Laser Cutting Applications in Product Design

by

John DiBacco, Jr.

Submitted to the Department of Mechanical
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ABSTRACT

A laser cutting system has been created for use in the Papallardo Laboratory. It is intended to be used by the MIT Mechanical Engineering community, especially for purposes related to prototyping and design work. Laser systems have many advantages over conventional manufacturing methods and this acquisition will enable students the ability to realize these benefits. In particular, this new piece of equipment will enable interested individuals the opportunity to achieve a new and higher level of refinement with their prototyping models. Also, it allows the MIT Mechanical Engineering community the chance to become familiar with one of the newest developmental tools in design and manufacturing.

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1 Introduction

In the last decade, the number of applications for laser cutting systems has expanded quite dramatically. The reasons for their new popularity are numerous and will be covered in this paper. The goal of this project has been to bring laser cutting technology to MIT's Mechanical Engineering community. In particular, the laser system purchased is intended to be used for the purposes of prototyping in conjunction with design classes. This paper will discuss the characteristics of the particular laser that we purchased and built for use in the Papallardo Laboratory. The applications of the system will also be covered. These points will be followed by a discussion regarding the reasons we obtained this type of laser, its capabilities and the safety issues relevant to its operation. The building and basic setup will also be include as will experimental result describing recommend cutting speeds for some of the most common materials. Finally, this paper will conclude with six sample cuts and some visuals of the finished products.

2 Method

2.1 How a Laser Cutter Works

Laser cutting systems use nothing more than focused light to slice through materials. Conventional light, that we see and use everyday, produces waves, which radiate in all directions to fill up and illuminate a wide area. The energy intensity rapidly decreases the further one is from the source. Lasers on the other hand offer a stream of collimated, coherent light, which give it exceptional intensity and directionality. The light produced by a laser does not disperse, like conventional light. For this reason, a laser can easily project a beam over relatively long distance while maintaining nearly all of its useful power output.

The focused beam of the laser creates intense heat energy when materials are exposed to it. If the heat input to the material is greater than the material's ability to reflect, conduct or disperse the added energy, it will cause a sudden rise in temperature of the material at that point. If the temperature rise is substantial enough, the input heat is capable of initializing a hole by vaporizing the material. The linear movement of this intense heat energy with respect to the material provides cutting action.

In most cases an unfocused beam of even a high power, multi-kilowatt, laser has inadequate energy to do much more than slowly heat a surface. In order to increase the energy density of the beam, it is directed through a focusing lens. This allows the energy to be concentrated into a spot of less than 0.5-mm thus producing power densities over a million watts per square centimeter. This incredible power density makes the vaporization of many materials possible.

Assist gases are used in conjunction with most laser systems. These gases are introduced through a nozzle coaxial to the focused beams. The assist gas serves many purposes, including aiding in the material removal by blowing out excess material through the backside of the work piece, assisting in the burning process and protecting the focusing lens from spatter ejected from the cut zone.

2.1 Choosing a Laser Cutting System

Many factors contributed to the decision to buy this particular laser. First of all we had budget constraints to consider. We were fortunate to receive a large grant from United Technologies Corporation for the purpose of buying this laser. Although this was a very generous gift, preliminary research into laser cutting system manufactures revealed that we were going to be limited to a certain power range, size and a limited number of degrees of freedom. To do the type of cutting we desire we determined that a 50W laser would be sufficient. More power would be preferred, but the costs associated a power increase did not appear to be worth the performance gains. Second, we wanted to have a cutting table that is about 48 inches square. This would provide users with the versatility to work with almost any size material common to design prototyping. Lastly, we desired cutting motion in the X and Y-axes. This last requirement also includes the use of a computer controlled cutting system that could be used to automate the system in conjunction with existing design software such as AutoCAD.

With these constraints in hand, I proceeded to research the product lines of several companies with reputable business histories who also possessed the ability to meet our specifications. The selection quickly narrowed down to only three companies, Kern Electronics, Concepts for Progress and LaserCAMM. The final decision was Kern Electronics and Lasers, Inc. from Wadena, Minnesota. They were the only company able to meet both our design requirements as well as our budget constraints.

2.3 Benefits of Laser Cutting Compared to Conventional Methods

Conventional cutting tools such as band saws, milling machines and lathes have become extremely efficient over the years. Despite their respective evolutions they still can not match lasers in many applications and performance capabilities. Due to the fact that laser-cutting systems use an entirely different method of cutting certain characteristics are intrinsically better.

The first place to look is cutting force. A standard milling machine must generate large forces in order to cut materials, but a laser, on the other hand, produces no forces on the material being cut. The difference between these different cutting methods is very significant for several reasons. A milling machine often requires extensive fixtures to hold materials in place. These fixtures are usually expensive to build, take considerable time to fabricate and consume additional time to set up for a job. This adds significant cost as well as long turn-around times. In contrast, a laser system does not require any of these things, making it ideal for quick turn-around work and experimental prototypes.

Laser cutting is also extremely accurate and consistent. The cutting head of a laser system is precisely controlled by a very refined set of stepper motors with feedback control and a computer control system. Also, a rigid cutting face (blade) does not exist. Even after thousands of feet of material have been cut no tool wear will occur, because there does not exist a physical cutting head. Consequently, there is no concern for an object being out of dimensional tolerance because the tools are flawed. If there is deterioration in the motor system, the feedback control system and computer automatically compensate to prevent any noticeable change.

The last significant benefit of the laser system is the ability to cut most materials. The most common materials cut with lasers include plastic, particularly acrylic, and wood. Other materials which cut well include vinyl, carpet, leather, synthetic marble, particleboard, paper, cardboard and rubber. The non-contact cutting process allows a laser to cut many of these materials even though they are not rigid.

The laser can also be used for engraving and drawing. The engraving feature is actually very unique. It enables a user to add designs and artwork to their models. One can even scan in a photo and from that develop a gray-scaled image to be engraved into their material of choice.

2.4 Safety Issues

The U.S. Federal Government regulates products containing lasers that are sold in the United States. These mandatory regulations are published and enforced by the FDA's Center for Devices and Radiological Health (CDRH). They specify product classification procedures as well as determine engineering features and labels necessary for each product class.

Products are classified in accordance with the laser energy that is accessible during normal operation. Energy that is accessible only during routing maintenance or during service will determine the need for interlocks, labels, shields, and protective eyewear.

The CDRH classification categories are Class I, IIa, II, IIIa, IIIb, and IV, in accordance with increasing hazard levels. Systems, like ours, that allow access to the CO_2 laser energy are Class IV. In this case, CO_2 laser energy is considered "accessible" by the safety standard if a finger or very thin, straight probe can contact a beam.

There are two main hazards present when using a CO_2 laser. The first is the collimated beam direct from the laser head or mirror before being focused. This beam may not have the ability to cut materials, but it still posses sufficient heat energy to damage eyes, skin or ignite flammable materials. This hazard exists at distance up to hundreds of feet away from the source. The second main concern deals with the focused beam. It contains an extraordinary power density capable of marking, cutting and welding. For obvious reason one would want to avoid direct contact with this beam. However, its power range only exists within close proximity from the beam focus. Past the focus, the beam pattern expands significantly, and there is a distance beyond which the power spreads over an area that is so large that the laser beam in no longer hazardous.

Class IV lasers and systems must include several features in order to meet government regulations. First, a key-switch to prevent unauthorized access must be part of the system. Our equipment uses a computer and access password, which is considered an acceptable alternative, as well as a manual keyswitch. Second, an indicator, such as light, must be operational to provide a warning of laser emission in advance of and during the emission time. Also, the system needs to have a shutter to block the beam, and it must be configured so that the operator must manually restart the system after a line voltage interruption.

The CDRH requires a certification report to be filed by the Original Equipment Manufacturer. Synrad has performed these tests and reported the result to the CDRH for us. This report discussed out particular system and the issues associated with regulations. The test procedure verified the operation of each required laser safety feature, verified that there is no unnecessary access to laser energy, and verified that the specified labels were affixed at the proper locations. Measurements of output power/energy levels were also included, but not required.

The last issue to discuss is the requirements that apply directly to end-users. The MIT Mechanical Engineering community is the end user and is subject to the ANSI Z136 series of standards for the safe use of lasers. For our Class IV system we are required to enclose beam paths where feasible, establish controlled access areas for trained personnel only, post warning signs, provide training to operators, use standard operating procedures, use protective eyewear and clothing, and utilize protective barriers. Lastly, according to the rules governing a Class IV installation, a trained Laser Safety Officer (LSO) should be appointed to evaluate potential hazards and to ensure that appropriate control measures are implemented.

3 Procedure

3.1 Setup

Before the laser cutting system arrived, some preparation work had to be completed. Safety regulations set by the government regarding class IV lasers had to be met as well as MIT Safety Office regulations. The biggest issues were the venting of the potentially poisonous cutting vapors and eye protection. To comply with the ventilation requirements we simply installed a flexible hose to duct the cutting vapor from the table to the outdoors via a powerful 1hp vacuum. Eye protection can be provided one of two ways. The first is to build an enclosure around the table so that only the operator needs to be concerned with eye safety. The second option was to require all people in the lab to wear safety glasses complete with eye shields whenever the laser is in operation. Since the current location of the laser is only temporary, I have assembled an enclosure out of office partitions and all people in the Lab are required to wear eye protection when the laser is in operation.

The cutting table is approximately 10-in tall. A support table had to be built in order elevate the system to a height that is convenient for the average user to work. I addressed this issue by constructing a very sturdy table out of tubular steel. This support table takes care of the height issue as well as providing a suitable location for some of the electronic components as well as material storage.

The system arrived in several pieces. Assembly required a few days work, but was for the most part it involved little more than completing some electrical and mechanical connections. However, a cooling unit (chiller) required some custom fittings to be fabricated, as did the ventilation system. The last fragment of setup involved configuring a PC to handle the custom software that the manufacturer included with the system. This process also included installing a Kern Electronics PC card to facilitate the automation of the cutting process and installing KCAM4 software. The final assembly can be seen below in Figure 1.

After confirming that all the connections were made properly and well secured, the computer was rebooted, the chiller and vacuum were turned on and the laser was powered-up. This test allowed me to verify the absence of leaks in the water cooling system, vacuum system and air lines. After all systems proved to be fully functional, I was able to move on to actual operation.

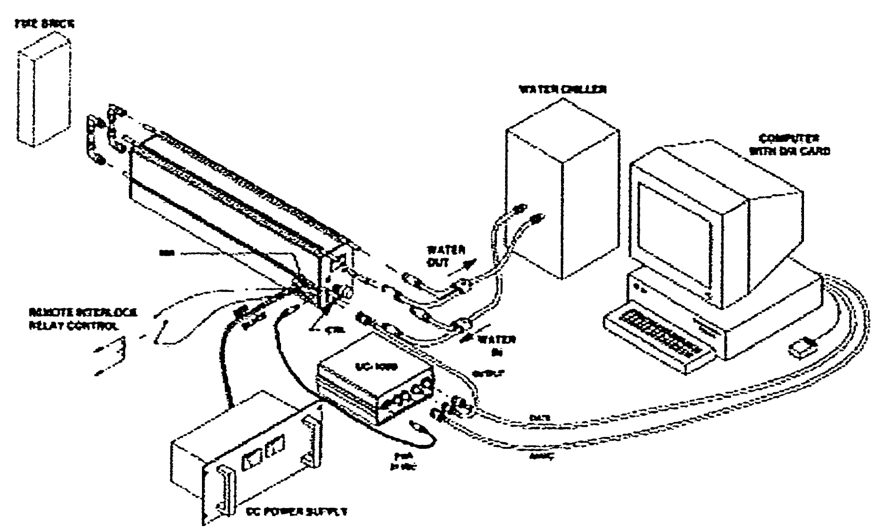

Figure 1: Laser, Chiller and Computer Control Assembly

3.2 Characteristics of our Cutting System

The laser cutting system we purchased uses a 50W CO_2 laser made by Synrad, Inc. It requires a constant 30volt-power supply, which is provided by a custom built DC power converter. This laser generates vast amounts of heat during operation and when in standby mode. To prevent it from encountering damage due to excessive heat, a 7 gallon, recirculating, distilled water cooling system is kept on at all times.

The large 48-in by 48-in cutting table provides ample space to perform even large jobs. Every square inch is accessible by the laser, so that materials up to the full size of the table can be worked easily. Not only does the table provide a surface to hold the materials to be cut or engraved, but it also is an integral part of the vapor removal system. The entire surface consists of an aluminum honeycomb, which is strong enough to hold materials, small enough not to allow the laser enough area to heat/cut (also, diffuses heat very quickly), and it is so porous that the vacuum can be applied over the entire area. At the back of the table two 1½ -in hoses collect the cutting vapors and feed them to the 1hp vacuum. These vapors are then ducted out of the building through an open window.

The cutting surface provides a full range of movement throughout the entire X and Y-axes. Motion is provided by a set of stepper motors and lead screws. The two degrees of freedom are totally separate in this split-gantry system. The laser is fixed to the X-axis and capable of moving only right and left; the table is fixed to the Y-axis and capable of moving only front and back. However, computer controls keep these two motions in unison with one another in order to produce very accurate cuts and refined engraved images.

Besides the external exhausting of the cutting vapors the only other component that is not internal is a single air pressure line. A line of 60-psi dry air feeds the table. The only purpose this line serves is to provide a continuous jet of air in the immediate local of the focusing lens and focused laser beam. Air provided by this system prevents dust, spatter and other debris encountered during operation from collecting on the focusing lens.

The final dimensions of the complete system are about 90-in by 80-in. This does not include the computer and monitor that are necessary to operate the laser. The complete system including supporting table weights approximately 1600-lbs. As one can easily see, this system is a permanent fixture that is not intended to ever be moved.

3.3 Capabilities of Our Laser Cutting System

This system is capable of cutting a broad array of materials. Materials that can be cut include, but are not limited to acrylic, wood, leather, vinyl, some plastics, cloth, particleboard, cardboard, paper and rubber. According to the manufacturer the system should be able to handle materials up to ¼ inch without much difficulty. Larger thickness can be cut, but only at significantly slower cutting speeds. In addition to cutting, the system is also capable of lettering and etching graphics. Any text can be engraved into materials as well as any image.

Kern Electronics has included some custom software know as KCAM4 for our use. It provides the ability to use most design tools such as AutoCAD, CorelDRAW and DesignCAD with the laser system. An individual can design or draw an object in one of the above mentioned software packages and then import it into KCAM4 to generate the appropriate toolpath. Another unique and potentially useful package provided by KERN is KTIF. This software allows an individual the ability to engrave a gray-scaled image directly on to their object material.

The system is rated to cut at speeds up to 8 inches per second and it can etch at speeds up to 5 inches per second. Cuts are accurate up to 0.05-in and can be repeated continuously with equal resolution. Etched images can be produced at a resolution equivalent to approximately 400dpi.

Single run operations are ideal for this system, but it can also be used to mass-produce parts. An image can be prepared that is 2-in by 2-in and then repeatedly cut from a large 48-in by 48-in piece of material by selecting a repeat function.

Another notable feature is the ability to cut a 3-D image into a series of equal thickness cross-sectional slices. These slices can then be cut by the laser and assembled to form a finished product that is realistic and accurate in three dimensions. An example of a car design using this feature can be seen in Figure 2.

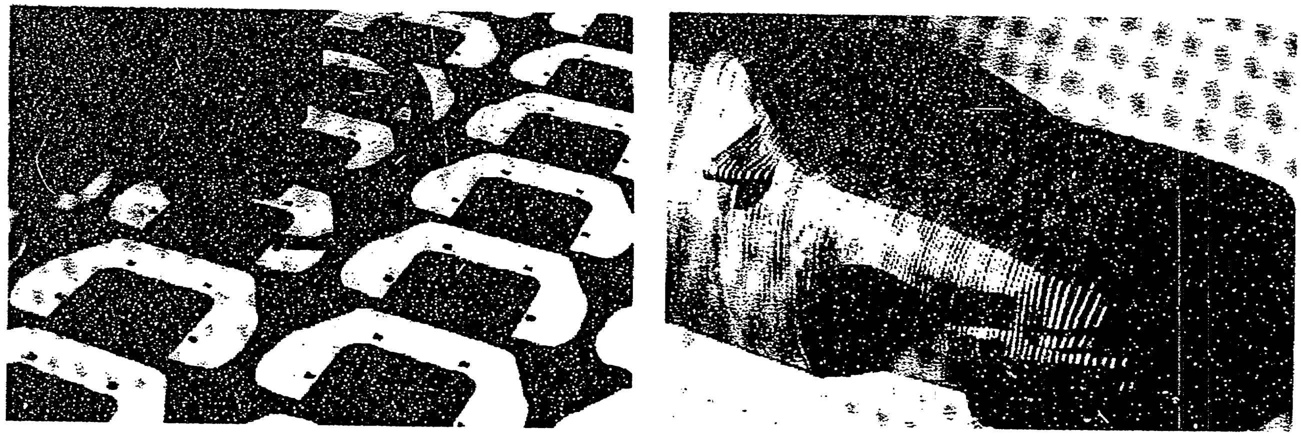

Figure 2: 3-D Cross-Sectional Slicing Method of a Model Car

4 Results

4.1 Performance Results

The actual output of the laser varies beyond its 50W rating. Testing conducted by Synrad for the purposes of requirements set by the Center for Devices and Radiological Health showed that the beam output fluctuates between 56W and 60W and maintains an average of 58W at a 5Khz duty cycle. When pulsed for 1 mSec at 100 Hz the peak output was recorded at 65W.

The accuracy of the laser is listed at 0.05-in. After doing some cutting test, where the system was require to cut a series of parallel lines through paper I found that it can maintain the stated tolerances. Also, a somewhat objective test indicated that the etching resolution of the laser is on par with its 400dpi rating. To determine this I compared a 400dpi image from a laser printer with the same image etched in wood. I could not detect a noticeable difference between the two samples. The laser appeared to etch sharp corners and did not have trouble rounding edges either.

Recommended Cutting Speeds		
Material	Thickness (in)	Speed (in/sec)
plywood	0.25	1
plywood	0.375	0.5
lexan	0.25	0.1
acrylic	0.125	0.25

Table 1: Recommend Cutting Speeds for Common Materials

The machine can cut many materials over a variety of thicknesses. Since the properties of these materials differ, in order to obtain optimum cutting quality the cutting speeds must vary. A series of trial and error experiments done on samples of some of the more common materials has indicated a preliminary set of recommended cutting speeds. The results can be seen above in Table 1.

The height of the cutting head in reference to the cutting table must also be varied with respect to the thickness of the material being cut. Since the most power is obtained at the focus of the beam this must be positioned to lie within the object material. The optimum height with respect to the surface of the material being cut is about 3/16-in.

4.2 Sample Results

There is probably no better way to understand the abilities of this laser than to actually see it running or examples of what it can make. I have run six examples from start to finish and have photographed the results. These examples cover a broad range of the different ways of operating the laser as well as a variety of materials and styles.

The first example is actually based on a preprogrammed file sent to us by Kern Electronics. It is based on a picture of a fish that was scanned into a computer and then imported to the laser cutting system. A toolpath was automatically generated and then run. The result can be seen below in Figure 3.

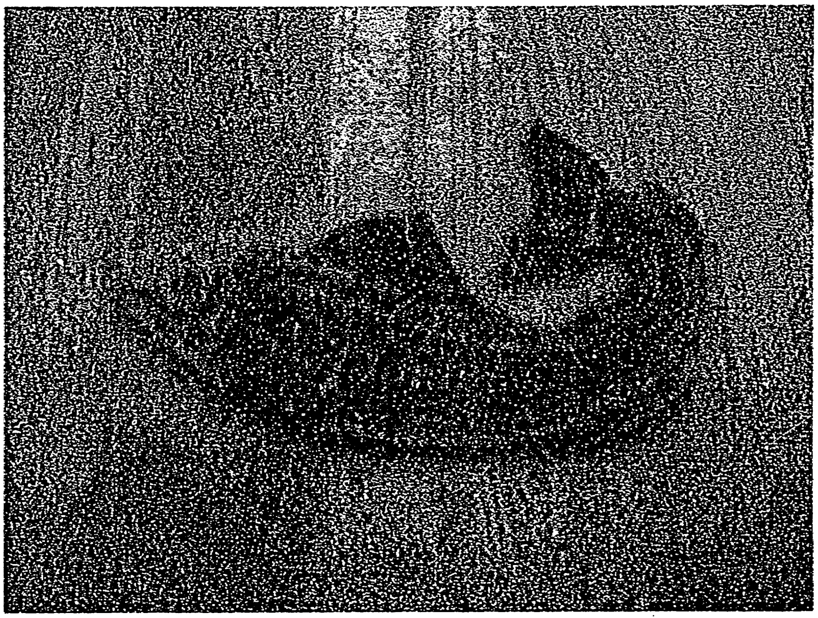

Figure 3: Fish Sample

Second and third samples were done using the scanning and etching features. Images were scanned in and then sent to the KTIF software package. Below in Figure 4, one can see a preliminary sample of a Porsche logo on the left and an image of three young children on the right.

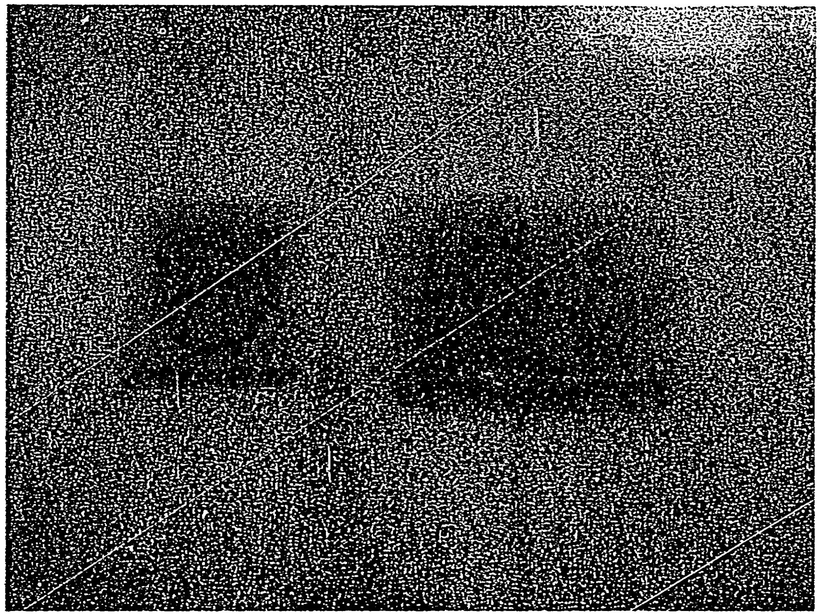

Figure 4: Sample Etchings of Porsche Logo and Three Young Children

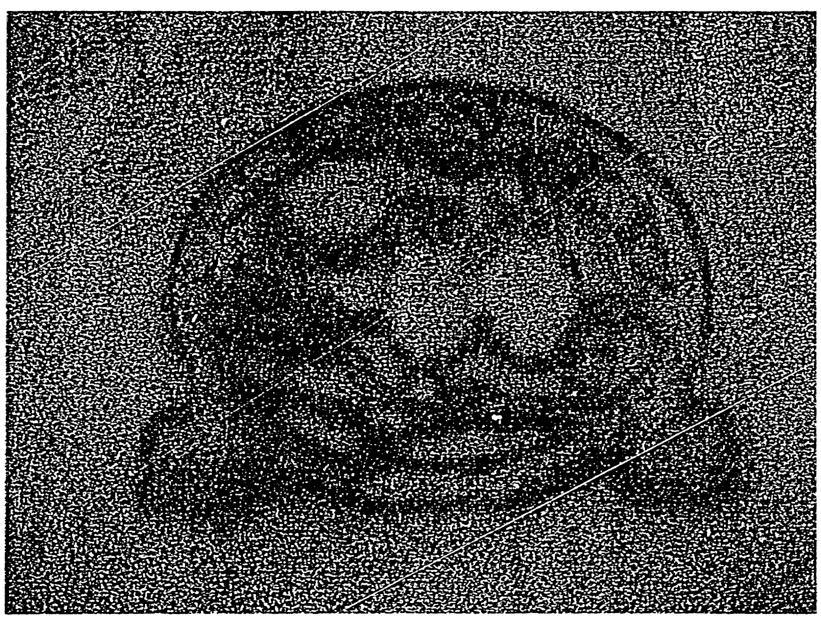

Figure 5: Sample Cut of Two Owls Using CoralDRAW and KCAM

Figure 5, shows a sample cut of two owls sitting in a tree. The design was done in CoralDRAW and then imported into the KCAM software package. The cut quality is a bit crude, but as I learn more about cutting speeds, materials, and power settings of the laser the cut quality should begin to rival flame polishing.

The last sample, a company business card, can be seen below in Figure 6. It is a good example of the high resolution the laser is capable of achieving when it etches text. The photo quality may prohibit one from seeing the very clear script text, but the actual sample easily rivals the quality of a laser printer.

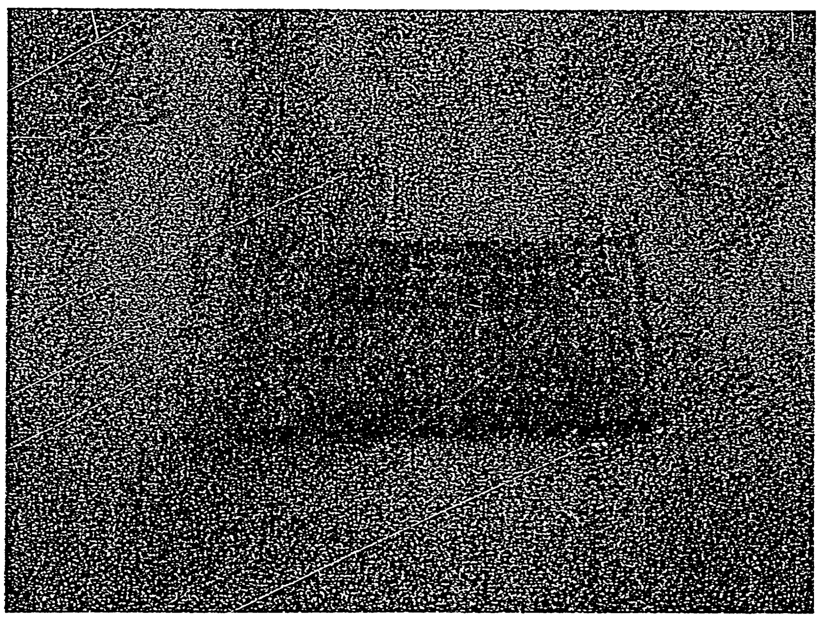

Figure 6: Sample Etching of a Business Card with High Resolution Script Text

5 Recommendations

It is hoped that this laser cutting system will be enjoyed by all of the MIT Mechanical Engineering community. Access should be open to all students and lessons regard its operation should even be integrated into some more advanced design classes.

Future plans could include creating templates and programs for cutting commonly used shapes and figures. In addition, standard operating procedures could be created for each of the different methods of usmg the laser. For example, a procedure could be written that specifically deals with designing a figure in AutoCAD and then importing it to the laser and having it cut and engraved. Another could discuss how to replicate a single drawing over the entire cutting surface in order to mass-produce a design.