method to Automate the Laser Marking of Alumni Medallions

6.1. Major Accomplishments.

The main accomplishment of this MQP was determining a technically feasible method to automate the laser marking of Alumni medallions. For this accomplishment to happen, three things had to happen. First, the location of the laser marking system had to be determined. Second, an automated system that would work in the chosen location had to be designed. The system designed needed to be able to communicate with the Mill Drill Center and the ABB robot arm. Two methods for the communication are via commands serial over RS232 (Eberhiem, R. 2015) or relay based communication (Bourque, D. et al.).

6.2 Design Method

The design method was sound. The cost of components hindered the implementation process. The main fault in the design process was that an excessive amount of time was spent waiting for data from possible venders.

6.3 Implications

This project, if brought to complete implementation, will have significant impact in multiple areas. The impact of the project will be initially noticed in the man hours saved in alumni medallion production and value added to the robotic machine tending and marking compound application projects. While the components needed are expensive, the payoff will come primarily from the education and research opportunities it will allow future students to explore, especially since automation and integration are becoming increasingly important (Vijay, S. 2014).

6.4 Future Work

For the most part, the future work that remains for this project is to see how it performs in practice. Other future work would be to see if this system could be used to improve any of the classes offered to the WPI community. What other future work that could be done depends on how the system performs once it is integrated. For this to happen additional funding, of approximately \$35,000 needs to be secured to purchase the required components. Except for the laser and the required fiber optic cable all components could be manufactured in house by student project groups.

Concluding Remarks

1. Determined that it is technically feasible to automate the production of alumni medallions with currently available technology.
2. Axiomatic design is an effective method to use with a large project that needs to be broken down into smaller subprojects that are tasked to separate groups.
3. The lack of sufficient funding prevented the testing of the fully integrated design.

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Machine Tending

A Class Project for ME/RBE 4815

Group 1:

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Executive Summary

Industrial robots have applications ranging from inspection duties of fabricated parts to packaging to food preparation. One of the most common applications is machine tending, where the robot manages supplying machine tools or similar machines with new workpieces and removing old workpieces. To explore this application, the WPI Manufacturing Lab's ABB IRB 1600 industrial robot was used to tend the WPI Manufacturing Lab's HAAS MDC.

The part to be produced was a round medallion, 2½" in diameter and ¼" in thickness. The parts were supplied having already been faced on the OD and on one side. They were also cut to a 0.267" thickness. The robot would pick up a medallion blank, position itself in front of the MDC and wait for the MDC to signal the robot to go. Once the robot got the go signal, it would enter the set-up area of the MDC (the door was already opened using the auto door feature), remove the finished medallion from the collet holder, drop the new medallion blank into the collet holder, leave the MDC set-up area and signal the MDC to resume. Once the MDC had resumed, the robot would deposit the engraved medallion and pick up another medallion blank to start the process over again. The medallion blanks were stored using a custom-constructed magazine system. Communication between the MDC and the robot was facilitated using the MDC's spare M-codes and the robot's I/O PCB.

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Introduction

Industrial robots have many different applications in the manufacturing setting. Uses include welding, painting, assembly, testing, and pick and place. They are able to make precise movements with small tolerances which makes them good at their jobs. This report will focus on the pick and place application, specifically loading a CNC mill.

Every year Washburn Shops makes close to one thousand medallions for various events ranging from Alumni Weekend to BattleCry. To accomplish this task, round stock is cut in the ST30SSY lathe to create the body of each medallion. Once the process is completed, each medallion blank needs to be moved to the Mill Drill Center (MDC) for engraving. Since there are many medallions that need to be moved to and from each of these machines, a robot is a better option than a person manually loading and unloading. Over time it is usually cost effective and the robot will pick and place with smaller error than a human.

The robot used in this project is the ABB IRB 1600 Robot Manipulator. This robot has 6 joints and a bolt on end effector. To program the robot, a pendant is used or code can be created in Robot Studio. Using the pendant to program positions was satisfactory for this project. The program developed for this project took advantage of digital inputs and outputs to communicate with the MDC. This allowed the two machines to automatically trigger loading, machining, and unloading without the potential of one machine getting ahead of the other. A specific gripper was designed for the task at hand and a magazine was constructed to organize the medallion blanks that are ready for engraving.

Goal Statement

It is intended to use the ABB robot arm to load and unload 2 ½” medallion blanks from the HAAS Mill Drill Center.

Task Specifications

The following task specifications were developed for this project:

- The robot should pick medallions either from a magazine system or from an extension on the ST30SSY
- The robot must unload the finished medallions and load the medallion blank into a suitable workholding setup on the MDC.
- The operation of any workholding setup should be automated.
- Engraved medallions should be deposited into a bin or other receptacle.
- No human intervention should be needed in between loading medallion blanks into a magazine and depositing engraved medallions in a repository.
- The time during which the MDC is not waiting for the robot to exchange workpieces should be minimized.
- The time needed for the robot to deposit the finished workpiece, pick up a new workpiece and position itself to be ready for the MDC should be shorter than the machining time for each part.
- The workpieces should not be damaged during handling. This includes scratching the medallion surface.

Workspace Setup

The ABB Robot is mounted on a plywood table in Washburn Shops. This table is positioned next to the MDC and ST30SSY. The layout of the machines and components can be seen in Figure 1. The ST30SSY will cut the blank medallions. When the turning program has finished, a person takes the medallions and places them in the magazine adjacent to the ST30SSY. From there the robot can pick up a medallion with the suction cup part of the end effector and move in front of the MDC's main door. It waits for a digital input signal of 24V that signals that the MDC is ready for loading. Once this signal is received the robot will grab an engraved medallion out of the MDC with the parallel jaw gripper and then place the blank medallion in the collet. After the robot has retracted out of the MDC it will send a 24V digital output signaling to the MDC that milling can resume. The finished medallion is then dropped into the finished part tray.

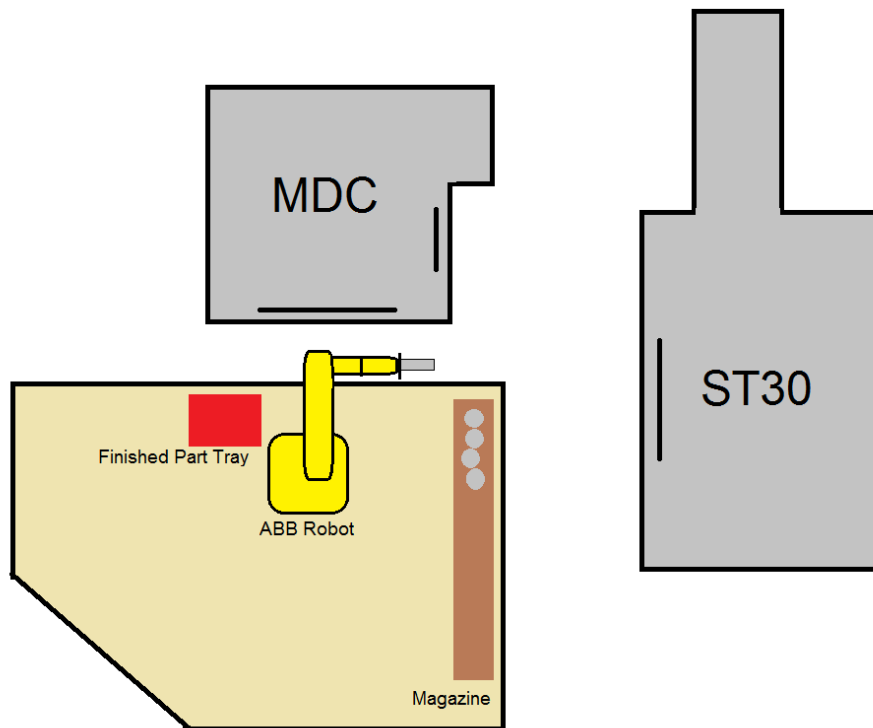


Figure 1: Workspace Layout

In order to maneuver in the confined space between machines and other components, a combination of J and L moves were required. High precision of positions was needed to have the program run without crashing or misalignment.

A magazine was designed to hold the medallion blanks. The blanks are placed with the cut-off side facing up and slide to the bottom of the magazine. There is a stopper at the base and tracks to help them stack as seen in Figure 2. The robot picks up the bottom blank in the stack and the next blank slides into place.

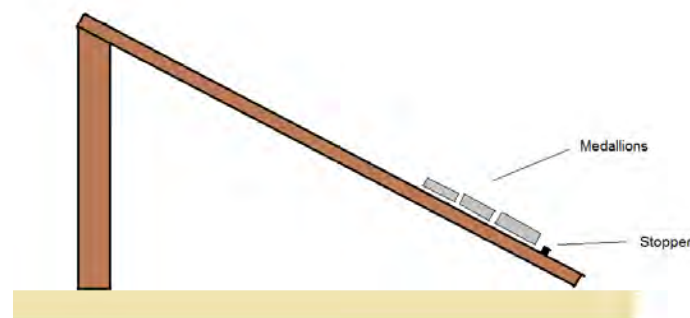


Figure 2 Magazine

The electrical setup consists of two relays. The M21 relay is activated by the G-code running on the MDC while the M-Fin Relay is activated by the ABB robot. The robot waits for the MDC to activate the M21 relay which connects a digital input channel with 24V. This signals that the machine is ready for loading and unloading. Once the robot has finished and retracted from the MDC, it sends 24V on an output channel which activates the M-Fin Relay. A wiring diagram is seen in Figure 2.

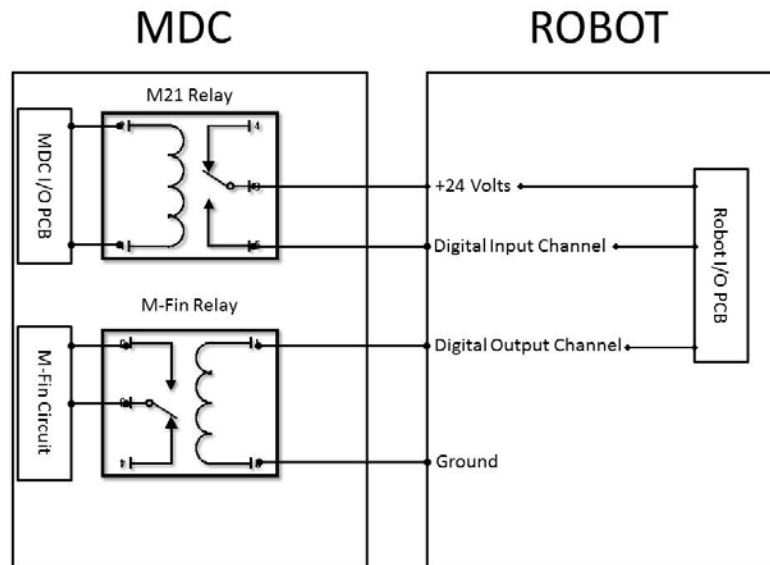


Figure 3: Wiring Diagram

Gripper Design

In order to reach the MDC workspace several inches would need to be added to the reach of the ABB robot through the use of an end effector. The end effector also needed to be able to handle two medallions at once so that the MDC would only have to wait in between machining operations for the robot to pick up the finished workpiece from the collet

holder and deposit the new workpiece. If the end effector could only handle one workpiece, the MDC would have to wait for the robot to pick up the finished workpiece from the collet holder, deposit the finished workpiece in a bin, pick up a new blank workpiece and position the new workpiece in the collet holder. This would take several times longer than the previous option.

Before designing the end effector, the team set about finding the necessary grippers. A suction cup gripper was desired for the un-engraved blanks while a parallel jaw gripper was desired for the engraved blanks due to the fact that the engraving would provide leak paths that would prevent proper operation when used with the suction cup. A suction cup and venturi vacuum generator that provided the needed performance were available from the supplies for the ABB robot. A small parallel jaw manipulator with the necessary strength was attached to the unused FANUC robot arm. Both of these grippers were obtained for this project.

To attach the gripper to the tooling plate, an existing but wrongly fabricated tool attachment plate was obtained from the robot supplies and fixed to allow for mounting to the existing tooling plate. To provide the needed extension, a piece of aluminum Unistrut was chosen from the Manufacturing Labs scrap cart as the Unistrut provided convenient mounting points for the grippers. The Unistrut was welded to the attachment plate and the grippers were then bolted onto the Unistrut. The parallel-jaw manipulator is actuated by the same airlines the normally feed the end effector used for the classes' lab exercises. The suction cup is actuated by a solenoid connected to a digital output.

Programming

The operation of the robotic arm works as a loop that retrieves an unmilled medallion, switches it with a finished medallion in the MDC, and deposits the finished medallion. In order to retrieve the medallion from the magazine, a move J is employed to align the end effector to the medallion material in the magazine. The robot program is able to control the suction cup that picks up the metal disk by using the set digital output command, SetDO, on output 2. After grabbing the medallion, the robot brings it up so that it is poised outside of the MDC's workspace. The purpose of this is to be able to load the MDC as fast as possible when it is ready to be loaded, and minimize the time between where the MDC is done with its operation but the robot isn't ready yet. The MDC is able to automatically notify the robot that it is ready to receive another medallion by outputting a signal to the 3rd digital input. The arm waits for this signal using the WaitDI command.

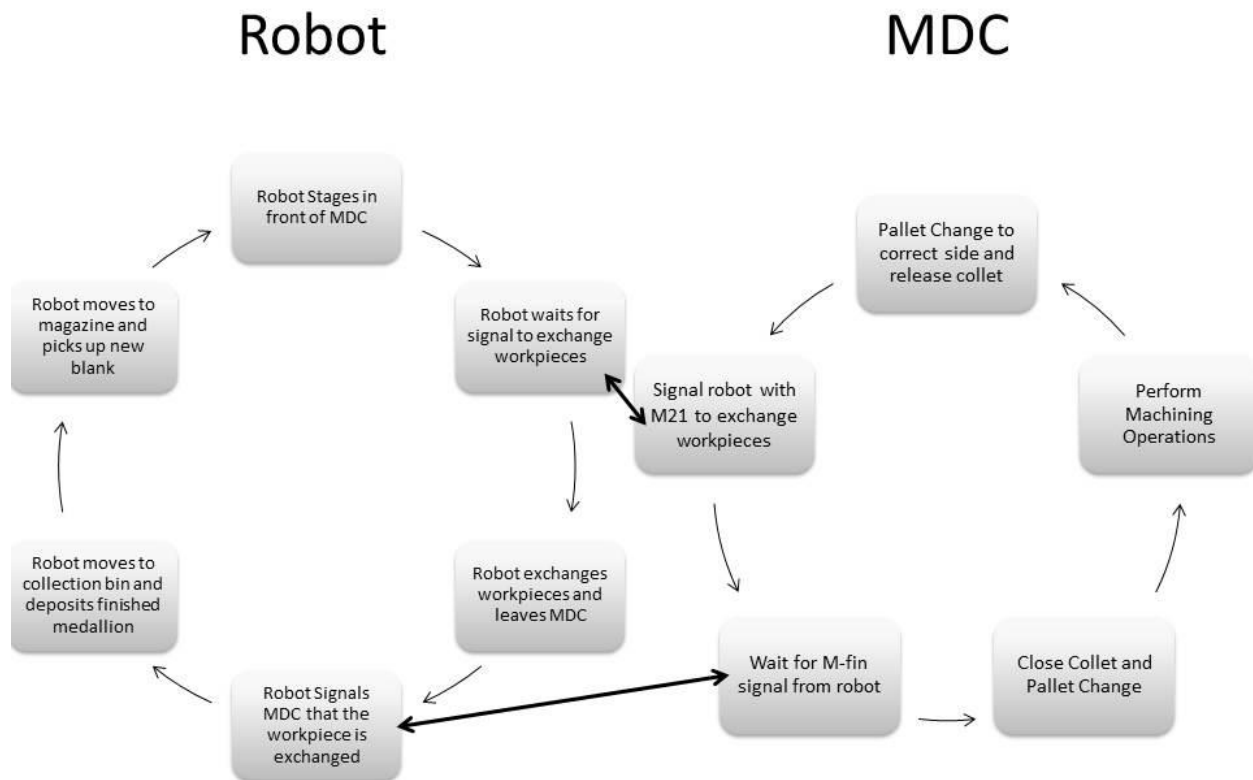


Figure 5: Programming Flow

After the MDC is ready to be loaded, the arm first removes the finished medallion using the gripper which is attached to the first digital output. The arm then exits the MDC workspace and then notifies the MDC that it is clear to operate by outputting a signal on digital output 3. Under normal operation this would be enough to start the milling process, however during development the auto door would not close when called by M81 or when a pallet change was called. This prevents the mill door from closing automatically without getting physical notification from a button beside the mill door. In order to work around this, the robot presses the button before depositing the finished medallion. The robot first pushes the door safety button before depositing the medallion in order to minimize the amount of time that the MDC is not in operation. (This issue has since been resolved but not before consultation with the Manufacturing Labs staff

members.) After the medallion is deposited, the arm is ready to start again at the beginning of the loop, and moves back to its starting position near the magazine.

Results and Discussion

The goals of this project were obtained. There is no needed human intervention between loading medallion blanks into the magazine and removing the bin of finished medallions. The MDC is only interrupted between machining cycles for a few seconds while the robot swaps workpieces. The cycle time for the robot to reset is shorter than the predicted cycle time for the engraving operation. The workholding is automatically operated by the MDC and the workpieces are not damaged by the process.

One issue that should be addressed is the fact that in the submitted video the robot is shown physically pressing the “Part Ready” button on the MDC. This was done as a workaround to the fact that the auto door close command was not working and auto door operation as part of the pallet change command on the MDC had been disabled. Since neither of these issues could be properly fixed before the submission deadline for the video, the “Part Ready” button was a temporary solution to get the program to work. Since then, it has not been determined why the auto door will not respond to the “M81” command but auto door operation was re-enabled as part of the pallet change call. This has been tested with the program and shown to allow the program to properly operate.

Conclusions

Though the program works as intended, if the project were to be done again the project team would perform the project completely differently. To start, the MDC is currently configured such that the air lines on both sides of the machine's table activate and deactivate together. However, the MDC appears to already be plumbed for the two sides to be operated separately; so all that would be needed to enable independent operation is attaching one airline to a different solenoid. This is the first thing the project team would do differently.

To enable efficient use of both sides of the MDC's table, the programming on both the MDC and the robot would need to be done differently. Currently, the MDC calls the robot using an M21 command which means that it waits for the robot to tell it that the robot is done before the MDC moves onto the next line of code. Since the goal is to get the MDC machining and the robot tending simultaneously this would not work. Instead, what could be done is the MDC calls the robot using M21 and the robot replies that it has received the message before doing anything else. This allows the MDC to continue while the robot does its job. Then, when the MDC is ready to pallet change, to confirm that the robot is ready for the MDC to pallet change the MDC can call M22 which will feed a new input for the robot. The robot will then finish its job and get clear if necessary and close the M-fin signal thereby completing the M22 call. Once the M22 call is completed, the MDC can continue and both the MDC and the robot can start over.

Where this project to be done again, the magazine system would also be implemented differently. Though functional, as the medallions fall down the magazine the magazine will occasionally drop a medallion off the robot end. It also offers low repeatability which means that the position for loading/unloading the collet holder must be tuned when the magazine gets moved. As an ultimate solution, the team proposes making a magazine out of several feet of metal bar stock. A groove - almost the length of the bar and slightly wider than the medallions - would be cut into the bar to a depth of 3/16" (1/16" less than the height of the medallions.). The groove would be open through the end of the bar on one side and end in a 1 1/4" radius on the other side for control of the position of the next medallion to be loaded. A cross bar that would also be added so that it was above the second to next medallion to be loaded in such a way as to

prevent lifting of the second to next medallion. A switch would also be added to see if there is a medallion ready to be loaded.

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Automated application of laser marking compound

Background:

Every year, the WPI machine shop makes over 600 medallions for alumni weekend. The medallions are round aluminum disks, 2.4" in diameter and 0.25" thick. Our current process for manufacturing them is:

1. The ST30 barfeeds, faces, and cuts off the medallions.
2. The operator moves the medallion to the MDC.
3. The MDC faces off, chamfers, and engraves the other side of the medallion.
4. The operator sprays the medallion with laser marking compound and waits for it to dry.
5. When a full tray of medals has been made, the operator loads the medallions into the laser cutter and initiates the marking process.
6. The operator unloads the parts, washes the extra marking compound off, and dries them.

This process is currently completely manual. The MDC is loaded and unloaded manually, the medals are sprayed manually, and they're moved into the laser cutter manually. This takes up a lot of time, somewhere around 100 man hours every year, which translates to over \$1200 in labor costs. The opportunity costs for that time are also significant.

As a result, the shop is working to automate that process using the ABB robot. There are several ongoing projects focusing on this. First, an MQP is working on building a laser-gantry system into the MDC. Second, ABB has volunteered to help integrate the robot with the MDC and ST30. Lastly, our group has worked to develop the end of arm tooling for the robot.

The proposed process for the production is:

1. The ST30 barfeeds and engraves the front of the medallion. It then faces and cuts off the blank, which falls into a vibratory bowl feeder than aligns it for the next step.
2. The robot moves the blank from the bowl feeder to the MDC.
3. The MDC faces and chamfers the back side.
4. The robot sprays the part with laser marking compound and waits for it to dry.
5. The laser in the MDC etches the part.
6. The robot unloads the parts and stacks them up for an operator to clean.

Overall, this process will likely have a longer takt time than the manual process, since the ST30 has a slower spindle than the MDC for engraving. However, if it is tuned enough, it will be able to do lights out manufacturing, which will make the process faster overall, and free up employee time for more valuable tasks. Additionally, the process is more flexible: by using the ST30 to engrave the part, it could allow both sides to be engraved, or allow painting of the part in the ST30 (using a paint pen system designed during summer 2014) and painting of the other side using the robot.

Our goal was to create end of arm tooling for the robot that can fulfill this process. It will need to be able to spray the part with marking compound or paint, and moving the part around sufficient clearance to go inside the MDC.

Design and fabrication:

Initially our design was planned to incorporate an aerosol type spray can of marking fluid. This is currently how the marking compound is applied to the medallions. However, an aerosol can as the source of marking compound would complicate the automation process. It would not provide a sufficient volume of

marking compound per container to adequately run in a "lights off" manufacturing setting. The necessity to change out cans in an automated environment would be problematic mainly due to the fact that it would be difficult to gage how much compound is left in the can until it ultimately ran out. A much more efficient solution would be a sprayer with a remote tank which could facilitate a much larger volume of marking compound.

To accommodate the needs for automation, a spray gun with a remote tank system was obtained and modified. To control the air output of the sprayer, a solenoid was implemented directly in line with the air feed to the sprayer. This control only needed to actuate on and off, as the adjustment for the amount of air pressure was separately controlled via the regulator on the remote tank. Also, the spray pattern/area is also controlled with a separate adjustable knob, so the main air switch could be completely bypassed by the solenoid.

To control the amount of compound sprayed, a separate pneumatic cylinder was incorporated directly into the sprayer gun. In order to fit the cylinder, a brass thread adapter needed to be manufactured. This adapter allowed the cylinder to thread directly into the section of the sprayer gun where the spray volume knob was previously. In order to maintain the adjustability of the spray volume, a threaded coupler was manufactured. This coupler had an adjusting nut with corresponding lock nut to control the spray volume. The original portion of the spray volume needle was kept and a threaded portion was added between to the cylinder. The nuts on this threaded portion acted as a stopper for the actuation of the needle for the spray volume. Depending on their positioning, more or less compound would be sprayed. The section of the coupler connecting directly to the cylinder was connected via a correcting spring. This spring not only reduced the shock on the needle valve from the cylinder, but also aided in maintaining the alignment of the system.

To manipulate the medallions, a vacuum pick up tool was chosen, as the medallions have a large flat surface and the tool would easily be able to grab hold of which. The sprayer gun chosen had a hook for hanging the sprayer gun in an upright position, which proved a convenient and functional location to mount the vacuum tool. It was essentially 90 degrees from the spray nozzle and was out of the spray pattern. It was easily affixed with a hose clamp and provided simple switching between the spraying and pick up functions by simply rotating the end effector.

To mount the sprayer and vacuum pick up tool to the robot, it was decided that the fixture would be fabricated as opposed to machined. This not only was more cost effective, but simpler and easier to implement as well. Machining a complex fixturing bracket would require more time, materials, and design than the scope of this project would allow.

A piece of steel channel that sprung to fit the width of the sprayer gun was chosen and a slot was milled in the rear of said channel to accommodate the existing adjustment knobs and added cylinder. The sprayer then fit snugly into the steel channel, but in order to maintain its rigidity and guarantee the sprayer stayed in place, it was also held by two hose clamps. In order to offset the sprayer an adequate distance from the robot arm to accommodate the added cylinder, two pieces of steel pipe were welded to the steel channel with feet attached that allowed for the whole fixture to bolt directly to the end of the robot. The fixture was then painted to reduce the risk of oxidation and maintain its longevity.

Programming:

We programmed the robot using RobotStudio. We had two main goals here. First, create a base template that can be used to program our tool for future jobs. Second, create a simple example program that demonstrates the capabilities of the tool. Both of these goals were achieved.

We started by creating a simplified model of the tool in Solidworks to provide collision detection. We imported this model into RobotStudio and set up tool center points for both the gripper and the paint sprayer. The precise location and orientation of the center points was taken using a 6 point calibration test that we conducted on the robot with the tool, and then moved the tool offsets to RobotStudio. The offsets for both tools were consistent within 5mm, which we consider suitable for this project.

Next, we set up the digital outputs that will be used to control the pneumatics. We used D652_10_DO1 for the paint control piston, D652_10_D03 for the gripper control, and D652_10_D04 for the air line for the paint. We configured these outputs within the virtual controller in RobotStudio, allowing us to program them offline without needing to manually edit the controls.

Next, we set up the simulation. We created a basic program to move and paint the medallion, with work coordinate systems attached to the start and end points. These points can be easily changed on the robot, allowing for it to run anywhere in the work volume. We then created events for the firing the various digital outputs. When DO3 is activated, it attaches the medallion to the gripper to simulate the suction. It then detaches when D03 is deactivated. When both D01 and D04 are active, it shows a cone attached to the spray nozzle in order to simulate the area of spray.

The program itself was quite simple. It uses a joint move to get the gripper above the robot, then uses a linear move to go down on top of the part. It then activates the gripper, moves up, and then moves to the painting zone. It lowers the part and releases the part. Then it draws back up, and switches to the paint gun. It activates the paint, jogs across the part, and then turns off the paint.

Our program was ultimately a success. It demonstrates the feasibility of programming the robot offline for this purpose, and the flexibility that we can achieve.

Testing and Results

The prototype end-effector underwent a number of tests before we deemed it a success. First the medallion manipulator was tested, to make sure it could consistently and effectively move the medallions. The medallions were picked up from a predetermined position, and then moved into the designated spraying area. Since we know that a vibratory bowl feeder will be used, we can be certain that the medallion will be in a predetermined position when this is integrated into the production line, so assuming that the robot does not need to find the medallion is valid.

After the vacuum pick up tool was working consistently, sprayer was calibrated. The air line solenoid the actuation of the cylinder required testing without material first. After this just water was sprayed through the system, to test the spraying pattern of the sprayer gun. This was done while also manipulating the position and rotation of the end-effector, to ensure that there would be no catastrophic failure. Once these tests were passed, we tested a latex based water-soluble paint. Running this through the lines proved a bit more difficult, as we had to carefully calibrate the sprayer for the paint, since the first sprays produced

a much too thick layer of paint. We also experienced leaking at the spray volume leaking, that ended being a result of our own missus of the sprayer, which cannot be used upside down. This required an adjustment in the intended tool paths, but was easily fixable in the programming. Once this and other similar problems were worked out, we were able to get a consistent layer of paint out onto the medallion. With the intend result of the project being the manipulation and then spraying of a medallion, this project resulted in a success. With some adjustment and refinement, this could be adapted to use the laser marking compound instead.

The one notable issue we had was this paint spraying created a considerable mess. While we had paper and cardboard down to spray into so that we wouldn't be coating everything in the shop in a layer of bubblegum pink paint, the back spray was enough to speckle the floor and parts of the surrounding area. With this in mind a simple enclosure would be a good idea to implement, but what that would be depends greatly upon how this ends up being integrated into the production line. Ideally, the spraying would be done with the medallion fixtured within Mill Drill Center, in which case the enclosure would need to be built into the MDC, so that we don't coat half of this machine. Another option would be a separate spraying station, where medallions could be coated with compound and allowed to dry before the robot would move it again. In this second case, we would be building a simple custom enclosure that provides just enough room for the end effector and medallion to be maneuvered in. It is important to remember though that the marking compound is much neater than the paint we used, creating much less mess when sprayed, so back spray might be much less of an issue. If back spray is an issue, continued use might require a shield for the ABB robot. This could be a simple bagging of the robot, or an added splatter shield at the tool end. What option is used here, however, will depend upon how it gets integrated into the production line, and will thus be entirely driven by the workspace in question. Since this workspace was not a part of project, we did not address this issue, but the results we had will be extremely useful to this future decision.

Moving forward with the project:

While we successfully proved that the painting process will work, it will still need to be developed more for the production process.

Robot end of arm tooling:

We will need sensors integrated so it can detect failure and stop the process. This may be a camera that can detect whether the part has been painted or not.

We will need to create a more accurate collision model for the tool for use in tight spaces.

We will need to configure the paint sprayer to use laser marking compound.

We need to create a more streamlined system for the pneumatics and electronics that won't get in the way during operation.

Controls:

We need to integrate the robot with the controls of the ST30 and MDC. ABB has volunteered to assist with this.

MDC:

The MDC needs to be configured for pneumatic workholding and have fixtures designed and built. They will need to be compatible with the pallet changing and the laser that the MQP group is building. They will also need to be able to tell whether they have a part properly loaded or not.

ST30SSY:

We need to attach a vibratory bowl feeder to the parts catcher and configure it to align parts for this project. The bowl feeder will need sensors to tell the robot when it has a part ready.

USING SERIAL COM ON THE MDC

How to externally interface with Haas machines
using the Serial Port

Created by:
Richard Eberheim

Important Hardware Notes

- Option only became available with software version 11.11 starting in June 2001¹
 - All machines shipped after that date include it as a standard feature
- Must use Serial Port 2
 - No given reason, experience says this won't work on port 1
- Need DB9 to DB25 cable to connect to the machine

Basic Operational Logic

- External Commands allow for both reading and writing values to macro and system variables
- Machine itself can look at these variables and use these values to control flow or alter machine operation.

A WORD OF WARNING

- THIS DOES NOT PROVIDE “REAL TIME” CONTROL!
- THERE IS A DELAY OF A FEW SECONDS BETWEEN CHANGING A VARIABLE AND THE MACHINE RESPONDING
- DO NOT USE THIS METHOD TO DIRECTLY DRIVE THE MACHINE

Machine Setup

1. Enable machine setting 143
 - This enables RS232 control as well as direct IO from the machine
2. Configure Serial Port Settings
 - Configure according to desired settings
 - See page 85 for more info
3. Connect cable to Serial Port 2 on the machine

Remote Computer Setup

1. Connect serial cable to computer
2. Determine which COM port the machine is connected too.
 - This can be found in Device Manager
3. Start Terminal Program (such as Putty)
4. Configure Terminal Program with the same Serial Port Settings as are on the machine

Connecting

- After configuring both the machine and the computer, start the terminal
- You are now ready to control the machine directly using the commands detailed on the next slides

Controlling the Machine

- There are two commands used to control the machine.
- Q Commands will cause the machine to return a value
 - Q600 command is specifically for reading variables
- E Commands will write a value to a system or macro variable

Commands

Q Commands

- Purpose
 - Reading Values from the machine
- Command Structure
 - Q600 xxxx
 - xxxx is replaced with the variable number that is to be read
 - Machine will reply with the following format:
 - Variable Scope, Number, Value
- There are also a number of special Q commands for reading other values

E commands

- Purpose
 - Writing values to the machine
- Command Structure
 - Exxxx yyyyyy.yyyyyy
 - xxxx is replaced with the variable number to write to
 - yyyyyy.yyyyyy is the new value for the variable

Other available commands

- `DPRNT[]`
 - `DPRNT[string to send]` will send the contained string to the Serial Port.
 - This enables output directly from the machine which can then trigger an external event

Commands Cont.

- See Section 3.5 RS232 in the manual (page 81)
- See page 82 and 83 in the manual for more information on commands, including other special Q commands
- See page 216 for more information on DPRNT[]
- **IMPORTANT: DPRNT[] COMMANDS ARE PROCESS AND PERFORMED AT INTERPRETATION TIME, NOT AT EXECUTION TIME.**
 - This can be eliminated with look ahead prevention with command G103, but look ahead cannot be used while machine is using cutter compensation

Bibliography

1. <http://www.cnczone.com/forums/haas-mills/18389-cnc-4.html>



Vytek



Proposal For: Edmund Resor, WPI

November 20, 2014'

Edmund Resor
WPI
100 Institute Road
Worcester, MA 01609-2280

Dear Edmund,

First and foremost thank you for taking the time to consider Vytek as a laser system supplier. We appreciate the opportunity to provide you with additional information on our systems.

I have provided you with an overview of our FC series OEM laser system along with a proposal.

I remain at your disposal to answer any questions you might have.

Sincerely,
Robin Barbero
978-849-1404
978-342-9800 X404
rbarbero@vy-tek.com

Vytek FC series 2 axis OEM Laser System Overview

Vytek is a world leader in laser marking and cutting systems and is pleased to offer a range of OEM Fiber laser packages for the OEM and integrator.

The Vytek FC OEM fiber laser series is a lightweight and self contained laser solution for the integrator and OEM that requires a compact yet full featured laser package for direct to part marking. The FC series offers unprecedented flexibility for small to extremely large parts that need to be marked in place or as part of a production line.



The FC OEM series offers all of the features and capabilities of our full systems but with the flexibility of a remote compact head assembly. The laser and the control are housed in a rack mount enclosure and are designed to work in industrial environments.

The remote head/galvo assembly are enclosed in a mono-block machined assembly allowing mounting at any angle including inverted or upside down.



All critical wiring to the remote head is strain relived and hosed in a flexible but rigid wire wrap enclosure that prevents crushing and dirt and dust from getting to the wiring. The control cabinet offers a full access at the rear of the cabinet to communications, I/O and safety circuits for interlock.



The FC OEM is offered in several formats and can be configured with an integrated rack mount enclosure that houses the PC, Laser, Keyboard and mouse to allow the user an easy and quick start format for integration in to any production environment. The FC series is offered in both Pulsed and CW Fiber laser formats from 10 watts to 200 watts for just about any marking requirement.





The FC OEM series can accommodate:

- Flat surfaces
- Round surfaces
- Complex angles
- Inverted surfaces
- Vertical surfaces
- Custom fixturing available

The FC series is the ideal laser marking solution when you need to be ready for a wide range of marking requirements and easy integration into any environment.

Features Include:

- High performance Integrated Fiber laser with power options from 10 to 200 watts
- Ultra-Light weight galvo assembly for easy integration.
- Full featured FiberScan C5 software with serialization standard
- Low power consumption operates at 110 or 220 volts using less than 250 watts
- Excellent beam quality $M2 < 1.5$
- Up to 50% wall plug efficiency
- 2.5 meter working cable with optional extender to 5 meters for some models
- Hi performance scan head made in the USA



Options include:

- Camera display of the marking area
- Class 1 laser enclosure
- Integrated fume extraction
- Motorized Z axis mounts
- Range of Optics to fit any application
- Custom fixturing
- Super portable options with extreme environment laptop options



FiberScan C5 is the latest generation of marking, engraving and cutting software specifically designed for Galvo/Scanner based systems. FiberScan is an intuitive easy to learn interface. FiberScan C5 is an integrated solution that runs in conjunction with **Vytek's exclusive scanner control system over a TCP/IP network connection.**

FiberScan C5 Can:

- Open multiple jobs
- Multi-head capable
- External control interface over RS-232, TCP/IP and Profibus (streaming mode)
- 4-axis motor control for rotary indexers, x-y tables, rotary tables, etc.
- Mark any installed TrueType font with serialization, and radial or vertical text
- Add Background templates
- Preview mark capability with visible pointer beam
- Allows importing of many graphics file formats
- Runs on Windows XP, Vista and 7
- Supports linear barcode types
- Code 39, Codabar, Code 93, Code 128, Interleaved, 2 of 5, POSTNET, UPC A, UPC E, EAN 13, BookLan
- Supports 2D barcode types, DataMatrix, Denso QR Code, PDF417
- Extensive array of Automation objects, Wait for input, Set Output, Time Delay, Message Box XY Motion, Serial Communication, Run Application, Alignment Tool, Laser Control
- Language Support English, German, Italian, Japanese, Korean, Spanish, Chinese (Simplified) Chinese (Traditional),

Appendix D - 8 of 15

System Specifications		OEM 2 axis fiber laser systems					
Laser Type		Fiber 10,20,30,50 and 75 watt pulsed other options available					
Ambient temperature		32..95°F					
Humidity		10..95%					
Air requirements		None with standard configuration					
Outside dimensions, mm (in), HxWxL		Model specific see factory for details					
Power consumption w/o laser*		≤450W					
Electrical requirements		100-240 VAC50/60Hz					
Available Marking Fields		100mm, 160mm, 254mm,330mm, 420mm					
Available Options							
Footswitch		x					
Barcode Reader		x					
Vision		x					
Automated Z		x					
Rotary Indexer		x					
Extended Opto-22 I/O		x					
Light Barriers		x					
Fume Extractor		x					
CCD Camera		x					
Available Lens Sizes		Field size mm(in)		Working focal length mm(in)			
100mm@1`064nm		59x59 (2.32"x2.32")		97 (3.82")			
160 mm@1`064nm		110x110 (4.33"x4.33")		176 (6.93")			
254 mm@1`064nm		175x175 (6.89"x6.89")		296 (11.65")			
330 mm@1`064nm		230x230 (9.06"x9.06")		387 (15.24")			
420 mm@1`064nm		290x290(11.42"x11.42")		493 (19.41")			
Laser Specs	Wave-length	Mode of Operation	Spot size (for 160 lens)	Energy per pulse	Cooling by	He-Ne pointer	Power consumption
Fiber 20W	1`064nm	Pulsed	60um/0.0024"	1 mJ	Air	Yes	<220W
Fiber 30W	1`064nm	Pulsed	60um/0.0024"	1 mJ	Air	Yes	<330W
Fiber 50W	1`064nm	Pulsed	60um/0.0024"	1 mJ	Air	Yes	<550W
Fiber Green 10W	532nm	Pulsed	30um/.0012	1mJ	Air	N0	<220W

Note: specifications for reference purposes only check with factory for current specifications. Specifications subject to change without notice

Vytek FC OEM Laser Marking System

<u>Item</u>	<u>Qty</u>	<u>Description</u>	<u>Unit Price</u>	<u>Ext.</u>
1	1	FC Series OEM Laser Marking System: <ul style="list-style-type: none"> • High performance Scan Head with 10mm aperture • Red light diode pointer • FiberScan C5 marking software • 19" rack mount controller • I/O 4 inputs and 4 outputs • Training at Vytek Facility - Fitchburg, MA • Warranty: 2 year laser module and 1 year parts & labor 	\$29,995.00	\$29,995.00
Available Options (not included unless indicated with a Qty)				
<u>Item</u>	<u>Qty</u>	<u>Laser Options</u>	<u>Unit Price</u>	<u>Ext.</u>
2	1	Upgrade to 20 Watt fiber <ul style="list-style-type: none"> • Air Cooled 	\$4,995.00	\$4,995.00
		Upgrade to 30 Watt fiber <ul style="list-style-type: none"> • Air Cooled 	\$8,995.00	
		Upgrade to 50 Watt fiber <ul style="list-style-type: none"> • Air Cooled 	\$10,995.00	
Scan Head and Optic Options				
3		Scan Head Upgrade 14 mm <ul style="list-style-type: none"> • Increases mirror size and clear aperture for smaller spot size requirements • Includes collimator and expander for laser 	\$6,995.00	
		Scan Head Upgrade 20 mm <ul style="list-style-type: none"> • Increases mirror size and clear aperture for smaller spot size requirements • Includes collimator and expander for laser 	\$11,995.00	
4	1	F-Theta Scan Lens <ul style="list-style-type: none"> • F-100 • F-160 • F-254 • F-330 • F-420 • <i>Other optics and field sizes available</i> 	\$1,995.00 \$1,995.00 \$2,495.00 \$3,000.00 \$3,495.00 POR	\$1,995.00
Axis Options				
5		Programmable Z Axis Stage <ul style="list-style-type: none"> • 15" of programmable vertical travel • Can be mounted in production line applications • Z positions can be saved with marking program • Integrated home sensor 	\$4,995.00	

6	XY Programmable Table Assembly <ul style="list-style-type: none"> • Allows for multiple part marking with programmable XY motion with a total travel of + and - 6" (152mm) • Special sizes upon request 	\$7,995.00
7	3 Jaw Chuck Rotary Axis <ul style="list-style-type: none"> • 2.75" diameter capacity • Adjustable Angle from 0 to 90 	\$1,995.00
8	3 Jaw Chuck Rotary Axis Heavy Duty <ul style="list-style-type: none"> • 5" diameter 3 jaw chuck • Up to an 8" diameter swing • 25 lbs. capacity 	\$3,995.00
<u>Fume Extraction Options</u>		
9	Air Blow Off/Air Assist Option <ul style="list-style-type: none"> • Use for deep engraving or dirty marking applications • Includes air regulator and water trap 	\$995.00
10	Portable HEPA/Charcoal Filtration System <ul style="list-style-type: none"> • Eliminates fumes and particles in air down to 2 micron • Exchanges inside air using a combination of HEPA and activated charcoal filtration 	\$1,495.00
11	Honeycomb Cutting Surface 10" <ul style="list-style-type: none"> • Includes down draft plenum and clean out tray 	\$995.00
12	Honeycomb Cutting Surface 16" <ul style="list-style-type: none"> • Includes down draft plenum and clean out tray 	\$2,995.00
<u>Special Options</u>		
13	Camera Option <ul style="list-style-type: none"> • Allows for manual orientation and inspection of small marks without moving the part • This is NOT through the lens vision system • Requires a PC 	\$1,495.00
14	Barcode Reader <ul style="list-style-type: none"> • Allows job selection using customers routing sheets • Requires specific format consult factory for details 	\$1,995.00
15	Dual Diode Focus System <ul style="list-style-type: none"> • Visible focus alignment using line and dot merge 	\$2,995.00
16	Start Mark Option <ul style="list-style-type: none"> • Allows for quick start operation without PC • Great for repetitive marking applications 	\$995.00
17	Industrial Rack Mounted PC <ul style="list-style-type: none"> • With 15" monitor, keyboard and mouse 	\$1,995.00

18	Rack Mount Enclosure • Integrates laser, PC, Keyboard for floor or wall mount • Integrates all electrical connections for power input for laser, PC and monitor	\$1,995.00	
19	Extended I/O Module • Adds 15 inputs and 15 outputs	\$2,495.00	
20	Air Knife • Use for dirty marking applications to keep debris from affecting lens assembly		
21	Fiber Laser Safety Kit	\$695.00	
<u>Training and Installation</u>			
22	Integration Support • Available on site at \$1500/day plus T&E	\$1,500.00	
23	On-Site Installation & Training at \$1,500/day plus expenses (expenses billed separately)	\$1,500.00	
24	Phone support • \$175/hr.	\$175.00	
<u>Shipping and Freight</u>			
25	Crating Charge for Overseas Shipments	\$350.00	

System Cost	\$29,995.00
Options Total	\$6,990.00
Sub Total	\$36,985.00
Educational Discount	-\$7,990.00
Total Cost	\$28,995.00

TERMS & CONDITIONS

The placing of this order by Buyer constitutes acceptance by the Buyer of the terms and conditions herein contained.

1. PURCHASE OF EQUIPMENT. Seller shall sell to Buyer, and Buyer shall purchase from Supplier for the Price provided above, the Equipment described above in accordance with the terms and conditions set forth in this Agreement. For purposes of this Agreement, the term "Equipment" shall include all components of the Equipment, all associated software licensed by Seller pursuant to Section 2 hereof, and all upgrades, enhancements, and replacements thereof made available, or required to be made available, to Buyer pursuant to this Agreement.
2. LICENSE OF RELATED SOFTWARE.
 - A. Seller hereby grants to Buyer a perpetual, irrevocable, nonexclusive, fully paid-up, transferable license to possess and use the operational computer software for the Equipment, including, without limitation, the object code embodiment thereof and all related documentation (collectively, the Software), solely with the Equipment and to reproduce the Software in connection with such use.
 - B. Buyer acknowledges that it is acquiring no ownership interest in the Software and that all right, title, and interest in and to the Software remain with Seller.
3. INSTALLATION AND TRAINING: Prior to the delivery date set forth above, if Buyer and Seller have agreed, Buyer shall prepare the installation site for the Equipment in accordance with Supplier's installation specifications. Upon notice by Buyer of the arrival of the Equipment at Buyer's facility, Seller shall install the Equipment in a timely manner and in accordance with Seller's installation specifications. In addition, Seller will provide Buyer with reasonable product and user training as per the quotation accepted by Buyer. Buyer agrees that no one will use the Equipment who has not been trained and who does not use the required safety equipment and safety practices outlined during the training.
4. WARRANTY: The Equipment is warranted to Buyer to be free from defects in material and workmanship for a period of twelve months for all parts and labor. Seller will repair or replace at its option and no cost to Buyer, any Equipment delivered to Seller's designated facility in a non-operating condition pursuant to the above warranties. Buyer shall be responsible for determining that the Equipment is in a non-operating condition upon receipt and will identify the suspected malfunction to Seller. The Seller's warranty does not apply to performance of the Equipment caused by abrasive materials, corrosion due to aggressive fluids, lightning, improper voltage supply, mishandling or misapplication in a manner inconsistent with that identified in Seller's catalogs and literature. Any warranty granted by Seller to the Buyer shall be deemed void if the Equipment is used for any purpose not permitted hereunder. In the event that the Equipment is altered or repaired by the Buyer without prior written approval by the Seller, all warranties are void. In no event shall Seller be liable for collateral or consequential damages. In addition, the Buyer shall indemnify Seller and hold Seller harmless from and against any and all claims, damages, losses, costs, expenses, and other liability of whatever nature that Seller suffers or incurs by reason of any such unintended use. This warranty is made in lieu of any warranty expressed, implied, or statutory; and no agreement extending or modifying it will be binding upon Seller unless in writing and signed by a duly authorized officer. EXCEPT FOR THE EXPRESS WARRANTIES STATED ABOVE, VYTEK, INC. DISCLAIMS ALL WARRANTIES ON PRODUCTS INCLUDING ALL IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS AND THE STATED WARRANTIES ARE IN LIEU OF ALL OBLIGATIONS OR LIABILITIES ON THE PART OF VYTEK, INC. FOR DAMAGES, INCLUDING BUT NOT LIMITED TO SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES, INCLUDING BUT NOT LIMITED TO SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES ARISING OUT OF OR IN CONNECTION WITH THE USE OR PERFORMANCE OF THE PRODUCTS.
5. INDEMNITY: Buyer shall indemnify and save the Seller harmless from any and all claims by, for, or against the Seller or Buyer as a result of injury or damage to Buyer, Buyer's employees, or other persons caused by the equipment during the course of its use herein sold by the Seller to the Buyer, unless the injury or damages is as result of negligent manufacture or otherwise.
6. GENERAL PROVISIONS: This contract is made, governed by, and shall be construed in accordance with the laws of the Commonwealth of Massachusetts. Seller and Buyer hereby consent to the exclusive jurisdiction and venue of the courts of Massachusetts or of federal courts in Massachusetts with respect to any dispute, controversy or other matter relating to or arising out of this order and agree that any such any dispute, controversy or other matter relating to or arising out of this order may only be brought in the courts of Massachusetts or of federal courts in Massachusetts. This contract is non-assignable, and any attempt to assign any right, duties or obligations under this contract will be void, except in the case of a change in ownership, contract will insure to present owner. All rights and remedies of either party, whether evidenced hereby or by any other contract, instrument or paper, shall be cumulative and may be evidenced hereby or by any other contract, instrument or paper, shall be cumulative and may be exercised singularly or concurrently. In the event either party shall, on any occasion, fail to perform any term of this contract, and the other party shall not enforce that term, failure to enforce on that occasion shall not prevent enforcement on any other occasion.
7. NOTICES: All notices, requests, consents, and other communications required, or permitted hereunder shall be in writing and shall be mailed by registered or certified mail, postage prepaid, or transmitted by Telex, TXW, or Facsimile to addresses set forth below, addresses subject to change by written notice.
8. ENTIRE AGREEMENT: This Agreement constitutes the entire Agreement of parties with reference to the subject matter hereof.
9. SHIPMENT AND PASSAGE OF TITLE: Shipment will be made F.O.B. Point of Origin. In the absence of specific shipping instructions, method of shipment will be determined by the Seller. In all cases, Seller's responsibility (except as stated in its

warranty) cease and risk of loss shall pass upon delivery of the material to the carrier, irrespective of the method of shipment and method of payment for shipment.

10. SECURITY INTEREST: Buyer hereby grants to seller a first priority lien and purchase money security interest in the Equipment purchased hereunder and in all subsequently purchased Equipment, and any and all components, material, systems and sub-systems incorporated therein, together with all operating and maintenance manuals and other documents required by this Agreement, and all moneys, securities and other property resulting from the sale, pledge or other disposition of the same. Buyer will keep the Equipment free from any and all adverse liens, security interests and encumbrances. Buyer hereby agrees to execute any and all promissory notes, UCC-1 Financing Statements and other documents, and pay any and all fees, taxes or other costs as necessary to allow the Seller to perfect its interest in the Equipment Seller agrees that upon full satisfaction of the purchase price and all related charges for the Equipment, Seller shall execute UCC termination statements as necessary.

11. DELIVERY: Seller will endeavor to meet delivery schedules, but in no case shall Seller incur any liability, consequential or otherwise, for any delays or failure to deliver as the result of any cause beyond its reasonable control, including, without limiting the generality of the foregoing, acts of God, of a public enemy, or of the Buyer; or disputes, accidents, transportation conditions, government actions of any kind, inability to secure adequate material or labor, or any cause similar or dissimilar to the foregoing. Quoted delivery dates are Seller's best estimate, on the basis of current schedules. In no event shall Seller be liable for special or consequential damages resulting from failure to meet requested delivery schedules. Incremental or additional costs incurred by Seller as a result of Buyer's alteration of the delivery schedule, whether or not such alteration constitutes a change under Paragraph 11 hereof, will be borne by Buyer.

Buyer agrees to inspect the equipment at Seller's designated facility prior to shipment, at Buyer's expense, for the purpose of confirming the operating condition, functions, features, and performance of the equipment. If buyer fails to inspect the equipment prior to shipment to Buyer's designated facility, Buyer relinquishes the right to refuse acceptance of and to make payment for the equipment for reasons relating to the equipment's functions, features and/or performance.

12. TERMINATION AND BREACH: This contract may be terminated by Buyer only when approved in writing by Seller. In the event of termination, Seller will take immediate steps to mitigate termination costs to Buyer, but Buyer shall reimburse Seller for the cost of labor, overhead, and material costs and other commitments made by seller in reliance upon this order. Insolvency of the Buyer, the filing of a petition in bankruptcy or the commencement of any insolvency or receivership proceeding shall be deemed a termination of the Buyer. Notwithstanding any provision to the contrary herein, if Seller shall at any time have grounds for insecurity with respect to Buyer's performance hereunder and buyer shall fail to provide adequate assurance of due performance within thirty (30) days after the mailing to it by Seller of a demand for such assurance, then Seller may consider this contract repudiated and shall have all the rights to a Seller for such repudiation under Chapter 106 of the General laws of Massachusetts.

13. CHANGES: No change shall be made in descriptions and specifications relating to this order without the written consent of Seller. Subject to the foregoing, Buyer, by written order, may make changes in drawings, specifications, delivery schedules, shipment or packing of articles if such changes increase or decrease the cost of, or the time required for performance of this order, or otherwise affects any of the provisions of this order, an equitable adjustment shall be made in the price or delivery schedule, or both, and in such other provisions of this order as may be so affected, and the order shall be modified in writing accordingly. Any claim for adjustment hereunder may be asserted at any time prior to shipment of the last item due under this order. It is agreed that the prices stated herein are based upon normal supplied and labor costs and that any request of Buyer necessitating overtime or other expense shall be deemed a change under this provision.

14. REPRODUCTION RIGHTS: Designs, processes, drawings, specifications, reports, photographs, data and other technical or proprietary information relating to this order shall remain the property of Seller and Buyer agrees that it will not use any of such items or information therein for the production or procurement from any other source of articles furnished in connection with this order, nor reproduce or otherwise appropriate the same without the prior written authorization of Seller or until such items or information become publicly known through a source other than Buyer.

15. CONFIDENTIAL: Buyer agrees that it will not disclose or make available to any third party any of the items referred to in Paragraph 14, or any information contained in such items without obtaining the prior written consent of Seller or until such information becomes publicly known, through a source other than Buyer.

16. INFRINGEMENT: Except insofar as this order calls for articles or materials not manufactured by Seller, or manufactured by Seller pursuant to Buyer's drawings or specifications, Seller agrees to defend any suit or proceedings against Buyer based upon an infringement claim that any article or part thereof manufactured hereunder, by reason of its manufacture, sale or use, infringes any United States patent which was issued at date of contract, and agrees to pay the amount of any judgment against Buyer resulting therefrom, together with all costs and expenses incident thereof, provided however, that such claim does not relate to articles or materials manufactured pursuant to Buyer's drawings or specifications, provided, further, that Seller is notified of such an infringement claim or the threat of commencement of such suit or proceeding within two weeks of the time Buyer received notice thereof and is given an opportunity, with the cooperation of Buyer, to conduct the defense or settlement thereof. Seller's liability to pay or incur expenses or to pay any costs, damages or judgments under the foregoing provision shall be limited to an amount equal

to Purchase price paid for the articles or material upon which such infringement claim is based less a reasonable allowance for the use and depreciation. Seller reserves the right to substitute for articles, materials, or parts thereof, which in its opinion might infringe other equally suitable products without altering the other conditions before or after sale. Seller shall also have the right to take back infringing articles, materials, or parts thereof, refunding the purchase price or an equitable portion thereof less a reasonable allowance of use and depreciation. Seller assumes no responsibility for the actual or alleged infringement of any foreign patent or other matter except as expressly stated in this Paragraph 17. Buyer agrees to pay to Seller all costs and expenses incurred by Seller in its defense, and to pay the amount of any judgment against Seller, in any suit or proceeding against Seller based upon a claim of infringement, resulting from Buyer's combining any articles supplied hereunder with any articles or device not manufactured or supplied by Seller or from the sale or use of any such combination by Buyer.

17. TAXES: The amount of any present future sales, use, or similar taxes, and import or export tariffs applicable to the products sold hereunder, shall be payable by Buyer when and as incurred.

18. SELLER'S ADDITIONAL REMEDIES: In addition to the rights specified herein, Seller shall have all the rights and remedies of a Seller under Chapter 106 of the General Laws of Massachusetts and no waiver of or failure to enforce and as such right or remedy on one occasion shall be deemed a waiver of such right or remedy on any future occasion.

19. SEVERABILITY: These terms and conditions shall be severable and the invalidity or unenforceability of any of them under any circumstances shall not affect those terms and conditions which are not held to be invalid or unenforceable.

20. BUYER ACKNOWLEDGES THAT SELLER HAS THOROUGHLY EXPLAINED TO BUYER HOW TO SAFELY OPERATE THE EQUIPMENT AND EXPLAINED ALL POTENTIAL HAZARDS THAT COULD RESULT FROM THE IMPROPER USE OF THE EQUIPMENT.

NOTICE: The equipment sold hereby should only be used by properly trained personnel who follow proper safety precautions. Familiarize all persons with safety practices before they use the equipment.

Proposal valid through 12/21/2014

Payment Terms: 50% deposit with order Balance prior to shipment

Shipping: FOB Fitchburg, MA – Freight collect

Delivery Date: TBD

Method of Payment: Wire, Bank Check, or Letter of Credit at site.

With this signature, I acknowledge that I have read, understand and agree to the included Terms and Conditions of the following purchase of the laser system described on the preceding pages of this document.

Signature/Title

Date