

Catheter Laser Drill

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ABSTRACT

The project that I have undertaken is to improve upon an existing machine and process at Applied Medical, a medical device company. The machine is used to drill four holes into the body of a catheter. The holes are located on a linear axis, rotated 90 degrees apart from each other. Currently, the machine utilizes a traditional drill bit to create the four holes. This creates burrs along the holes, which increases the manufacturing time because a worker must remove them. The project calls for the use of a laser to replace the drill bit. The machine designed through this project effectively decreases the occurrence of burrs by vaporizing the excise material, thus decreasing production time. Each catheter will be manually loaded onto the motor shaft, which will then hold and rotate the catheter through the duration of the drilling procedure. This report documents the design of the machine and the selection of its components.

ACKNOWLEDGEMENTS

Applied Medical is an innovative medical device manufacturer. The company is passionate about its products and passionate about the community. The company accepts sixty students into the internship program each summer. I am fortunate to have been selected for two consecutive summers. Last summer I was an intern for the Tooling and Automation department. My supervisor from that department agreed to act as my Technical Supervisor for my Senior Project. In addition to a sincere thanks to Applied Medical, I extend immense appreciation to my Technical Supervisor, Arpad Szabo, for giving me a project and diligently helping me along the way.

Throughout the project, I worked with numerous companies to design the Catheter Laser Drill. I would like to thank Keith Chalman of Miyachi Unitek, Peter Tkocz of LaserStar, and Randy Kimball of DPSS Laser Inc. for taking the time to discuss various aspects of their lasers. Furthermore, I would like to thank the lab technicians of LaserStar and DPSS for testing my samples and their diligence in their responses. I would like to thank Automation Direct for the numerous phone calls regarding their products.

Lastly, I would like to thank my Faculty Supervisor, Lou Tornatzky. Throughout the duration of my project, he set aside time for numerous meetings outside of the scheduled class time. I extend particular thanks to him for his encouragement regarding pursuing a project with Applied Medical, and the ensuing direction of the project.

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SECTION I INTRODUCTION

Applied Medical is an innovative medical device company which is located in Rancho Santa Margarita, California. I have held intern positions at this company for the last two summers. The first summer I worked in the Engineering Department, and the second summer I worked in the Tooling and Automation Department. I would like to eventually work in the medical manufacturing industry and chose to work with Applied Medical for my senior project. Through collaboration with my previous supervisor, Arpad Szabo, the Tooling and Automation Department Supervisor, we selected a project that involved the redesign of a machine. The machine is called the Catheter Laser Drill.

This machine is to be designed over the span of the winter and spring quarters of the Cal Poly 2010 school year. I will be working in close contact with Arpad Szabo, acting as my technical supervisor, and Lou Tornatzky, acting as my faculty supervisor. The deliverables are further explained in the project proposal. Essentially, throughout the span of time, I will create the full scale design of the Catheter Laser Drill, with the accompanying 3-D modeling and vendor information.

Problem Statement

The purpose of the project is to create a machine design that utilizes a laser to drill four different holes into the body of a catheter. These holes are situated on the same linear axis, but are offset from each other by ninety degrees. The machine is being designed in order to create greater efficiency and productivity. The use of a laser will decrease the amount of time necessary to drill each hole using conventional methods. This will in turn improve Applied Medical's time per part ratio. In addition, by using a laser to drill the holes, one is able to reduce the size of the burrs left from machining. To those unfamiliar with this term, the Merriam-Webster online dictionary defines a burr as, "a thin ridge or area of roughness produced in cutting or shaping metal." In the case of this project, a burr is the plastic ridge left by the drilling operation. In dealing with invasive medical devices, burrs can be particularly dangerous. To ensure that no patient is left with microscopic plastic bits in his or her body, Applied Medical has very rigid requirements for what size burrs are acceptable.

The catheters are a high demand product of Applied Medical. By decreasing the production time, it will allow for a larger profit margin and a more efficient production schedule. The machine will be placed in the Plastics Building at Applied Medical. This building also houses the extrusion lines. As the catheters are produced on the extrusion lines, the batches will be sent to the adjoining Clean Room to be drilled. A Clean Room is a room used in manufacturing facilities to assemble products. It is so called because it is an environment which is free of dust, microbes, particulate matter, and other airborne pollutants. This machine will replace the current one and will be used as soon as it is cleared for production approval.

Company Needs

The requirements of the project are laid out with very broad guidelines. The only true guideline set by Applied Medical is that the machine must employ the use of a laser. The laser is the component which will result in the solution to the problem. It was recommended that this machine generally replicate the current one, but with the addition of the laser in place of the drill press. The current machine will serve as the basis for the initial design process.

Background or Related Work

Within Applied Medical, there are no other employees who have investigated the issues with the current machine. My Technical Supervisor, Aprad Szabo, assigned the project to me and was aware of the issues. He is a Supervisor of the Tooling and Automation Department, so projects are delegated out through him. Previous research has been conducted on lasers through Applied Medical because some of their current machines utilize lasers for different applications. The first companies which were consulted during my project were previous laser suppliers of Applied Medical. Lasers are not predominately used for drilling, so it is largely an area with which Applied Medical is unfamiliar. My project will provide research for future machines which deal with laser drilling.

Potential Solution(s)

At first glance, I foresee two different types of lasers being the most probable for drilling into Applied Medical catheters. From my preliminary research, I have found that gas lasers and solid-state lasers show the most promise. The major issue which is going to be a limiting factor is the

ability of the catheter material to hold heat. There are various types of lasers under the general titles of gas and solid-state. It is my assumption that the laser with the lowest amperage and power exertion will be the laser that will produce acceptable holes. As for the actual structure of the machine, I anticipate the laser resting above the motor configuration. The machine will be manually loaded, with the catheters being placed on a mandrel. The motor layout will consist of an electric slide that will be the source of the linear motion. There will also be another motor mounted on the slide which will cause the rotational movement. The final selection of the motor will determine whether the layout remains in this orientation.

In the event that a laser will not suffice as a viable solution to the drilling issues, there is an alternative. The current process, despite requiring additional work to clear the burrs, does indeed work. As an alternative, the current process can be renovated. The cycle time for the process is 40 seconds and could be dropped dramatically. When the drill moves into position, it stays in the lowered position for roughly seven seconds. There is no reason for the drill to stay down for that amount of time. By eliminating the extra time across four holes, there could be a potential time savings of approximately 12 – 16 seconds. In addition, the tooling for clearing the burrs could be renovated. The alternative is dependent upon how the laser works.

Contribution

This project will help Applied Medical in a multitude of ways. Upon its completion, the project will provide Applied Medical with a design that will satisfy its needs. As discussed previously, the machine will increase part production and decrease cycle time. This in turn will have financial benefits for Applied Medical. Allocating the project to me enables another Tooling and Automation engineer, who would have been assigned this task, to work on a different project.

Scope of Project

The scope of this project largely covers areas of technology which my prior coursework does not address. The scope of the project will entail the digital design of a machine which uses a laser. The project deliverables will involve 3D SolidWorks models and part drawings. The literature review portion of the project has evolved into a research paper of laser types. The design of the machine is heavily dependent upon which laser is chosen, so the first quarter was devoted solely to the laser review. The 3D models are to be assembled throughout the second quarter. The

component vendor list and assorted portions of the appendices will also be completed during that time. The report itself will be completed toward the end of the second quarter and will describe how the project was completed, as well as the machine itself.

SECTION II

REVIEW OF LASER LITERATURE

Purpose

The purpose of this literature review is to facilitate the selection of the proper laser for use in the design of the Catheter Laser Drill. In addition, accompanying each section will be a synopsis of the operating principles of each type of laser. The research is meant to inform the reader and myself about the working principles behind the laser, and to familiarize both parties with the terminology of the field. The machine will utilize the laser to drill four holes along the body of a catheter. This project has been commissioned by the medical device company, Applied Medical. I have been advised that the machine budget will only allow the use of a single laser.

Applied Medical has set very few specifications as to the requirements of the laser. From the little information provided, I will have to find a viable solution through my research. The main reasons for the use of a laser, in place of conventional methods, are to increase the speed of drilling and lessen the size of burrs. Due to the nature and power of a laser beam, it is presumed that the use of a laser will greatly increase the speed of drilling and decrease the size of burrs.

The goal of the following information is to allow the selection of the proper laser to be used in the Catheter Laser Drill. In the following pages, I will provide an in-depth look at the three major types of lasers which are used for machining. Within these laser types, I will explore individual sub-types which will be possible solutions. Lastly, I will include the best possible laser from each category.

Laser Drilling

The machining operation needed for this machine is drilling. Therefore, the first section of this paper will be an analysis of the specifications of lasers that will be most important to estimate drilling capabilities. As discussed in the book, *Lasers in Industry*, there are three major benefits to using a laser over traditional methods. According to Reinhold (1972), “Because there is no physical contact between the hole-forming tool and the material, problems such as drill-bit breakage and wear are nonexistent” (p. 229). Secondly, “Precise hole location is simplified because the optics used to focus the laser beam can also be used to align and locate” (p. 229). Thirdly, “Large aspect ratios (hole depth to hole diameter) can be achieved” (p. 229). The

characteristics of the beam are going to be the laser specifications that matter most. The quality, power, and width are all going to be crucial factors in the drilling capacity. According to the Reinhold (1972) text, in laser drilling, a pulsing beam is the most efficient operational mode. In addition, it states that Nd:YAG and CO₂ Gas Lasers have shown the greatest potential for hole drilling applications. Gas lasers are considered to have increased uniformity in the output beam profile and physical hole, as compared to solid-state lasers. The Reinhold text also states that the large hole diameters are obtained by repetitive laser pulses at lower power levels.

Laser Types

Through my initial research, I have found that there are six broad types of lasers from which I will choose: solid state lasers, gas lasers, chemical lasers, dye lasers, metal-vapor lasers, and semiconductor lasers. Through my early research, using various sites such as RP Photonics and various books listed on the reference page, I have substantially narrowed the scope of possible lasers. Of these larger groups of lasers, some are used primarily for research and development, and some are used largely for defense-related matters. To date, the largest use of chemical lasers is in the area of weaponry and military materials research. Dye lasers are a small sub-category of lasers, which deals largely with skin treatments. Similar to dye lasers, metal-vapor lasers are used for dermatological purposes and scientific research. Therefore, the three laser types which I will research for a solution are gas lasers, solid-state lasers, and semiconductor lasers. According to Aldrich (n.d.), there are three parts to a standard laser. The three parts are the laser material, the optical cavity, and the pump source (Aldrich, n.d.). In analyzing the different types of lasers, it will be most important to analyze the variations in the three parts of a laser and how they affect the beam.

Gas Lasers

Gas lasers are unique in that the medium which the electric current is transferred to is a gas. For the vast majority of lasers, this transfer medium typically has a solid crystalline structure. These lasers contain a shaft which is filled with various gases. Most gas lasers are generally excited by an electrical current. The accompanying source of current is then pushed into the shaft. The current excites the electrons in the gas and the beam is then projected out through the mirror. A diagram of a rudimentary view of a gas laser can be seen below in Figure 1. In general, gas lasers

have a high beam quality and the gas is able to dissipate heat quickly. A disadvantage to the gas laser is that it requires a high voltage supply with an accompanying high electrical power.

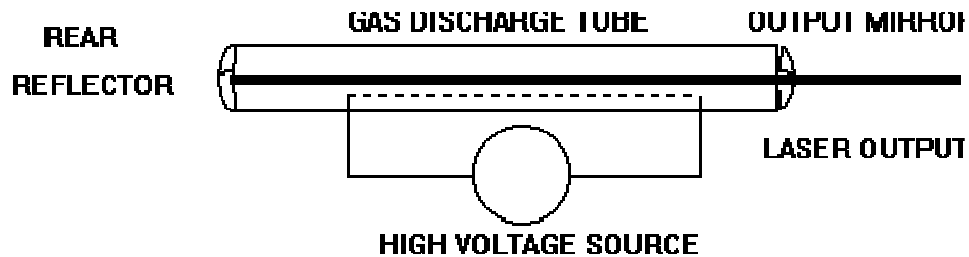


Figure 1: Simplified internal view of a gas laser (Aldrich, n.d.).

1.1 Carbon Dioxide Laser

As Svelto (1989) discussed, “The carbon dioxide (CO₂) laser is actually one of the most powerful lasers and one of the most efficient” (Svelto, 1989, p. 310). The gas discharge tube is loaded with CO₂ and that serves as the medium through which the beam is emitted. Like most lasers, this one is pumped electrically with an electrical current in the range of 20-50kHz. (Paschotta, 2010). This laser is capable of emitting both a continuous wave and pulsing waves. The ratio of output power to pump power can be as high as 30%. When used in the continuous wave mode, this laser has found high use in cutting and welding machining operations. The pulsing mode has been proven effective for vaporizing, chipping, and erosive processes. According to the chart found in Appendix B at the end of this report, one finds that the average wavelength for a CO₂ laser is 10,600 nanometers.

1.2 Carbon Monoxide Laser

The carbon monoxide (CO) laser incorporates the high efficiency and high power of the carbon dioxide laser, but has a shorter wavelength. As shown in Appendix B, the standard wavelength is 5000- 6000. Just as with the CO₂, the CO laser can operate at a continuous or pulsing wavelength. When compared, the carbon monoxide laser and carbon dioxide lasers share very similar specs. As stated previously, a short pulsing beam is perceived as being better for drilling. The pulsing beam of a carbon monoxide laser could be a factor in choosing it over the carbon dioxide laser.

1.3 Helium Neon Laser

The helium neon laser uses a combined gas as the media gain in the laser. “Laser action is obtained from transitions of the neon atom, while helium is added to the gas mixture to greatly facilitate the pumping process” (Svelto, 1989, p. 298). Listed in Appendix B, this laser registers a 543, 594, 612, and 632.8 (nm) in terms of wavelength. Similar to the carbon oxide lasers, this laser also operates with a continuous wave. The varying degrees of wavelength are dependent on the combination of features in the lasers. It is common for these lasers to produce up to tens of milliwatts of power. According to Aldrich (n.d.), helium neon lasers are capable of .5-100 milliwatts. “They are not sources of high power laser light. Probably one of the most important features of these lasers is that they are highly stable, both in terms of their wavelength and intensity of their output of light” (Newman, 2002). Another advantage to using a helium neon laser is that it is considered the most inexpensive laser.

Solid-State Lasers

In a general sense, “The term solid-state laser is usually reserved for those lasers having as their active medium, either an insulating crystal or a glass” (Svelto, 1989, p. 287). The broad name for these lasers comes from the makeup of the “host” material. In Figure 2, a simplified internal view of a solid-state laser can be seen. These lasers are very versatile and can generate output powers between a few milliwatts and many kilowatts, in high power versions. (Paschotta, 2010). Due to the nature of the pumping system in solid-state lasers, they have fairly low power efficiency. The pumping system is usually optically pumped, which means that light is used to excite the medium. Utilizing a flash bulb or arc lamp, the media is excited. As mentioned, an example of how a flash bulb acts as a pump can be seen in Figure 2. In solid state lasers, a laser diode typically acts as the pump. This can be seen in Figure 2. There is a vast array of laser diodes from which to choose. The diodes can be electrically pumped or stimulated by photons which create the optical pumping. “These diodes offer a compact setup, long lifetime, and often very good beam quality.” (Paschotta, 2010). This laser is well suited to my project due to the nature of the pulse. The pulse can be stored up and emitted at peak power, and it can also be shot in extremely short pulses. In addition, an option called the Q switch can be added to the lasers. According to Paschotta (2010), by purchasing a laser with a Q switch, the laser will be able to achieve nanosecond pulses of high energy.

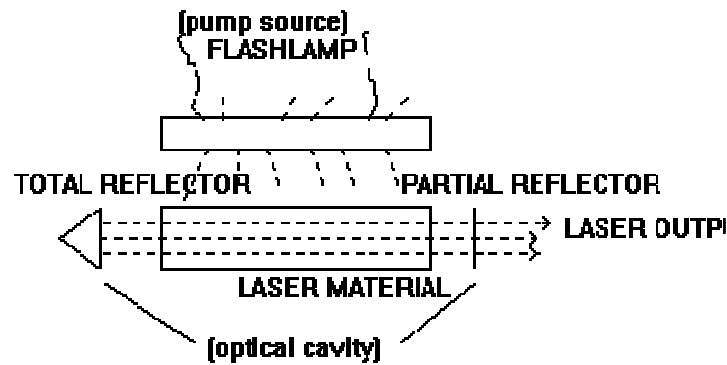


Figure 2: Simplified internal view of a solid-state laser (Aldrich, n.d.).

2.1 Nd:YAG Laser

Nd:YAG lasers utilize an abbreviation for neodymium-doped: Yttrium Aluminum Garnet. YAG pertains to the rare earth doped crystal. It's considered to be one of the most versatile solid-state laser sources. According to Aldrich (n.d.), this laser operates in a pulsing mode. It also states that the peak power attainable is 10^{10} watts. This is lower than the carbon dioxide laser, but would be more than sufficient for my application. The most common wavelength for these lasers is 1064 nanometers. These YAG lasers are used in materials processing, welding, cutting, medical laser systems, and slab technology (Roditi, 2007). The four level operation permits a low threshold pulse.

“Neodymium-doped gain media face competition from ytterbium-doped media in the 1- μm spectral region. The latter have a smaller quantum defect, usually a higher emission bandwidth and a higher upper-state lifetime, also a simpler energy level structure which avoids various quenching processes. However, they exhibit quasi-three-level behavior, which tends to lead to a higher threshold, so that the power efficiency is not necessarily better than for neodymium-doped media.”

(Paschotta, 2010)

As expressed in the above statement, the neodymium doped crystals do lack in certain areas when compared with ytterbium doped crystals. Though such factors as lifetime are of importance, the difference is not substantial enough to prefer one more than the other. The negative quasi-three-level issue will be discussed in part 2.2.

2.2 Yb:YAG Laser

The Yb:YAG laser shares some of the same characteristics with that of the Nd:YAG laser because they both utilize a Yttrium Aluminum Garnet crystal as the media. The difference is that this YAG crystal is doped with Ytterbium. According to Paschotta (2010), the Yb:YAG laser typically emits between a 1030 and 1050 nanometer wavelength. Typically it has a wide pump band and is the ideal media for diode pumping.

“The small quantum defect also has a usually unwanted consequence: the significant quasi-three-level behavior, particularly at short wavelengths. This requires such lasers to be operated with relatively high pump intensities and makes it more difficult to realize fully the potential for high power efficiency. Another difficulty arises for the resonator designs of end-pumped ytterbium lasers: a resonator mirror for injecting the pump light must have a high reflectivity at the laser wavelength and a high transmission at the only slightly shorter pump wavelength. Dichroic mirrors with such properties for closely lying wavelengths are difficult to make.”

(Paschotta, 2010)

As discussed in part 2.1, this three level behavior is not an issue with the neodymium doped crystal. This laser could certainly work for the application I need, but the mirror combination and power setting issues could affect the beam.

Semiconductor Lasers

Just as the gas and solid-state lasers have a unique gain medium, so does the semiconductor laser. Shown in Figure 3, the key part of a semiconductor laser is the p-n junction. This is created by placing two different semiconductor materials together. When electric current is sourced to the semiconductors, an electric current rapidly flows in one direction. The current shoots through a lens located at the forward biased side of the p-n junction. These lasers can be either electrically or optically pumped (Paschotta, 2010). “The cw (continuous wavelength) laser emission wavelengths are normally within 630-1600 nm” (Columbia University, n.d.). The power of these lasers is also dependent on the quantity of the stacked semiconductors. A stacked

diode is capable of producing a peak power of 20 watts in a semi-continuous wave. These lasers are extremely diverse and range greatly in price.

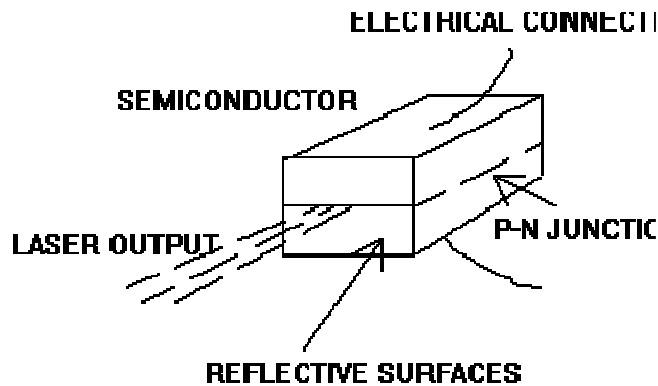


Figure 3: Simplified internal view of a semiconductor laser (Aldrich, 2010).

3.1 Semiconductor Laser Diode

Semiconductor lasers are comprised of two semiconductors which determine the characteristics of these lasers. According to Power Technologies Incorporated (2004), laser diodes can vary substantially between manufacturers. As mentioned previously, the diode is largely dependent on the variations in material and layer thickness. These factors will affect the wavelength and operating current. In Appendix B one can find that the standard wavelength for a laser diode is in the range of 630-950 nm. In contacting companies to inquire about their laser diodes, I will need to discuss the specs of each one in order to decide whether it is usable.

3.2 InGaAsP Laser

The InGaAsP Laser is named after its photodiode materials. It is made out of indium, gallium, arsenide, and phosphide. According to Paschotta (2010), this laser produces a “low dark current, high speed, and good sensitivity roughly between 900 and 1700nm (best around 1100-1300 nm).” An immediate drawback to this laser is that it is rather expensive. This laser contains very similar specs to that of the other semiconductor materials, such as silicon and germanium. The largest variation is in the wavelength, which is best in germanium at 1400-1500 nm and best in silicon at 800-900 nm.

Conclusion

The completed research has led me to the Nd:YAG laser medium. The power capability and frequency cover the range of what is expected to be used. Early in the quarter, it was anticipated that a standard Nd:YAG welding laser would be used. After speaking to sales representatives and technicians, primarily from Miyachi Unitek and LaserStar, the consensus was to use a Nd:YAG Laser Marker. Laser Markers are used to engrave metals and plastics with writing or images. Using the proper settings, they can be used to drill holes in plastics, as well as vaporize the excise medium. The use of the laser welder, instead of the laser marker, would result in a heat level that would be too intense for the plastic. The catheter would warp and burn far beyond an acceptable level. LaserStar is one of the largest suppliers in the industry and they offer testing of sample parts. Samples will be submitted to LaserStar for testing of the 3000 and 3500 series Nd:YAG laser markers. This laser is air-cooled which lowers the original cost of the unit, as well as the operational cost. The laser markers have a high frequency and low power. These settings are what will create an acceptable heat level for the drilling of the catheters. Though the laser is expected to create the specified holes, samples must be submitted because lasers largely depend on the frequency material reaction.

SECTION III SOLUTION

The following section discusses the most critical components of the Catheter Laser Drill. The laser and motor selection are the factors which determine the outlay of the machine. This section will outline the process by which these components were chosen.

Purpose

The purpose of this project is to design a machine that will use a laser to drill four holes in a catheter at the proper locations, to the desired dimensions. The holes will be located on a linear axis, but offset from each other by 90 degrees. The holes must be free of burrs and follow the guidelines as displayed in the drawing. In addition, the laser must create a faster cycle time for the product and improve upon the current process.

Laser Solution

The type of laser selected for the machine is a critical part of solving this problem. Throughout the quarter, this project has been rapidly changing. In researching lasers, I consulted both books and journals, as well as various companies. During the project, I have been in contact with three companies: Miyachi Unitek, LaserStar, and DPSS Lasers Inc. As issues arose with a laser of one company, another would offer a more viable solution. Finding an adequate laser which could produce the desired results proved to be the hardest and most time consuming part of the project.

As discussed in Section II of the report, the “Laser Review” led me to the laser medium I would use. Through my research during winter quarter, I found that the Nd:YAG laser medium would presumably be the most successful at drilling the holes. As the quarter progressed, the research and results from the testing led me to different Neodymium (Nd) doped mediums. The other change arose from the selection of a marking laser, rather than a cutting/welding laser. This section of the paper outlines the quarter long process of establishing the right laser.

1.1 Miyachi Unitek

When purchasing machinery or components, Applied Medical has to establish payment contact. This process adds additional time to the purchasing and overall project schedule. Therefore, the companies which I contacted were companies from which Applied Medical had previously purchased products. The most promising of the group was a company based out of Monrovia, CA, named Miyachi Unitek. My technical supervisor had utilized one of their lasers for a machine he designed. Following my laser review, I pursued the use of a Nd:YAG laser. I spoke with Keith Chalman, my contact at Miyachi Unitek, multiple times over the course of two weeks to determine which laser was best suited to my application.

The Miyachi Unitek laser which proved to be most apt to provide the proper drilling capacity was the LMF 2000. The LMF 2000, as seen in Figure 4, is a fiber optic laser marker. This differs from the standard laser for numerous reasons. The first is that it is used for marking materials. The majority of lasers are used for cutting and welding. The marking laser was selected because it emits less heat than the welding and cutting lasers. The laser has a frequency of 1064 nm, an expected usable level. In addition, the combination of a laser diode as the pump source and an air cooled system allowed for lower energy usage levels. The specifications for the LMF 2000 can be seen in Figure 5. The laser was high power and low frequency, which was presumed to create the best holes. The cost of the laser would be in the realm of \$50,000. In doing a cost analysis amongst other companies, I found the company LaserStar.



Figure 4: Picture of the Miyachi Unitek LMF 2000 series laser. Picture contains both the control unit and laser unit (Miyachi Unitek, n.d.).

LMF1000 & 2000 SPECIFICATIONS	
Wavelength	1064nm \pm 5nm
Power / Q-switch:	10W(LMF1000) & 20W(LMF2000) 1 – 100kHz / 20W(LMF2000-HP) CW, 1 – 500 kHz
Pump Source:	Laser diode
Guide Laser	Yes (630-650nm)

Figure 5: Specifications of the LMF 1000 and 2000 laser markers. (Miyachi Unitek, n.d.).

1.2 LaserStar Laser

LaserStar is one of the country's largest, and most diverse, laser companies. After conducting a topical cost analysis, it was decided that LaserStar had the best suitable laser for the application. I decided that LaserStar offered a superior product in terms of cost and capabilities and stopped pursuing Miyachi Unitek. In addition, the engineering department at Applied Medical was in the process of creating the vendor information for LaserStar. Purchasing the proper laser through LaserStar would cost between \$40,000 and \$50,000. I began discussions with Peter Tkocz regarding which particular LaserStar product would be best. Following the advice which I gathered from Chalman, Tkocz also believed that the best suitable laser would be a fiber optic laser marker. Given that the holes which needed to be drilled were as small as .018 inches, fiber optic lasers, with their minute drilling capabilities, seem to be the best choice. Through our conversations, he further analyzed the LaserStar products.

The 3000 and 3500 series fiber optic laser markers were chosen as the probable solutions. This laser can be seen below in Figure 6. These lasers shared very similar specifications with those of Miyachi Unitek. They emitted a frequency of 1064 nm and were diode pumped and air cooled. The power capabilities of these lasers were significant enough to vaporize the excise material, leaving a burr free catheter. They operated at a high frequency and low power. In Figure 7, the specifications of the laser are displayed. Whether it was operated at high or low peak power, it was a low maintenance machine with a long life. In addition to the financial

benefits of LaserStar's products, a large factor in my decision was their customer service. In talking with Tkocz, he stressed that the laser would work depending on the frequency material reaction. Frequency would be the determinant of which laser would work. The Applied Medical catheters are made of 98% polyester and 2% various colorants. Therefore the issue was whether the frequency of the fiber optic laser marker would react properly with the polyester material.



**3500 Series
FiberStar Marking System**

Figure 6: Picture of the LaserStar 3500 Fiber Optic laser marker. Picture contains both the control unit and laser unit (LaserStar, 2009).

Laser Source- FiberStar 3500	
Laser Type	Direct Fiber Laser
Wavelength	1065 nm +/- 10 nm
Beam Diameter (focus)	< 30 μ m
Pulse Duration	20-200 μ s
Pulse Frequency	1 - 500 kHz
Laser Peak Power	10 kW
Output Power	10 Watt, 20 Watt, 40 Watt
Output Fiber Length	2.0 Meters
Laser Class	Class 4
Cooling System	Fully air cooled, heat-sink

Figure 7: Specifications of the FiberStar 3500 series laser marker (LaserStar, 2009).

Another aspect of the allure of LaserStar was that the company would test lasers on samples. My machine would deal with the “Four French Catheter,” or 4F. All four different types of catheters were submitted to LaserStar’s Los Angeles lab. After two weeks, the samples were returned. To my surprise, the samples were not completed to an acceptable level. The medical industry has very rigorous quality standards for its manufacturing. That being said, a catheter which contains burnt plastic and burrs is certainly unacceptable for use in a hospital. After analyzing the samples, it was clear that the charring was on the bottom third of the hole, where it pierced through the wall of the catheter. There were small blisters and discolored plastic in the holes. In addition, the entireties of the holes were not concentric. The top of the hole was roughly two to three times larger than the bottom of the hole. The samples clearly showed that the 3000 and 3500 fiber optic laser markers were not suitable for my machine.

After my technical supervisor at Applied Medical received the samples from me, he came to the same conclusion that the samples were not acceptable. Through further discussions with Tkocz, we discussed alternatives through LaserStar. The laser didn’t work because too much heat was exerted onto the plastic. “Still too much heat for your plastic. We have been successful making these sized holes and even smaller holes in metal using the fiber markers. The plastic material reaction to the heat component is the limiting factor,” he stated in an email (P. Tkocz, personal communication, April 21, 2010). It was Tkocz’s thought that regardless of how the settings were changed, the laser would not be able to reach the set standards. In further discussions, it was also his thought that LaserStar did not have a product that would be capable of producing the desired holes. It was his idea to research cold lasers and lower frequencies, particularly lasers which reside in the ultraviolet (UV) frequency range.

1.3 DPSS Laser

Tkocz had a friend who dealt specifically with UV lasers, at a company called DPSS Lasers Inc. After speaking with Randy Kimball, my contact at DPSS, we quickly made the decision to use the 3500 series. This laser can be seen in Figure 8. Monetarily speaking, this laser was dramatically better because it would cost only \$32,000. This particular UV laser is considered a cold laser. It produces dramatically less heat when compared with cutting and welding lasers. This laser is used specifically for drilling small spot sizes. Whereas the laser from LaserStar operated with a wavelength of 1064 nm, the DPSS 3500 series operated at 355 nm.

Figure nine shows the broad specifications of the 3500 series. As stated on the DPSS website, “It takes advantage of the short UV wavelength to provide a small spot size and a large depth of focus. UV lasers take advantage of the cold marking process not requiring high average powers and allowing damage free marking on many materials.” When discussing the drilling capacity of the lasers from Miyachi Unitek and LaserStar, the possibility of foul-ups in the laser drilling were never mentioned. Kimball had a detailed discussion about potential problems. Like the samples received from LaserStar, we expected a 2:1 or 3:1 ratio from the top to the bottom of the holes. The laser was not expected to cause any burning, but there was the possibility that it would cause discoloration. Just as the sun can lighten the color of certain materials, the UV laser was apt to whiten an area of a few microns around each of the holes. In speaking with my technical supervisor at Applied Medical, we decided that the tapering of the holes would potentially be accepted by quality control, but that the UV discoloration would be the determining factor for that laser. In early May, I submitted samples for testing to DPSS.



Figure 8: Picture of the DPSS Series 3500 UV laser marker. Photo contains the laser unit (left), cooling system (center), and control unit (right) (DPSS, n.d.).

DPSS Series 3500 UV Laser	
Marking Area (Diameter)	75 mm
Average Power	1 W
Pulse Frequency	30 kHz
Pulse Length	25 ns
Pulse Energy	30 μ J
Peak Power	1.5 kW
Power Consumption	< 700 W
Input Voltage	100 - 250 VAC/ 50 - 60 Hz

Figure 9: Specifications of the DPSS 3500 series UV laser marker (DPSS, n.d.).

Upon receiving the samples, I made the decision that the laser from DPSS was the best option. The samples displayed a lot of information. The holes had a defined circular profile, from top to bottom. The ratio appeared to be less than the best presumed 2:1 ratio. The expected discoloration was no larger than what was expected from the conversations with Kimball. For all four different types of catheters, there were holes which would be deemed acceptable by Applied Medical Quality Control.

In the final discussions with Kimball at DPSS, the factors for running the machine were established. Within the DPSS 3500 series, there are numerous different types of lasers. The actual laser utilized in the testing was the 3530-30. This member of the 3500 series uses a three watt system at a 355 nm frequency. It is a diode pumped solid-state laser. During operation, the laser was Q-Switch enabled, which means that the laser was operating by using large pulses of power rather than a continuous beam. The scan rate was running at 500 mm per second, and the laser was operating in a circular pattern. In order to create the hole, three scans were completed at .25 msec. each. The settings tested were not optimized for speed and each hole was still created in only .75 msec. In terms of actual drilling time, that means the holes can be created in 150 msec. or less. Additional time is added for the plastic to settle from the previous drill. This adds a total time of 500 msec. per hole. Kimball stated that with optimized settings, the machine should be capable of completing a hole in .5 sec, for a total time of 2 sec. The initial estimate for the laser was \$32,000. In testing the samples, the specific laser changed, which amounted for a cost change. The 3530-30 laser costs \$50,000. In addition, that is the base level laser which runs

at 1 W. The laser tested runs at 3 W. This amounts for an \$18,000 cost difference. The total cost of the laser will be \$68,000.

Motor Solution

The laser being used in the machine will constitute the large majority of the total machine cost. In order for the laser to be utilized, there are numerous backing components which I needed to research. As the laser evolved to different models, so did the overall design. The original motor configuration, as well as the linear slide, was eliminated. The final design amounted to a much simpler configuration than anticipated. The following section describes the research and selection of the components in the machine.

As mentioned, the motor system originated as an overly complex figuration. In mid-April, I held a meeting with my technical supervisor and had the opportunity to watch the current process. The current process is flawed in its drilling method, not motor layout, so the design originated off the existing machine. After viewing the machine, I began searching online with the companies Festo and Automation Direct. These companies were selected because Applied Medical had previously purchased parts from them. During my internship positions at Applied Medical, I aided in the design of a machine which used parts from both companies. Applied Medical uses parts from these companies in virtually every machine they create. The first task was to find a suitable motor. This took place largely during the first half of the second quarter. The first motor which I chose was a general purpose AC motor (Reference Part Number- MTR-P33-1AB18) from Automation Direct (AutomationDirect, n.d.). It was a single phase motor with a base RPM of 1800. The motor had substantially more power than what was actually needed. It was the least expensive motor of the general motors, listed at eighty six dollars. Accompanying the motor was a worm gear box. The worm gear box (Reference Part Number- WG-262-060-R) was intended to rotate the catheter (AutomationDirect, n.d.). The rotary gear box can be seen in Figure 10. The worm gear box cost \$215. The shaft of the worm gear box would attach to the general motor. The power of the motor was then transferred fully to the worm gear box. The worm gear box would then be fitted with a clamping mechanism to hold the catheter. Each catheter would then be loaded and clamped, and when the motor was activated, the motor shaft would wind the gear box, and consequently the catheter. After submitting the design to my technical supervisor, he suggested some changes.



Figure 10: Worm gear box utilized in initial motor configuration. The general motor would be attached to the shaft, located to the far right in the image, to create motion in the box (AutomationDirect, n.d.).

The second generation motor layout consisted of a single motor. The major change suggested by my technical supervisor was to eliminate the use of the worm gear box. Aside from being used for power transmission, they are also used to reduce speeds. In this case, there was no major purpose for using the worm gear box. By eliminating the worm gear box, the only thing needed was a motor. The general motor which had been chosen through Automation Direct had some unforeseen issues. Through a conversation with a technician at Automation Direct, he informed me of the issue and a plausible solution. Unknown to me at the time, a general purpose motor has a tendency to glide. The catheter must have four holes drilled into it on a linear axis. As mentioned in the previous sections, the holes must be offset by 90 degrees. Having a motor that glides makes it unable to achieve the necessary 90 degree rotations. To solve the issue, a servo motor was selected. These motors are able to attain high power from a small unit. They can achieve precision turns and consume, proportionately, a low level of energy.

In searching for the proper servo motor, I consulted a sub-company of Automation Direct called Anaheim Automation. After dissecting the available motors, I chose a lower torque, smaller gauge motor. The servo motor (Reference Part Number- EMJ-02) cost \$236.90. In discussing the matter with my technical supervisor, he advised me of a less expensive alternative. The servo motor was chosen to eliminate the issue of glide. He informed me that a stepper motor could solve this issue at a fraction of the cost. Through Automation Direct I found what would be

the final solution. The stepper motor was two amps and attained proper power and size ratings. In addition, by using a stepper motor instead of a servo motor, I was able to cut the cost by 90 percent. The cost of the stepper motor was \$19 (Reference Part Number- STP-MTR-17048) (AutomationDirect, n.d.).



Figure 11: Image of the stepper motor which is used in the final motor configuration (AutomationDirect, n.d.).

SECTION IV

RESULTS

During the final few weeks of the second quarter, the machine design began to fully come together. With the laser and motor assembly chosen, the final design issues were solved and the 3D models were created. The design hinged on the selection of the laser. It was the determinate of how the machine would operate and which components would be required. This section of the report outlines the component assembly and how the machine will operate.

Purpose

The purpose of the Catheter Laser Drill is to use a laser to drill four holes into the body of a catheter. The holes are situated along a linear axis, but are offset from each other by a 90 degree rotation. The machine must be designed with the proper components to position the catheters at the required locations. The holes created must follow the dimensions set forth by Applied Medical. The holes must be free of burrs and burns. In addition, in order to make the purchase of a laser worthwhile, the cycle time of the current process must decrease.

Structural Layout

The current process for drilling holes in the Applied Medical catheters utilizes a traditional drill bit. One aspect of my project was to incorporate the use of a laser in drilling the holes. The machine which I designed uses both parts and principles of the current machine. This section will outline how the machine will be structured and how it will operate.

The main structural component will be Bosch extruded tubing. Bosch is an American based company which specializes in many different technologies. One such area of specialization is structural support for machines. The supports which I chose were the Bosch aluminum extruded bars (Reference Part Number- 3842517173). The extruded tube will be purchased in a single length of 3000mm (Bosch Rexroth, n.d.). The accompanying hardware will be accounted for through existing purchases by Applied Medical. One additional part of the structure will be a mounting plate for the components. A plate measuring roughly 7" by 4" will be machined from

the plastic delrin. The machine will contain two tiers. The delrin plate will be situated on the lower tier of the machine. Below, Figure 12 shows the 3D model of the delrin plate.

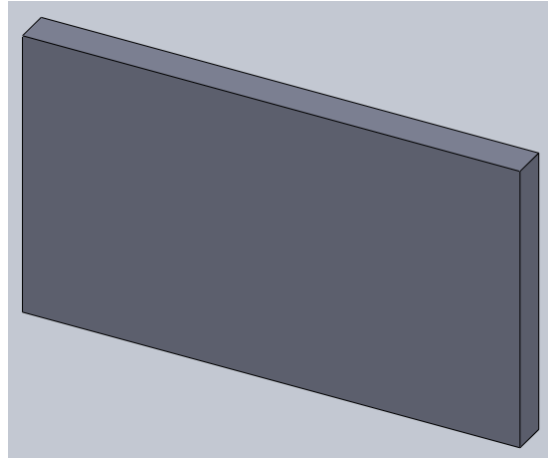
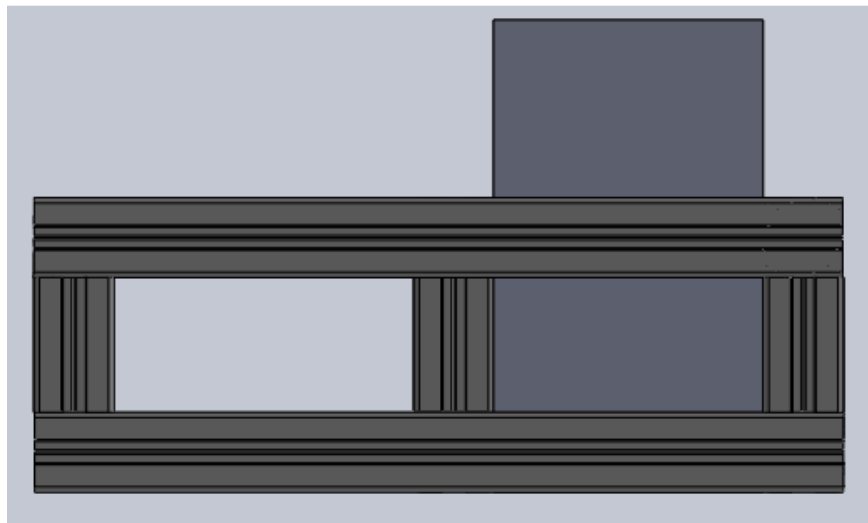


Figure 12: The delrin mounting plate, to which the majority of the components will be fastened.

The most basic parts of the machine are the structural components. The Bosch tubing will form the outer structure of the machine. The shape is largely a rectangle, but with a small offshoot. Figure 13 shows the structure of the Bosch tubing, with the mounting plate fixed in place. The main rectangular structure will be made of Bosch Tubing and will measure 12” by 4.36” by 6.18.” The height of the structure doesn’t include the eventual height of the laser. The offshoot will protrude from the bottom tier of the machine. The offshoot of the structure is where the delrin plate will be mounted.



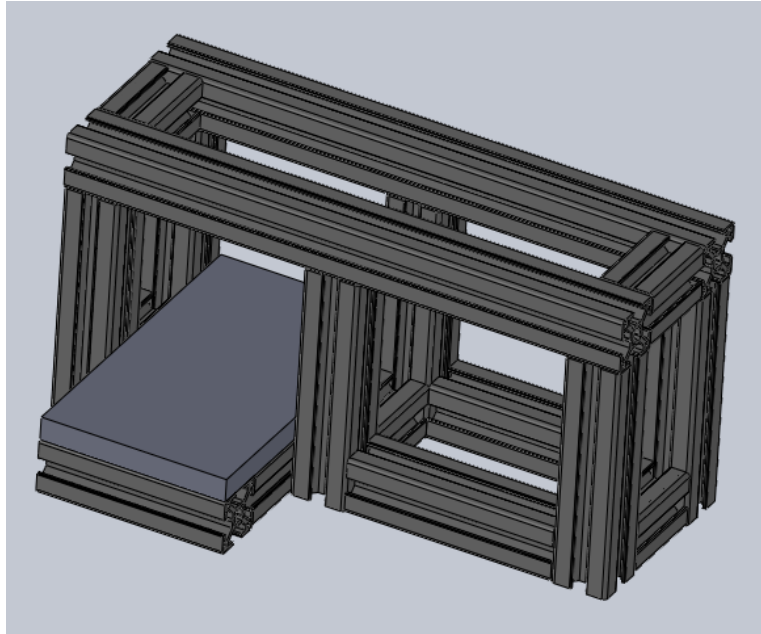


Figure 13: The Bosh tubing support structure, with the mounting plate set in position. The uppermost image is the aerial view of the structure, and the bottom view is the isometric view.

Component Layout

The motor will be fastened down after being centered along the width of the mounting plate. In referring again to the aerial view in Figure 13, the motor will be mounted half beneath the framing and half on the outside of it. This will serve to segregate the area with which the beam from the laser will hit. This will be further explained in the Machine Safety section. Using custom blocks, the motor will be fastened to the plate. The blocks will be machined from aluminum. The external casing of the motor will not emit a high enough level of heat to inhibit the strength of the delrin plate or aluminum blocks. The aluminum for the set blocks will be purchased through the online company McMaster-Carr (Reference Part Number- 89215K427). The block is 2024 aluminum in pre cut bar stock, measuring 12” by 1” by .5”. The price is listed at \$18.96 (McMaster-Carr, n.d.).

The other aluminum component which will be cut from the McMaster-Carr bar stock will be the mold set. This is the component which will house the tip of the catheter, or the area which will be drilled. The mold set will have a machined profile of the catheter. The profile will be slightly larger than the actual catheter in order to avoid frictional blockage. In order to ensure consistency in the drilling, the end of the profile will serve as a built-in jig. In Figure 14 there is a

3D model display of the mold set. The catheter will slide through the motor shaft and into the mold set. Once the catheter reaches the end of the profile, it will serve as an indicator to the operator that the catheter is in position. In order to keep the catheter in the correct place, there will be a polycarbonate cap, which contains the opposite image of the same profile. This can also be seen in Figure 14. The mold set cap is a crucial piece in the design. It contains a window in the middle of the block, which will remain as an open space for the laser to pierce the catheter. In order to avoid issues with the catheter being guided correctly into the mold set, both components are machined with a chamfer at the entry. This will aid in guiding the catheter into the correct position for the laser to drill.

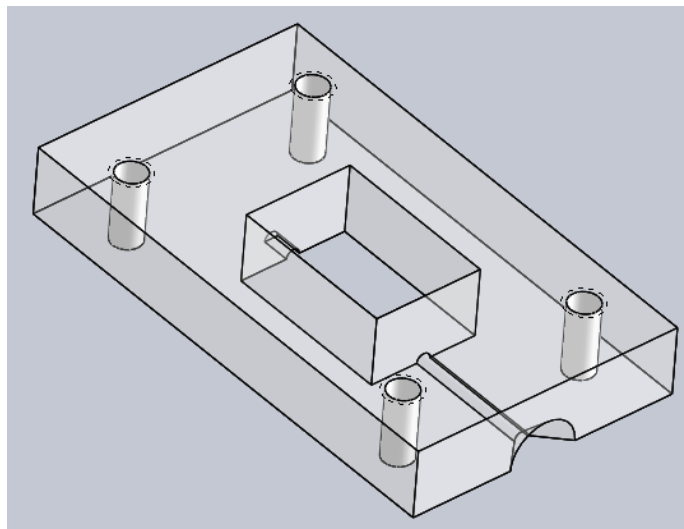
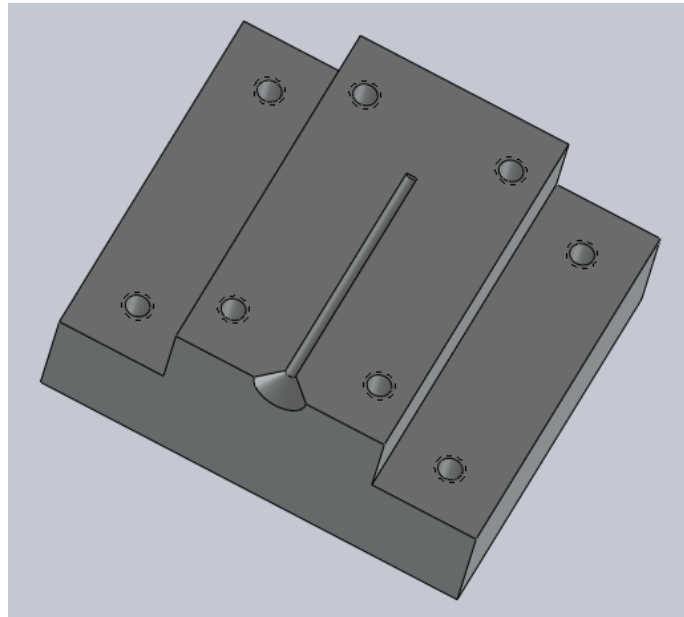
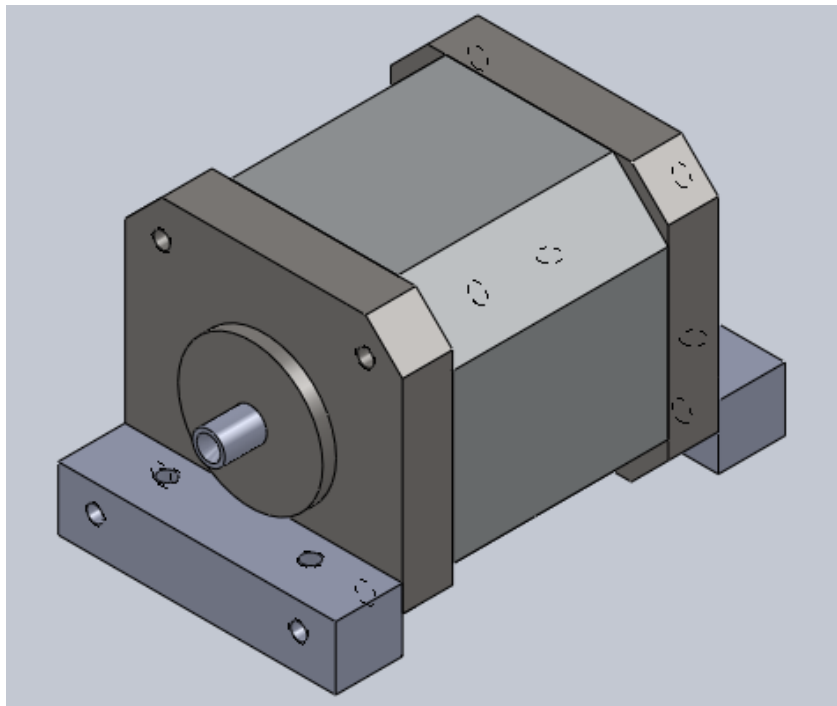


Figure 14: The mold set will be mounted directly to the delrin plate and will be the location where each catheter will be drilled. The top image is of the aluminum set block and the bottom image is of the polycarbonate cap.

The motor shaft evolved through a series of designs. The original design involved the use of a mandrel. The mandrel was meant to support the catheter and allow for rotation. The original design for the mandrel was going to involve a small rod, machined to the size of the interior diameter of the catheter. This rod would then be screwed into the threaded hole at the end of the shaft. This was intended to allow for interchangeable tooling to be incorporated for the different size catheters. As the laser and motor shifted through various setups, so did the mandrel idea. As mentioned, the mandrel was originally intended to be used just for support. When the samples came back from LaserStar, the bottom portions of the holes were burnt. It was my assumption that the use of a mandrel would pull some of the heat out the plastic, thus keeping the plastic from burning. After speaking with representatives from both LaserStar and DPSS, we came to the conclusion that the plastic would retain the heat even with the use of the mandrel. With that conclusion, the design changed to a hollow motor shaft.



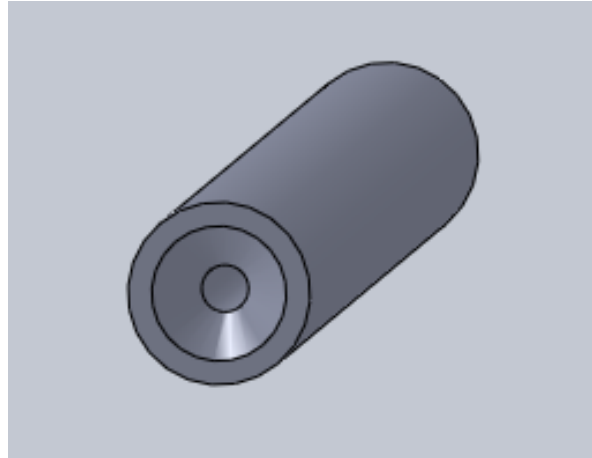


Figure 15: The top model displays the motor configuration. The two blocks at each end of the motor are used for mounting the motor to the plate. The second image is a close up view of the motor shaft. It clearly displays the chamfer on at the front end of the shaft.

The mandrel layout involved pushing the catheter onto a shaft, but the new one involved pushing a catheter through the shaft. The new design was largely taken from the current machine in operation at Applied Medical. The shaft would have a hole through it that was slightly larger than the outer diameter of the catheter. The hole at one end of the shaft would have a chamfer, as displayed in Figure 15, in order to make it easier for the operator to push the catheter through the shaft. This way the catheter has a larger opening to enter and has a propensity to move through the tube. At the chamfered end, there is also a specialized clamp. The current machine at Applied Medical uses a clamp that is taken from another product they sell. When I visited Applied Medical at the end of the first quarter, I had the opportunity to view the machine while in production. The clamp worked extremely well. After researching various options, it was decided that the clamp currently being used was the best solution.

Machine Safety

Another factor which makes this machine unique is the precaution you must take with it. A UV laser poses potential optical threats to the operator and bystanders. The design of the machine allows an operator to access one side of it. The side of the machine that the operator can access is segregated from where the laser will hit. The operator will only have access to the clamp and entry point of the shaft. The barricade will enclose the walls surrounding the laser and will fall across the body of the laser. This can be seen in the aerial view of the machine, as displayed in

Figure 16. The area which is affected by the laser output will be shielded with hard plastic. These UV protected plastic windows can be inserted in the openings within the Bosch tubing. The UV protected plastic can be purchased from the company Laser Vision. The plastic costs \$112 per square foot. In addition, the operator of the machine will wear UV protected goggles. This will ensure that in the case of the UV windows failing, the operator will still be protected.

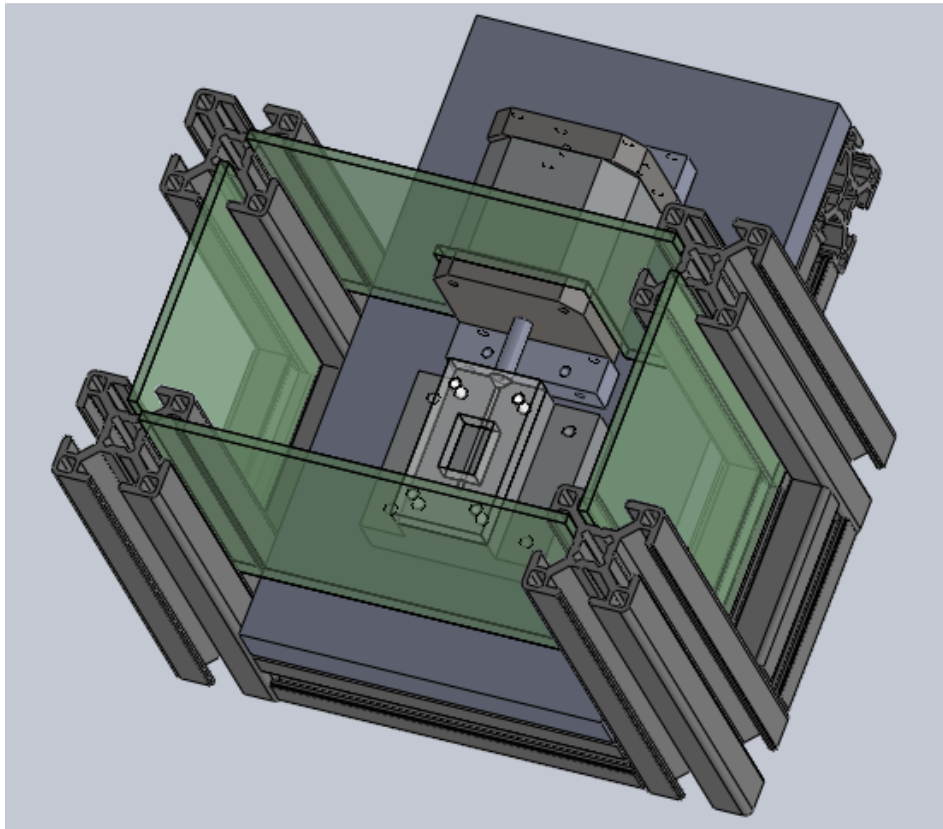


Figure 16: The transparent green components represent the UV protective windows of the machine. The image is not displaying the laser and Bosch tubing which will be used to block the top of the machine.

Machine Operation

Throughout the previous sections, all of the components for the operation of this machine have been explained. This section will outline how the machine is loaded and how it operates. A batch of catheters will be sent from the extrusion lines to the Catheter Laser Drill station. The catheters will rest in the appropriately labeled bin: parts or finished parts. A catheter will be picked up with one hand and the clamp will be squeezed with the other.

With the clamp squeezed in the open position, the operator will push the catheter into the motor shaft. Using the viewing window, the operator will continue to push the catheter into the shaft until it hits the end of the mold set. Setting the catheter in the appropriate location is the most important part of the operation. With a drill bit, it is easier to physically see whether the catheter is lined up correctly. The laser beam's lack of visibility will make viewing difficult, so by ensuring that the catheter is pushed through to the end of the mold set, it will guarantee the correct placement. Once the catheter is in the correct spot, the operator will release the clamp so that the catheter is set in place. The laser contains what is known as a moveable beam. This means that the laser is able to hit any area within the scope, and that a motor for linear movement is not necessary. That being said, the laser will drill one position and then automatically rotate by 90 degrees. The laser will then drill another hole and complete the process two more times before finishing the cycle. Once the cycle is completed, the operator will squeeze the clamp and pull the catheter out of the shaft. The part will then be placed in the finished parts bin and the process will restart. The machine will be push button operated. There will be an external unit which will house the activation buttons. When the green push button is activated, the laser drilling process will begin.

SECTION V

CONCLUDING REMARKS

Summary

This project has covered an immense amount of material. The first quarter was largely centered around the dissection of the different types of lasers. The quarter began with my initial assumption that a welding laser would simply be chosen from one of Applied Medical's existing suppliers. Lasers are an area of technology which I knew very little about prior to this project. This preliminary research I conducted led me to three different broad types of lasing mediums. They were gas, solid-state, and semiconductor lasers.

As the research progressed, it was clear that the selection of the laser would prove to be more difficult than previously thought. The broad categories were subdivided into individual laser groupings. The two most promising lasers were the gas Carbon Dioxide Laser, and the solid-state Nd:YAG laser. Choosing the most suitable lasers based upon their specifications provided a powerful starting point for the next phase of the project.

With the lasers chosen, the first companies were contacted. Among the first calls made, was the company Miyachi Unitek. This company, being an existing supplier to Applied Medical, was amongst the first called because of the benefits of the relationship. Being a previous supplier, it would avoid the need to process vendor information through the purchasing department. My contact at Miyachi Unitek spoke confidently about one of their lasers being able to drill the necessary holes. I contacted other companies to compare prices and validate the information, and these results led me to LaserStar. Samples were submitted to LaserStar, under the assumption that the laser would work. Upon receiving the samples back from testing, it was evident that the heat was too intense for the plastic. The holes were charred and blistered. It was clear that LaserStar products were unable to drill the needed holes.

My contact at LaserStar discussed the alternatives with me. He mentioned that the frequency material reaction was not what he had expected. This meant that a cold laser or lower frequency laser was needed. He led me to one of his contacts at DPSS lasers. In working with DPSS, it was quickly decided that a UV laser was the best option. Samples were submitted to their testing department. In the meantime, the other machine components had come together.

Throughout the second quarter, the general design of the machine had stayed roughly the same. The Bosch tubing would provide the structural support, while the delrin plate would serve as the mounting location for components. The motor assembly began as a general motor and eventually a worm gear box was added. My supervisor felt that this configuration was overly complicated. The motor configuration was then fully changed to a servo motor, because of its ability to perform precise motions. I was again persuaded to avoid this layout due to cost reasons. I was informed that a stepper motor would be able to achieve the same precise turns as the servo motor.

The samples from DPSS came back with great results. The holes were drilled to their set specifications. There was no charring and very little discoloration. The machine was then able to be completed. The 3D Solidworks models were completed and the documentation of the report followed. The quarters were broken up between research and application.

Knowledge Learned

Throughout the course of the project I have learned a great deal about lasers. After speaking to numerous vendors about possible laser solutions, it is clear that UV lasers are the only viable solution. UV lasers are the only lasers with low enough heat levels to avoid charring or burning the catheters. In the event that this project is set aside until more funding is readily available, I would urge Applied Medical to pursue the use of the UV laser I have chosen. Pertaining to the motor, there are multiple solutions. The option I have chosen for the machine is the least expensive motor that can attain the turns needed. I would not recommend the use of a servo motor or larger stepper motor, purely from a cost perspective.

Problems

The machine which I have designed has very few drawbacks. In an assessment of the cons of the design, I have found only one. The machine is operationally sound and is capable of producing the needed holes. The drawback occurs in the ability to incorporate additional tooling. There are numerous types of catheters, but this machine is designed specifically for a single one. With such a large portion of funds allocated to this machine, it would be more reasonable to incorporate all types of catheters. The components which would need to be altered would be the mold set and cap, as well as the motor shaft. In order to access these components in the machine, the Bosch

structure would need to be unscrewed. By unscrewing the structure, you could then remove a UV window and gain access to the components. This process is tedious, but would allow for multiple types of catheters to be run on the machine. The layout of the components could remain the same, but the profile of the catheter would change. Despite the difficulty of changing tooling, the machine offers substantial benefits to Applied Medical. The issue of interchangeable tooling is one which could be fixed in the following weeks prior to the construction of the machine.

Future of the Project

The completion of my report marks the end of the design phase of the project. Thus far, the machine has been designed and the components tested. The laser, being the most critical component, has successfully proven itself. The next step is for a member of the Tooling and Automation Department to take on my project. Once the budget is cleared through purchasing, the building of the machine can proceed. The parts must be ordered and then assembled. In addition to building the machine, the electrical layout must be completed. The project manager must research how the laser console will interact with the electrical box. It is certain that the motor will need a motion control board, which will be incorporated into the electrical box. In addition, a programmable logic controller, or PLC, will be needed. This will serve as the central nervous system of the electrical operation. After the completion of the electrical layout and the building of the machine, there are very few final steps. All equipment being used to build products must be validated. Applied Medical must validate the process, the machine, and log the assets. Once these are done, the machine can be put into the Plastics Building for production.

Implementation

The construction of the machine will not demand much time. In addition, a member of the Tooling and Automation Department specializes in electronics and can quickly construct the layout. The greatest determinate of whether the machine is built, is whether the budget is acceptable. In Figure 17 you will find a breakdown of the machine construction costs.

Component	Supplier	Cost
UV Laser Series 3530-30 (3 Watt)	DPSS	\$68,000.00
Aluminum Bar Stock	McMaster-Carr	\$18.96
Delrin Plate	McMaster-Carr	\$37.54
Bosch Structural Tubing	Bosch/Rexroth	\$23.30
Stepper Motor	AutomationDirect	\$19.00
Polycarbonate	McMaster-Carr	\$12.06
Motor Shaft	McMaster-Carr	\$2.17
UV Windows	LaserVision	\$224.00
Total		\$68,337.03

Figure 17: Cost breakdown for the Catheter Laser Drill Machine. The electrical components and labor costs are not included in the total cost.

The original quote for the UV laser from DPSS was \$32,000. After seeing the samples, DPSS made the decision to choose a laser more capable of the task. As explained in previous sections, the laser which was chosen cost \$50,000. This was for the one watt laser, but the samples were tested on the three watt machine. The three watt machine is more capable of producing the holes, but adds a cost of \$18,000, for a total of \$68,000. I was not allowed access to the sales history or forecasting of the catheters. Therefore, I was unable to calculate the plausible payback of the machine. The only gauge of payback is in the production. Currently, a catheter can be completed in roughly forty seconds. From the information gathered by speaking with Kimball at DPSS, it is presumed that each hole can be drilled in half a second. Aside from loading time, this would set the drilling to two seconds for four holes. Under the presumed five seconds of loading time and five seconds of unloading, this brings the total time to twelve seconds. Based on rough time estimates, this machine is capable of producing three and one third catheters in the time during which the current machine makes one. The catheter laser drill will clearly increase productivity and profits.

In the event that Applied Medical cannot incorporate this machine into the budget, it will be important to alter the current machine. The machine is functional, but portions of the process are flawed. One alternative would be for the drill timing to change. The drill bit stays in the down position longer than needed. By shortening the time the drill is in the down position, the

machine would be capable of producing more parts. Another alternative solution is found in the methods for removing material. Currently there are small pick type tools which are used to clean out the holes after they have been drilled. These tools could be changed to incorporate a more efficient cleaning process. This could be an automated air tunnel which clears burrs and excess material from the catheter. If funding for the new machine is unavailable, these are the two most viable alternatives.

Closing Remarks

This project has provided me with a powerful learning experience, allowing me to use my Industrial Technology knowledge in a practical setting. Through this project, I have gained the confidence necessary to enter the workforce and tackle ambitious projects. Working with Applied Medical has been an encouraging and broadening experience. The laser I selected, in conjunction with the machine I designed, will provide Applied Medical with the optimal solution to its problem. By building this machine, and putting it into production, costs will be cut and productivity will rise. Investing in the Catheter Laser Drill will vastly improve the production efficiency of the Applied Medical catheter line.

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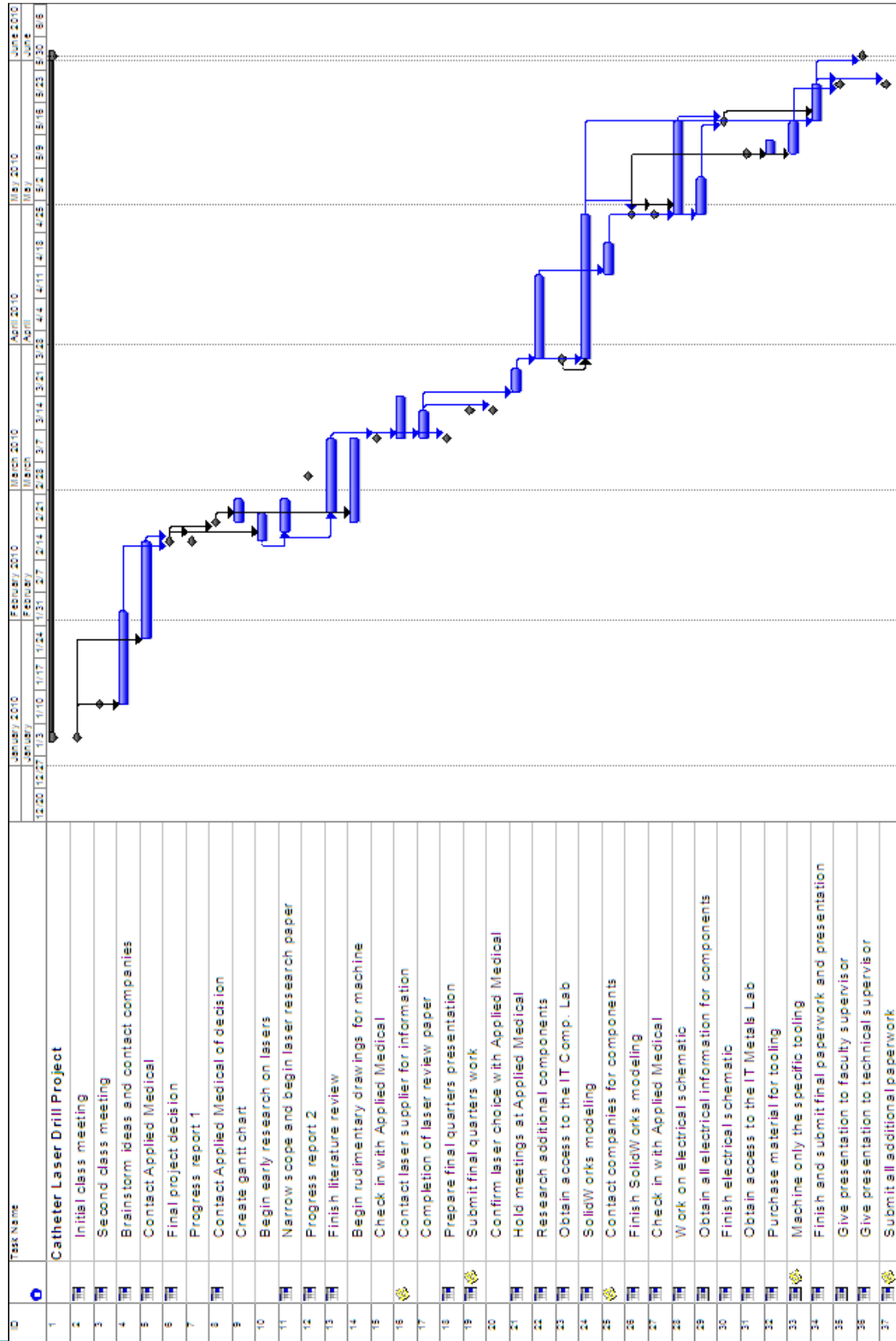
<https://docs.google.com/viewer?a=v&pid=gmail&attid=0.1&thid=1274a5ae772fb76a&mt=application/pdf&url=https://mail.google.com/mail/%3Fui%3D2%26ik%3Db01e22ecd4%26view%3Datt%26th%3D1274a5ae772fb76a%26attid%3D0.1%26disp%3Dattd%26zw&sig=AHIEtbS6HWmf87qOY7YNAHQrXBfQ7ihZcQ&pli=1>

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APPENDICES

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APPENDIX A.



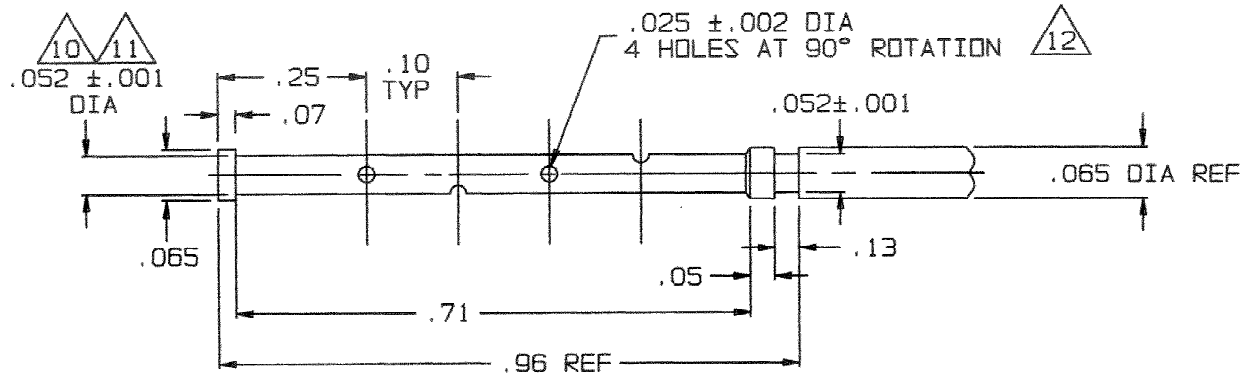
APPENDIX B.

The chart indicates the standard wavelengths emitted by each type of laser. (Aldrich, n.d.)

LASER TYPE	WAVELENGTH (Nanometers)
Argon Fluoride	193
Xenon Chloride	308 and 459
Xenon Fluoride	353 and 459
Helium Cadmium	325 - 442
Rhodamine 6G	450 - 650
Copper Vapor	511 and 578
Argon	457 - 528 (514.5 and 488 most used)
Frequency doubled Nd:YAG	532
Helium Neon	543, 594, 612, and 632.8
Krypton	337.5 - 799.3 (647.1 - 676.4 most used)
Ruby	694.3
Laser Diodes	630 - 950
Ti:Sapphire	690 - 960
Alexandrite	720 - 780
Nd:YAG	1064
Hydrogen Fluoride	2600 - 3000
Erbium:Glass	1540
Carbon Monoxide	5000 - 6000
Carbon Dioxide	10600

APPENDIX C.

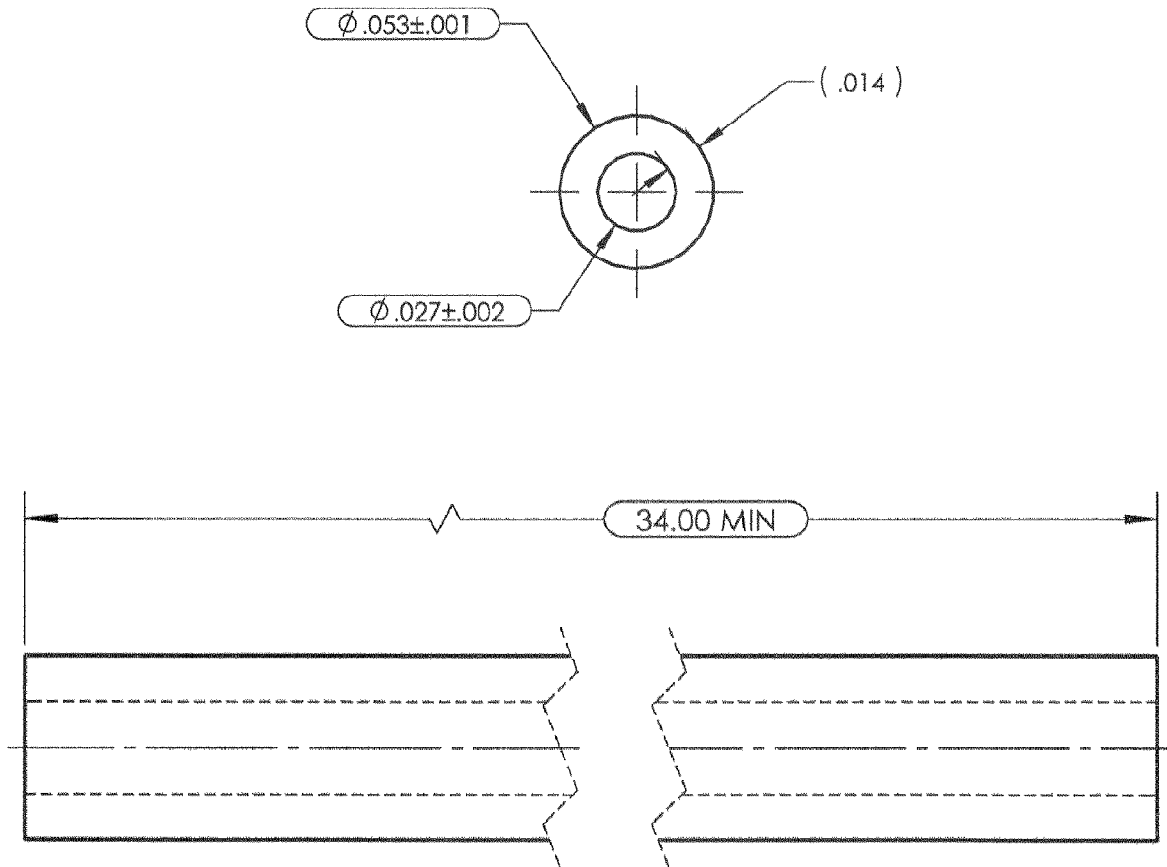
The drawing below displays the locations of the four holes to be drilled by the laser.



DETAIL "B"
SCALE: NONE

APPENDIX D.

The drawings below show the dimensions of the catheter tubing prior to machining.



APPENDIX E.

FIBERSTAR MARKING & ENGRAVING SOURCES

3500 Series

FiberStar Marking Sources offer the benefits of a **Direct Metal Marking**, non-contact, abrasion-resistant permanent laser marking onto almost any type of material. High-speed, high precision, micro-marking, engraving and cutting FiberStar systems are ideal for a wide range of industries and integration applications.

FiberStar Systems offer state-of-the-art technology with the highest laser beam quality and more than 30,000 hours of maintenance-free operation. High precision markings are achievable on almost any type of material including stainless steel, strength alloys, carbide, copper, titanium, platinum, aluminum, as well as a wide variety of medical-grade alloys and plastic.

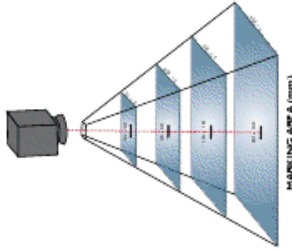
Identification text, serial numbers, corporate logos, 2-D data matrix, bar coding, graphic and digital images, or any individual process data can be produced with laser marking.

- Logos, certification symbols, barcodes, serial codes, and 2-D data matrix code
- Simple custom text, serial numbers, bitmaps, graphic and CAD-files (HPGL)
- Marking and cutting of foils and light-gauge steel sheets (i.e., labets) in one cycle
- Rapid marking on precious metal with heat-sensitive materials
- Plastic materials: day & night design for items such as mobile phone keyboards, dashboards, and other illumination components for aerospace and automotive markets

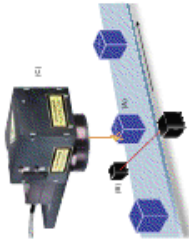
HIGHLIGHTS

- MOPA Architecture
- Advanced WaveForms
- Excellent Peak Power
- Pulse Freq. 1 to 500kHz

ScanHead Marking Fields



Mark On The Fly



The compact part (A) permits marking the high accuracy (B) which saves a separate step before laser marking (C).

3500 Series FiberStar Marking Sources

L A S E R S O U R C E	
Laser Type	Direct Fiber Laser
Wavelength	1060 nm +/- 1.0 nm
Beam Diameter (Nozzle)	< 30 µm
Pulse Duration	20-200 ns
Laser Frequency	1 - 500 kHz
Laser Peak Power	100W
Output Power	10 Watt/20 Watt/30 Watt
Output Fiber Length	2.0 meters
Mode	Mastermode (TEM ₀₀)
M ² Value	≤ 1.1
Laser Class	Class 4
Coating System	Fly eye coated, stainless
M A R K I N G H E A D	
Scanhead	Two-axis galvano-scanner-driven deflection system
Marking Field Size	40mm x 40mm / 10mm / 10mm / 10mm x 10mm
Focal Length	100mm / 60mm / 25mm
Focusing Optics	F-Theta (OD Fiber Feed Lens (OD) 4 or 21H)
Fiber Laser	Visible and beam pilot laser for easy positioning of the workpiece
C O N T R O L U N I T	
Electrical Connection	110-230V (V+H20) 16A, 50 Hz
Power Consumption	< 110W
Interface	RS232
Integrated Computer	Optional system model and type supplied at module laser's discretion
M I S C E L L A N E O U S	
Warranty Coverage (Parts & Labor)	2 years
Laser Safety Compliance	FDA/CE/DRPA/UL/CSA/IEC
Country of Origin	Made in USA / United Kingdom

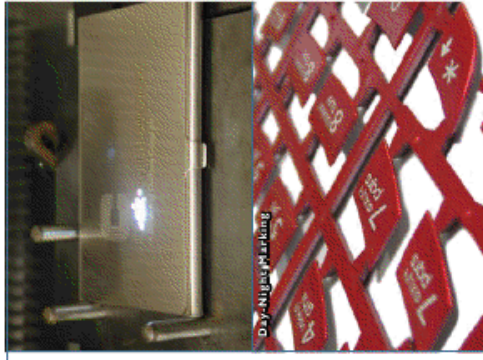


SPI Lasers UK Ltd is a strategic partner of LaserStar Technologies Corporation.

Component Dimensions



40



48

APPENDIX F.

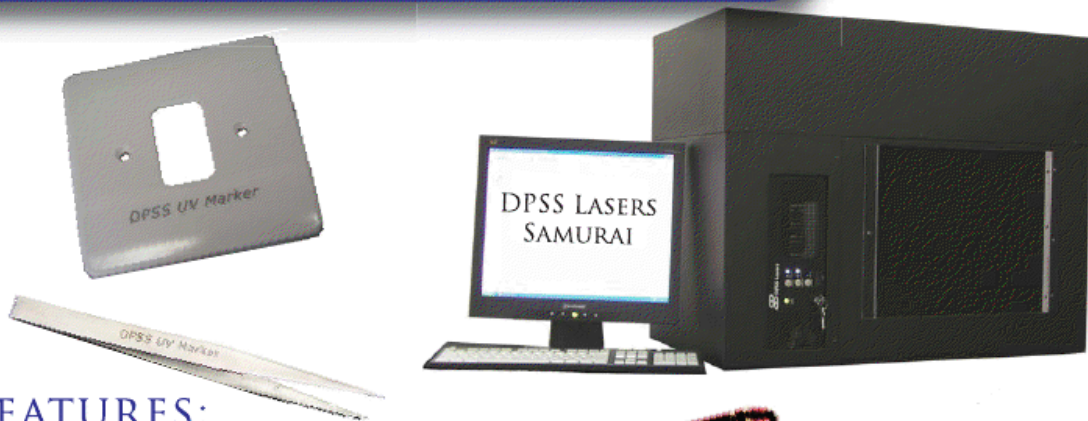


SAMURAI

UV LASER MARKING SYSTEM

DPSS Lasers introduces the Samurai Laser Marking System. It is the first marking system specifically designed for UV lasers at 355 nm. It takes advantage of the short UV wavelength to provide a small spot size and a large depth of focus. UV lasers take advantage of the cold marking process not requiring high average powers and allowing damage free marking on many materials. The Samurai marking system is also capable of UV ablation and engraving of many materials.

355 nm



FEATURES:

- Small spot sizes
- Cold UV Marking
- Easy to use software
- Fast scanning speeds
- Proven Scanning Technology
- Integrated UV Marking Solution
- Large work area with large depth of focus
- < 700 Watt single phase utility required
- Field proven model 3500 Series 355 nm laser
- Materials which can be marked, engraved, scribed, cut or drilled includes: wires, metals, sapphire, glass, diamond, polyamides, PCBs, coatings, ITO removal, silicon wafers, ceramics, plastics, fiber, paper, etc.



SILICON WAFER



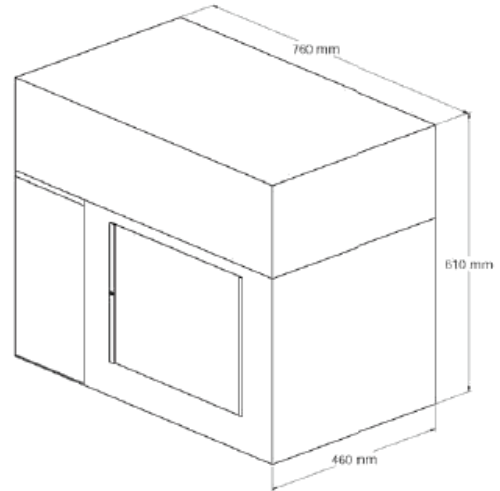
WWW.DPSS-LASERS.COM

Marking Specifications

	<u>STANDARD</u>	<u>CUSTOM RANGE</u>
Marking Area (Diameter)	75 mm	up to 170 mm
Smallest available spot size	< 25 µm	down to 6 µm
Drawing Speed	300 mm/s	up to 2 m/s
Peak Power Density	300 MW/cm ²	up to 10 GW/cm ²
Power Control	Mechanical	Electronic available

Laser Specification

Laser Technology	Frequency Tripled DPSS Laser	
Laser Type	Nd:YVO ₄ laser - 3500 Series	
Wavelength	355 nm	
	<u>STANDARD</u>	<u>CUSTOM RANGE</u>
Average Power	1 W	up to 2 W
Pulse Frequency	30 kHz	30 - 100 kHz
Pulse Length	25 ns	25 - 70 ns
Pulse Energy	30 µJ	up to 70 µJ
Peak Power	1.5 kW	0.1 - 3.0 kW
Pulse Stability	< 5%	< 5%



Dimensions

	Width	Depth	Height
Marking Enclosure (mm)	760	460	610
Marking Chamber (mm)	560	460	410

Utilities

Input Voltage	100 - 250 VAC/ 50 - 60 Hz
Power Consumption	< 700 W



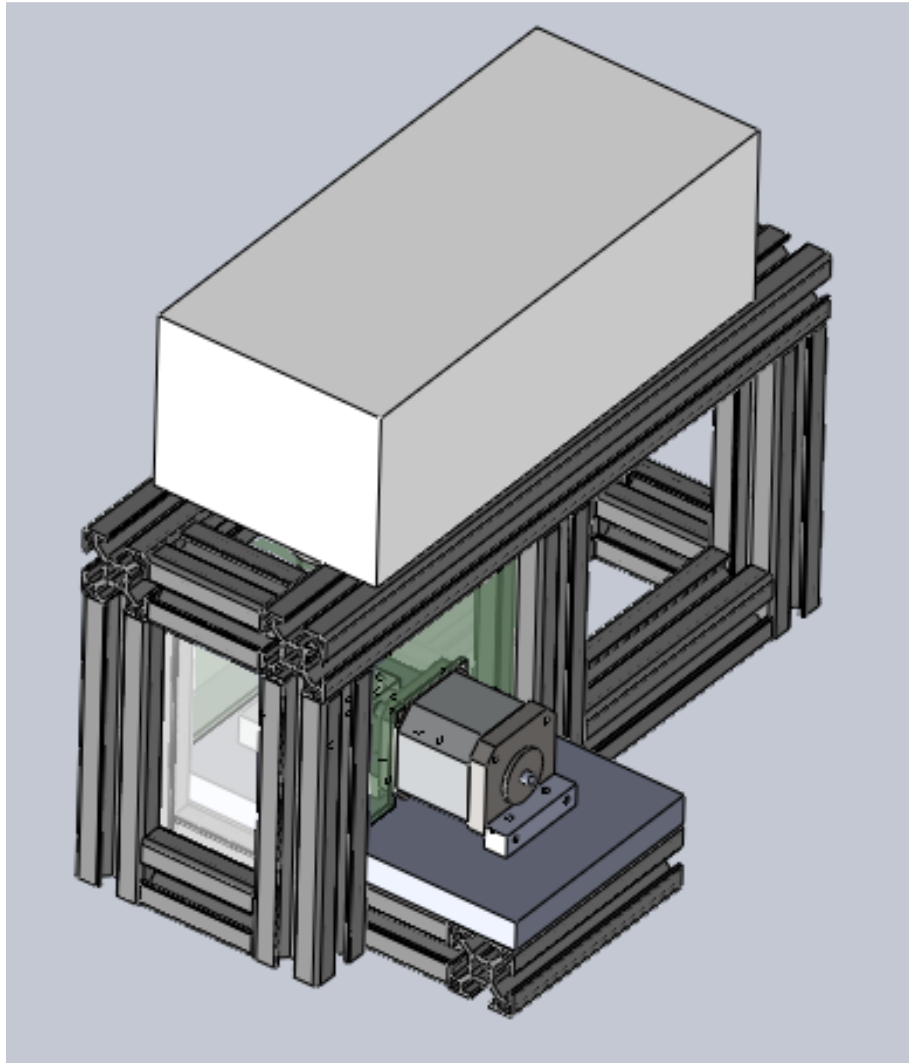
2525 Walsh Ave.
Santa Clara, CA 95051
United States

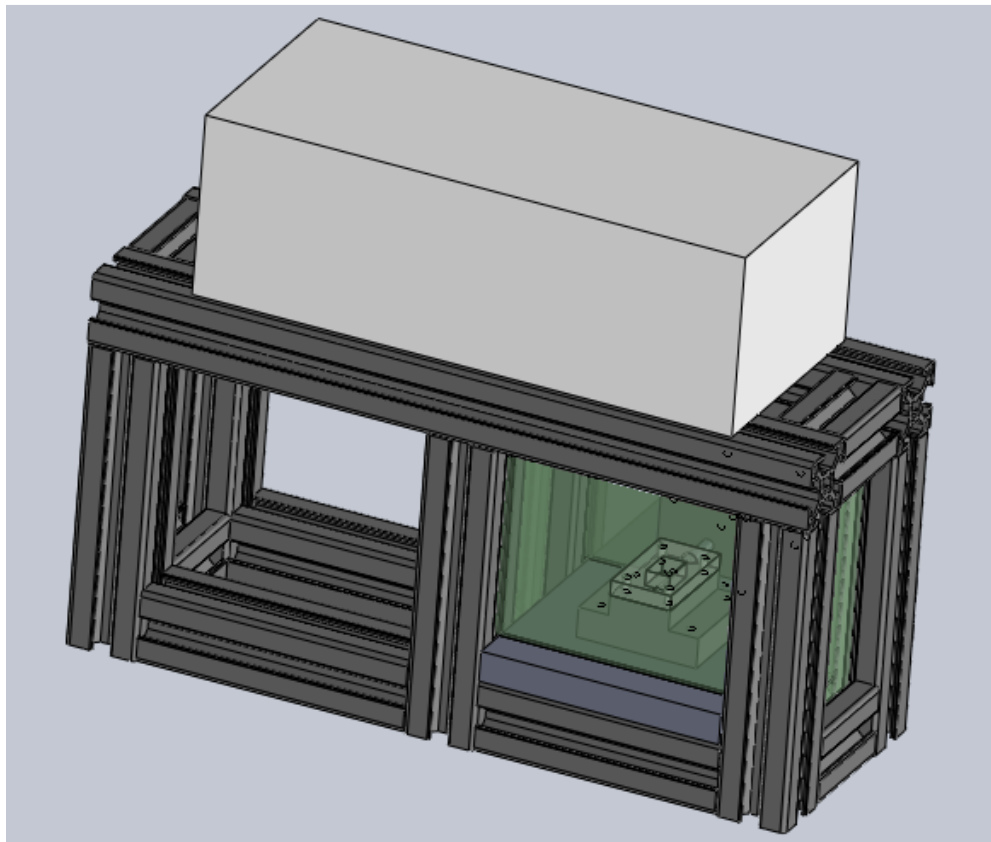
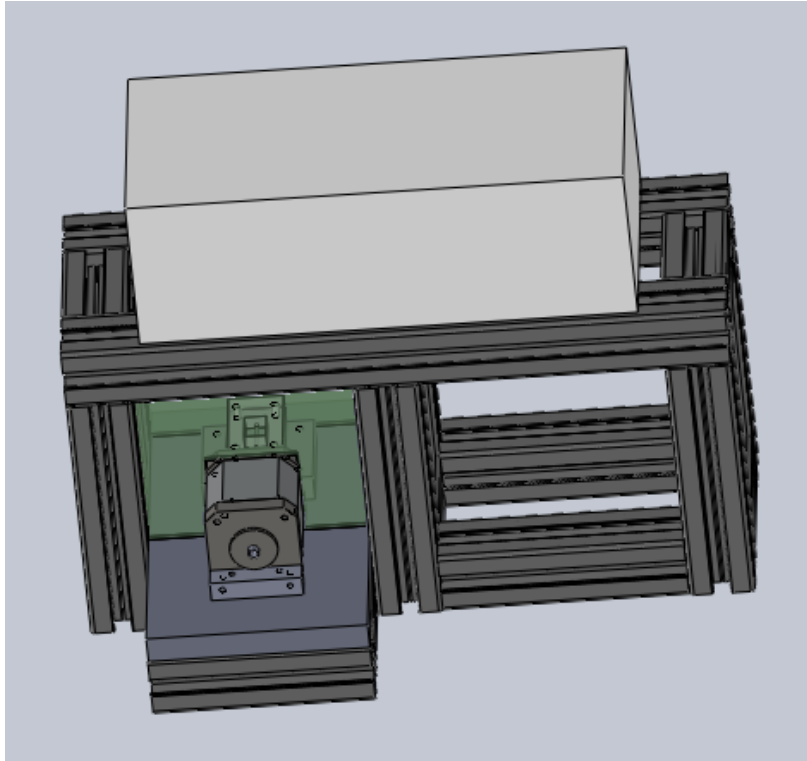
Sales@DPSS-Lasers.com
www.DPSS-Lasers.com

Phone 408.988.4300
Fax 408.988.4305

APPENDIX G.

The following three images show the completed SolidWorks model of the machine.





APPENDIX H.

a. The following is the documented email correspondence between me and Peter Tkocz. Tkocz's emails are displayed in black ink and mine are displayed in blue ink.

Hi Brady,

Thanks for the opportunity to speak with you today. I appreciate your time.

I have attached a comprehensive catalog describing our company and our specialization in laser welding and laser marking servicing 6 different markets. We are a leading supplier. It is provided to you as follow-up to our discussion and in order to demonstrate the depth of our products, application knowledge, and tailored solutions leading each market.

Overall, the benefits of our LaserStar Technologies are :

- 110 VAC powered,
- made in the USA,
- direct contact with the manufacturer,
- desktop and Pedestal with 24/7 durability,
- many happy customers across 6 different markets, and
- stability in our company, people and products.

Best Regards, Peter Tkocz
Regional Sales Manager

Hi Brady,

SAMPLE SUBMITTAL PROCEDURE

We invite your submittal of sample parts to our Application Lab in order to better understand your products, your application, and to better recommend the right machine. We will also advise you about the laser parameters we used to complete the job, and the cycle times we measured.

Please send (all will be returned to you):

- A part to practice on and determine the best laser marking parameters for your metal materials and mark look.
- A couple of parts to be completed, and returned to you.
- A description of your mark - size location, content.

Ideally the parts to mark will cover a range of your application ie:

- the smallest part to mark,
- the largest part to mark and
- possibly the "bread and butter" product of highest value or volume, and big part of your decision making process.

We will try to turn around these parts as soon as possible depending upon our travel schedule and available equipment.

Send by UPS or FedEx:
Bruce Mills
LaserStar Technologies
510 West 6th Street, Suite 1030
Los Angeles, CA 90014
Tel: 360-607-7993 (Cell)

Hello Peter,

I have decided to send in four different types of Applied Medical catheters. Attached you will find the information included in the packet which I am mailing out. What is the approximate completion time for the parts? Thanks again for your help.

Sincerely,
Brady Haug

(949) 291-4019

Hi Brady,
Please advise the material type(s) and confirm the material tube thickness(s). Please advise when you feel the parts will arrive.

Thanks, Peter

Hello Peter,

Thanks for responding with the information so quickly. I did actually mail out the parts the day which I sent the email to you, so I was unable to add the material information. Is there an email address to which I could send additional information about the parts or should I just mail an additional sheet with the information? Thanks for the help.

Sincerely,
Brady Haug

(949) 291-4019

Hi Brady,

I will advise you when the parts come in. We are planning to run the samples next Mon - Wed in the the RI Factory, when Bruce visits there for our regularly scheduled LaserStar in-house Training.

Please send the info by email and copy Bruce and Todd - the Engineers planning to complete your APP.

NOTE: Generally I advise our customers to avoid mailing items of value to the LaserStar LA office. It's a small "Big Bldg" mailbox (1950's vintage) and items get jammed in and bent. Always better to send by traceable service like UPS or FedEx.

Thanks, Peter

Hello Peter,

I have decided to send in four different types of Applied Medical catheters. Attached you will find the information included in the packet which I am mailing out. What is the approximate completion time for the parts? Thanks again for your help.

Sincerely,
Brady Haug

(949) 291-4019

Hello Peter,

Attached you will find the drawings which correlate to the different catheters I sent in. All four different catheters are made of polyester with a two percent colorant. Thanks for the help and please advise me of prospective completion dates.

Sincerely,
Brady Haug
(949) 291-4019

Hi Brady,

Thanks for your emails. The samples are located with Todd and Bruce - both our APP Engineers working together in LaserStar/RI for the next couple of days.

The first feedback step is confirmation the ability for the YAG laser maker to affect the poly material in order to create a clean 0.020" hole in 0.031 thin-walled diameter poly tube ... or a 0.025" hole. in 0.052" or 0.058" or 0.068" thin walled diameter poly tube. The issue is not to create too much heat so that the material is melted beyond the 0.002" spec. The poly tube thickness is not clear to me from the drawings, but we have the samples in hand to measure. Heat absorption is also affected by the color of the poly.

The feedback time frame is dependent upon their jointly scheduled activities and they will advise us of the review scheduling plans.

The scanning field the the maximum movement the laser beam can move and mark anywhere in that noted square area. This is accomplished by the scanning head using X and Y mirrors to control the movement of the laser light in the scanned area according to the marking program.

If the holes are successful we will then look at the fit of our mechanical device to move the part linearly for positioning and then to rotate accordingly. Best Regards, Peter

Hello Peter,

I just sent a email containing the missing information for the testing of Applied Medical catheters. We discussed the using the 3000 and 3500 series Laser Markers. For my application I will need to drill these holes on four different faces of the catheter, which would then imply the use of two motors in the machine, one to move linearly and one to move rotationally. I found in the catalog that these series lasers have variable marking field sizes. The holes I will be making will be roughly in the span of .4 in linearly. What does the marking field size indicate? Thanks for your help.

Sincerely,
Brady Haug
(949) 291-4019

Hi Brady,

Thanks for email reminder. I have interviewed the APP Engineer who completed this study, Bruce Mills.

His conclusion is that the Infrared portion of the YAG laser wavelength is detrimental to the goal of cutting a clean hole using a LaserStar Fiber marker system.

Bruce was able to achieve a "round-ish" hole in the blue tube type but:

- the walls were angled (not same diameter through the tube wall thickness) and
- the lower section of the wall was burnt black

Bruce feels that the YAG Fiber technology will not meet your goals.

Please advise if you would like the materials to be returned to you and if so please confirm the address.

Thanks,
Peter

Hello Peter,

I appreciate the help and prompt response. I would greatly appreciate it if you could return the samples to the address below. It is the same address I had written down on the information sent attached to the catheters.

1224 Carmel Street
San Luis Obispo, CA 93401

Is it your opinion then that these holes are not able to be created with LaserStar products? Originally it sounded like you had thought this fiber laser marker was the best bet. Thanks.

Sincerely,
Brady Haug
(949) 291-4019

Hi Brady,

I will mail the samples today. I will highlight the trial pieces.

QUESTION: Is it your opinion then that these holes are not able to be created with LaserStar products?

ANSWER: Yes, and it is the APP dept's opinion that all YAG frequency markers 1064nm - either traditional YAG rod or fiber marker generated - will not work for this application.

QUESTION: Originally it sounded like you had thought this fiber laser marker was the best bet.

ANSWER: True, but still too much heat for your plastic. We have been successful making these sized holes and even smaller holes in metal using the fiber markers. The plastic material reaction to the heat component is the limiting factor.

Best Regards,
Peter

Hello Peter,

I wanted to ask you about another option regarding the laser which was used on our parts. I have been discussing different options with my supervisor, and we considered using a mandrel in conjunction with the laser. The mandrel would be inserted into the catheter. The mandrel, made from the proper material, would act as a heat sink, pulling heat away from the hole. Do you think this would potentially eliminate the charring on the catheter holes? Thanks.

Sincerely,
Brady Haug

(949) 291-4019

Hi Brady,

Doubtful. The plastic holds the heat and reacts as you see it. It is hard to wick it away.

Better would be to look for a different wavelength laser - more in the UV.

IDEA: Please give Randy Kimball a call at DPSS in Santa Clara 408-988-4300. I met him at Westec (we know each others from a couple of years past) and i was just looking at his card when your email came in. You can mention my name. I can't make any promises for him - so please ask. I know they mark at 900+ nm and last he told me is they can make small holes in some materials.

Best Regards, Peter

APPENDIX H.

b. The following is the documented email correspondence between me and Randy Kimball.

Kimball's emails are displayed in black ink and mine are displayed in blue ink.

Hi Brady,

It was a pleasure speaking with you today and thank you for your interest in our DPSS 355 nm laser technology.

Attached is a data sheet on our Samurai UV laser marker and our 3500 series laser. We typically use the model 3510-30 for applications such as yours.

If you will send your samples to my attention at the address below, we will be happy to determine which system is best suited for your needs.

Cheers,

Randy

Hi Randy,

I sent in the parts which we discussed last Friday and they were supposed to arrive Monday. Is there a prospective testing date? If they have already been tested, please let me know the results. Thanks.

Sincerely,
Brady Haug

(949) 291-4019

Hi Brady,

We did receive the samples on Wednesday, but we have a backlog on the in-house systems. We have a conference starting tomorrow May 8th until May 12th in Seattle. I will process the samples once I return.

I do have a question regarding the green Catheter. The diameter of the tubing is 0.031" and you are requesting a 0.020" hole. Is that correct? Depending on the thickness of the wall, the hole could easily take up most of the diameter and because it transitions down the side-wall of the tube, it will most likely be oblong instead of circular.

Cheers,

Randy

Hi Randy,

Thanks for updating me on the status of the parts. I hope to hear positive results soon. I checked the drawing and it does appear that what you called out is correct. I anticipate difficulties on the green catheter and will expect the the holes oblong as you stated. Thanks for checking back.

Sincerely,
Brady Haug

(949) 291-4019

Hi Brady,

I did some quick test on three of the samples prior to my leaving the office on Friday afternoon. The holes are clean and without charring. There is a slight bump on at the entrance site and slight discoloration of the top surface, but the sidewalls of the holes are clean. I noticed some elongation on the one smaller white piece and I expect even more of this effect on the very small green piece.

Do you have a target in terms of speed for a single hole?

I will continue me testing when I return later this week.

Cheers,

Randy

Hi Randy,

Thanks for the update. I expect to find a certain degree of deformation and I will pass along the information to my supervisor. We will really have to see the samples before making a decision. As far and cycle time, the quicker the better. The machine I am designing is going to replace the current machine, which drills a hole and rotates to the next in roughly 7 sec. What sort of times might I expect per hole?

Another question I had was pertaining to a movable beam. As you can see in the drawing I sent, there are three/four holes spaced out .1 in. apart from each other. Is this laser capable of drilling all four holes without moving the catheter in a linear direction. Certainly some of the holes would be angled. I know this is capable with certain lasers, but I am unsure with UV.

Thanks,
Brady

Hi Brady,

I am sending you samples of the different types of tubing that has been drilled with our UV laser. There is a small amount of discoloration at the entrance of the holes and some taper. I drilled two holes in each sample to demonstrate that the system can drill multiple holes without moving the part. The holes have to be on the same axis.

I am also including some of my test samples so you can see the different results when changing the lasers parameters. All of the holes were drilled in less than the typical seven seconds you see from you existing drilling operation.

Please let me know how you would like to proceed once you receive the samples.

Cheers,

Randy

Hi Randy,

I received the samples and they look great. I don't see the discoloration as being an issue with my supervisor. In addition, the holes appeared quite defined. I would greatly appreciate any information you can supply on the settings which you used and which exact model was used, in order to incorporate the information into my report. Over the next two weeks I am compiling my report to present to my supervisor. When I present the material, I will have a definitive answer as to Applied Medical's decision. I will let you know in the next two weeks. Thanks for your help throughout the duration of this project.

Sincerely,
Brady Haug
(949) 291 4019

Hi Brady,

I am glad to hear that the holes met your approval. Here are the settings I used, but they are by no means optimized for speed.

The system is a Samurai UV system for laser marking and micromachining. The laser used in the Samurai was our model 3530-30, 3 watt 355 nm UV laser. The type is an IntraCavity, Diode

Pumped Solid State laser. We have a patent on this design in the US, Japan, Germany and the UK.

The laser was being Q-Switched at 30 kHz and the scan rate was 500 mm per second.

I used a solid circular pattern and removed the unwanted material using three different types of crosshatch scans. The time for each circle/scan is approximately 25 msec so three scans takes 75 msec. I made two holes per side so the total time for the micromachining was 150 msec per pass but I added a 500 msec delay at the end of each pass to allow the plastic time to settle. This delay time can be optimized in the process development stage. Each pass removes a small amount of material and I used 8 passes on the final samples.

Therefore, the time to micromachine two holes was 1.2 seconds of drilling time and 4 seconds of delay time. I believe that with process development you can get the time to do two holes to less than 1 second. At that, time the part needs to be rotated 90 degrees and the remaining two holes can be drilled.

The basic Samurai with a 3510-30, one watt laser is \$50,000. For the tree watt version, you need to add \$18,000. There may be some advantage to adding an f-theta lens to keep the focus in the same plane over a larger area, but if you are happy with the latest results, you can probably live without it. Ultra Violet F-theta lenses cost between %\$5,000 and \$10,000.

Depending on the final configuration, the cost of the system would be between \$68,000 and \$78,000. If speed is not an issue, you could use the basic Samurai at \$50,000.

Please let me know if you require more information for your report.

Cheers,

Randy
