An Analysis of Laser Technologies and How They Can Be Used to Promote Sustainability and Address Cost-Intensive Engineering Malpractices

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Dong Wook Kim
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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signature ____ Date 12 May 2022
Dong Wook Kim

Approved ____ Date 03 May 2022
Richard Jacques, Department of Engineering and Society

Sarah Sun
Approved ____ Date 12 May 2022
Sarah Sun, Department of Mechanical Engineering

Preface

Laser cutting manufacturing technology is still relatively less adopted compared to other technologies one might find in a machine shop. One will probably encounter a waterjet cutter, which serves to cut out sheets of metal and other materials such as plastics in a similar capacity as the laser cutter using highly pressurized streams of water and sand through a nozzle, before they find a laser cutter to do the same job. Laser cutting falls under the umbrella of rapid prototyping technologies, that is, technologies that enable the fast fabrication of physical parts or models using 3D computer-aided design software. People usually associate rapid prototyping with 3D printing technology, which is a form of additive manufacturing (whereby materials are added in layers to form complex shapes). However, laser cutters provide subtractive manufacturing, where, as the name implies, materials are removed in order to make engravings, cuts, and holes.

Laser cutters serve a crucial niche in manufacturing that neither waterjet cutters nor 3D printers can satisfy. While laser cutters are comparable to waterjet cutters in the function they both hold (both being subtractive manufacturing processes), unlike waterjet cutters it can work with tighter tolerances and even smaller and thinner materials. Laser cutters are also comparable to 3D printers in that they can facilitate additive manufacturing functions by quickly cutting out individual parts to a larger assembly, but unlike 3D printers, laser cutters are better at handling larger materials than 3D printers. In this way, it is easy to see just how versatile laser cutting technology is yet just how underutilized it could be. The University of Virginia’s mechanical engineering department alone has devoted more resources to acquiring and maintaining waterjet cutters and 3D printers for their manufacturing needs than laser cutting systems, and that is something that should be looked at.

The technical aspect of the Capstone project relates to how a more cost-effective laser cutting machine could be built while not sacrificing power nor accuracy when compared to market-wide competition. Upon performing a marketing survey of existing models, it was seen that current laser cutters either sacrificed cost for power and accuracy (with platforms that perform robust cutting services going for upwards of $7000 and more) or sacrificed power and accuracy for cost (falling to $3000-$4000 price range but giving up on power and/or accuracy). The Capstone project aims to utilize a $4000 budget to create a functional laser cutter that rivals the $7000 platforms. With a $4000 price tag and a competitive power and accuracy delivery, the laser cutter's adoption could be incentivized and accelerated in college as well as personal use settings. It is the hope that such a technology would also encourage the industry to innovate new laser cutting systems that can be more widely encouraged and used.

For the STS topic, an analysis of the current trends in manufacturing processes and the sustainability issues that they pose will be discussed. Specifically, the argument will be made in favor of laser cutting technology and other laser-based manufacturing processes for their ability to curb environmental waste while promoting ethical engineering practices. The areas in which the benefits of laser-based manufacturing processes will be contended are the medical device and robotic surgery sectors. While the Prospectus is written strictly on the area of robotic surgical platforms, the medical device sector provides a plethora of more examples of how laser-based processes are used in everyday form. In addition, the robotic surgical platforms employ numerous subsystem-level use of medical devices, so it remains relevant to talk about them.

The outline of this paper will be as follows: first, the history and current developments in laser-based manufacturing technologies will be explained, then, the general environmental sustainability issues incurred by traditional manufacturing techniques will be analyzed in comparison to the benefits that laser-based manufacturing processes provide, followed by a discussion of how laser technologies can be more encouraged in the medical device industry.

Body

LASER stands for “Light Amplification by Stimulated Emission of Radiation,” but before it was coined by Gordon Gould, a graduate student at Columbia University, the work had to be built from the ground up. The progenitor of lasers was the MASER, which stood for “Microwaves Amplification by Stimulated Emission of Radiation.” Charles Townes of Bell Laboratories was working on radar assisted bombing systems and microwaves generators during World War II, and in the 50’s, would take Einstein’s theory of stimulated emission, whereby photon particles are emitted from a transition in an atom or molecule, and use it to create a flux of photons (Bensoussan, 2016). The idea was that excited molecules could be contained in a cavity to induce a feedback loop as the radiation emitted by some of the molecules reflect back and interact with other molecules causing further stimulated emission (Lindley, 2005). The emitted photons would be collectively similar in phase, direction, as well as frequency (“Difference between Laser and Maser”). After Townes recruited Arthur Schwalow, his brother-in-law, the two realized that a similar effect could be induced with atoms contained in a long, narrow cavity with mirrors at either end, using shorter waves in the visible light spectrum region with higher energy than the microwaves (Bensoussan, 2016).

Lasers are categorized by the medium that they employ, whether that be solid, liquid, gas, or semiconductors. There are many types of lasers within each category, and every laser has its own advantages and disadvantages and is suited for different applications. Among the most widely used lasers are the diode, CO_2, and fiber lasers. Diode lasers are semiconductor lasers that produce light when electrons interact in a p-n junction, arranged in a similar fashion as those in electrical diodes, acting as the medium of the laser. Diode lasers are very compact in size, are simple to construct, have low operating costs, and have extremely high energy efficiency, which makes them dependable for various applications such as barcode scanners, laser pointers, CD/DVD/Blu-ray players. CO_2 lasers, which is the choice of laser for the Capstone project, are gas lasers which use electrically stimulated carbon dioxide gasses to emit energy to cut through materials. They are most effective on non-metallic materials, such as wood, paper, acrylic, and most plastics. CO_2 lasers are widely used in industrial and medical practices because of their relatively high efficiency, high output power, and high laser beam quality. Fiber lasers are special types of solid-state lasers that are able to create straight, precise laser beams. They usually have a longer service life than the diode and CO_2 lasers, and they can engrave on materials that other lasers cannot engrave on, which makes them useful for material processing.

To prove that a cheaper laser cutter than the market-available counterparts can be made with just as good of a functionality, a marketing survey was taken. The laser types sampled were the K40 laser, two Omtech lasers with different tube powers, and the Lasersaur laser. These four types were chosen as they varied in cost, accuracy, and power, allowing the group to observe the advantages and disadvantages of each model and apply them to create the ideal laser between them. The resolution and focal length correspond to the accuracy of the laser. Resolution measurements are in dpi, which is defined as dots per inch, or how many dots can be lined up in an inch without overlapping. In simple terms, the larger this value is, the more accurate the laser cutter will be and the better it can engrave and cut very small shapes. Furthermore, focal length refers to the cutting performance of the laser. A larger focal length allows the laser to cut through thicker material with better efficiency. For example, a high focal length allows the laser to cut through a thick material in less trials than a lower focal length laser would permit.

The K40 laser is by far the cheapest out of the options at only five hundred dollars. However, it lacks tube power and accuracy. On the other hand, the Lasersaur laser has extremely high accuracy and tube power yet is ultimately much too expensive. The Omtech lasers find a good balance between cost and power but are not as accurate as desired. Therefore, the Capstone model intends to meet the same high resolution and focal length as the Lasersaur laser, while achieving a budget similar to that of the Omtech one-hundred-watt laser.

Laser Type	K40	Omtech 80 W	Omtech 100 W	Lasersaur	Us
Cost	$500	$3,200.00	$3,900.00	$7,300.00	$4,000.00
Bed Area	200x300 mm	500x700 mm	500x700 mm	1220x610 mm	610x1219 mm
Resolution	300 dpi	335 dpi	335 dpi	840 dpi	700-850 dpi
Focal Length	50 mm	63.5 mm	50 mm	100 mm	50-100 mm
Tube Power	40 W	80 W	100 W	120 W	100 W
Aiming Laser	No	No	No	No	Yes
Air Assist	No	Yes	Yes	Yes	Yes

Figure 1: Laser Cutter Marketing Survey

So why lasers over traditional manufacturing equivalents like the waterjet cutter and 3D printer? How can the encouragement of laser use bring about more environmentally sustainable practices in the engineering space? As mentioned before, both laser cutting and waterjet cutting are subtractive manufacturing processes. Both can be used on plastics, glass, woods, and metals, but some key primary differences lie between the two methods. For one, laser cutters can work with a material thickness range of 3 to 10 mm as opposed to the 10 to 50 mm range of waterjet cutters. Secondly, laser cutting boasts a higher precision than waterjet cutting. The minimum size of the cutting slit is 0.15 mm for laser cutting and 0.5 mm for waterjet cutting. The processing tolerance is also 0.05 mm for laser cutting and 0.2 mm for waterjet cutting. Unlike laser cutting, however, waterjet cutting involves more risks, waste and pollution, and high maintenance. Laser cutting may produce minor dust and smoke depending on the materials cut, but proper ventilation can eliminate most of the harmful effects. Waterjet cutting, on the other hand, is a process that produces extreme noise and requires ear protection. Eye protection is also needed against the pressurized waterjet, and many of these protective gears have limited-use plastics and Styrofoam built into their makeup, which will inevitably need to be recycled in the proper manner over the lifetime of the waterjet cutter. This doesn't even include the sludge that gets formed as the water and abrasives accumulate in the machine and need to be disposed of in an environmentally friendly manner ("Laser Cutter vs Waterjet Cutting"). To add more costs upon the user, there is a non-insignificant material wear in waterjet cutter components like pumps and cutting heads that need to be replaced depending on how frequently they are used ("Cut with a Laser More Quickly"). The biggest problem of not utilizing laser cutting technology becomes apparent when machines like the waterjet cutter become replacement for cutting out materials that are more optimal for laser cutting. In some machine shops, even sheets of metal of a quarter inch thickness are often cut with a waterjet cutter. A quarter inch thickness falls within the 3 to 10 mm range that laser cutters are primed for. Using a waterjet cutter for such a material incurs the costs and also doesn't take advantage of the significantly higher throughput speeds that the laser cutter provides. The brief processing times and precise results of the laser cutter help lower the production energy costs ("Cut with a Laser More Quickly"). Additionally, using a waterjet cutter runs the risk of significantly deforming the material compared to the laser cutter, which means that in the worst cases the part may be more likely to require a complete redo. This is because using a highly pressurized stream of water is more strenuous on a thinner material than the contactless method provided by the laser which imparts no force on said material (“Laser Cutter vs Waterjet Cutting”). Laser technology, under the right circumstances, is less likely to introduce harmful byproducts and waste because of its operation compared to the waterjet cutter.

How can laser cutters improve the user’s ability to make more sustainable engineering choices than can only be offered with the 3D printer? To put the 3D printer’s capability into context, laser cutters typically work with flat materials, whereas 3D printers create complex 3D geometries layer by layer. Laser cutters are viewed as more versatile than 3D printers. Laser cutters can work with a variety of raw materials easily found in various hardware stores, while 3D printers require polymer filaments that are often ordered first and more likely to be brand exclusive and thus more expensive. These polymer filaments always have a lower tensile and shear strength than the materials processed on laser cutters. Taken together, 3D printers often produce parts that are less durable than those made with laser cutters and other traditional manufacturing techniques and have the potential of placing a burden on the user to frequently burn through expensive and harder to acquire raw materials. Filament jams are a regular problem with 3D printers and depending on the volume of the part that needs to be created, a 3D printer may need 4-8 hours just to print out a single piece. Laser cutters boast a higher throughput speed, and this allows the user to eliminate production time by a large margin. In many cases, time may be better spent using the laser cutter to rapidly generate the individual parts of an assembly and put them together (“The Role of Laser Cutters,” 2020). A prime example is when creating a box or enclosure. A box can be made using a 3D printer, but it would be much quicker and less cost intensive to acquire the raw materials from a store, run it through the laser cutter to generate each of the side frames, and then to assemble it after. If a new box were to be made with different dimensions, the 3D printer would have to run again for the entirety of the box, but it is plausible to assume that the side frames created by the laser cutter could be detached from its assembly and salvaged for reuse especially if only some of the dimensions of the box are changed. A 3D printer's slower operation speed, combined with the more expensive and less durable material makeup means that users find themselves going through multiple painstaking prototype iterations that result in an accumulation of failed parts and assemblies.

In the medical device industry especially, sustainable manufacturing practices must be taken into account in the coming years as an increasingly aging population places a strain on the capacity of healthcare engineering giants. At the moment, around 90% of medical device waste comes from disposable, one-time-use products or components. This is due to the biological contamination that occurs because of using these devices and the high cost of product sterilization and reprocessing. The waste is typically incinerated to reduce the volume of waste and destroy biohazardous materials, but this has the unintended consequence of releasing nitrous oxide and known carcinogens into the atmosphere, with prolonged exposure linked to damage in the adult body and the acidification of land and ocean. As stated before, the amount of energy needed to clean the disposable components makes it difficult to avoid waste. However, there are things that can be done to curb the sheer impact of the substantial number of disposable components that are produced as a result of medical device usage. Relevant to this paper, sustainable manufacturing is one way that the product life cycle of the medical device as a whole can be controlled to limit pollution. Processes that use less water and energy should be seen as more commercially attractive to businesses, and in turn these practices play an important role in limiting environmental degradation and pollution. Improved productivity and shortening time to market through high quality rapid prototyping are also some ways that companies can reduce costs and be allowed to focus more of their efforts on how their products can be disposed of in an environmentally friendly manner (I'ons, 2020). The water and energy conservation aspects are clear examples of where the laser cutter should be used when able to limit the impact that waterjet cutters have on those types of pollution. When it comes to rapid prototyping, laser cutters in conjunction with traditional manufacturing techniques also beat out 3D printers in many cases. They result in higher quality prototypes and have a faster throughput time, which allow the company to quickly assess the proper way to minimize raw material volumes and maximize product performance.

Beyond the clear benefits in the environmentally sustainable alternatives that the laser cutter provides, the importance of the Capstone project is to prove that more work can be done on the laser cutter and other laser-based systems to bring cost down, even for the high-end models. This allows students to take advantage of them, sure, but also benefits companies from lowered acquisition costs who are then able to offer cheaper manufacturing services to consumers and other parties. As noted before in the Prospectus, the da Vinci surgical system makes use of various medical devices on its platforms. When a hospital decides to purchase this system, they are not only paying for the upfront cost but also the maintenance cost required to replace the instruments that are disposable. Regular maintenance can exceed costs up to $100,000, and the result is that hospitals place intense financial pressure for the trainees to use the technology and financially reimburse the hospital. Often this pressure comes even as the notorious problem persists in the surgical robotics field of unqualified surgeons with minimal training using the da Vinci surgical platforms prematurely to perform life-altering surgeries on patients. Using a laser cutter, many of the instruments that are crucial to the da Vinci surgical system can be easily manufactured. The laser cutter's ability to cut hollow tubes like the stent and hypo tube means that the very instruments that enter the person's body on some of the most common surgical procedures can be easily replaced. Laser welding technology can also be used to construct endoscopes, which are often placed at the end of a surgical robot arm for medical imaging purposes during surgery ("Medical Device Manufacturing"). Overall, a decrease in the cost of laser technologies is a direct way in which engineering ethics can be prioritized in many facets of the healthcare system.

Conclusion

Laser cutting and other laser-based technologies have so much to contribute to society. They have the potential for addressing several of the environmental problems caused by the more widely used manufacturing methods in general as well as giving companies the option of taking a more ethical route in their engineering practices. The University of Virginia's mechanical engineering curriculum could benefit hugely from the integration of laser cutters into their courses, and the appreciation of this type of technology in comparison to other modes of manufacturing will no doubt help grow the students' awareness of the choices that they have to make to facilitate a more sustainable and ethical future.

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