

Laser Printing Principles and Manufacturing

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MIAE 311: Manufacturing Processes
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02-12-2024

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Abstract

Laser printing is a type of additive manufacturing that has emerged as a revolutionary technology in manufacturing, offering a new flexible, efficient and precise process across industries like aerospace, automotive, and medicine. This project broadly explores the mechanisms of laser technology and its interaction with materials, its importance in the modern manufacturing world, and certain application in some fields of interest. An analysis of laser mechanism in manufacturing applications highlights its advantages in the fast production of complex geometries, that conventional manufacturing methods cannot or struggle to deliver. However, the high cost of equipment and maintenance still pose an obstacle to its implementation, especially for widespread industrial production. Real-world applications such as lightweight aerospace components, or orthopedical patient tailored implants, underscore laser technology's importance in delivering advances performance. The project then concludes with a summary of the key concepts of laser printing technology and its future prospects.

Introduction

Laser technology operates on the principle of amplifying light to produce a high energy concentrated beam of light. Different laser technologies are used manufacturing, such as laser assisted machining, surface texturing, welding, shock peening, or our subject of interest, additive manufacturing [1]. Laser technology is valued for its high level of control and precision. As the industrial arena becomes more competitive with technologies that produce highly accurate products, laser technologies align with this trend, their ability to cut, fuse or heat a very small area makes them ideal for applications requiring intricate details.

In the context of manufacturing, laser printing technologies have revolutionized production methods by offering a fast, precise and flexible manufacturing alternative. Unlike traditional manufacturing methods like turning, forging, or casting that require consumable tools, laser printing is a contactless process, eliminating this important cost. Additionally, laser printing is a strong prototyping tool, since it offers a fast method of materializing a concept or a design, this is due to the wide range of complex shapes it can produce as opposed to conventional manufacturing methods that often limits the creativity of the designer [2].

The primary goal of this work is to explore the principle mechanisms of laser technology, with and emphasis on it s role in modern manufacturing. By understanding how lasers fuse, cut or melt different materials, we aim to highlight the versatility and efficiency of laser technologies, and their benefits to advance manufacturing. Additionally, this work seeks to explore the advantages and limitations of laser printing and discuss future trends that might influence its evolution.

Principles and Physics of Laser Technology

The word LASER is an acronym for Light Amplification by Stimulated Emission [3]. More precisely a laser is an optical device that stimulates atoms or molecules to emit photons in a synchronized and controlled manner producing an intense, coherent and collimated beams of light [4]. A laser, as a device, comprises of three main components, a source that delivers the energy to initiate and maintain the laser, a resonant electromagnetic structure, and an active medium composed of atoms and molecules [5]. The key concept behind a laser is stimulated emission, where a source of energy interacts and excites electrons in atoms, causing them to emit photons. This photon emission is highly coherent allowing a narrow-synchronised trajectory, and the travel of these photons along this path creates an intense beam. Unlike ordinary light sources that disperses in all direction, a laser beam is monochromatic and directional, and with the use of optical amplification through mirrors, laser systems can create an amplified concentrated beam capable of interacting with materials in controlled ways, through fine tuning energy to cut, engrave, or weld with remarkable precision [6].

Materials Interaction with Lasers

Several physical processes can occur when a laser interacts with a material, depending on the energy of the laser beam and the optical properties of the material. For example, in a cutting operation, the laser's energy is absorbed by the material, causing intense heating and therefore melting of the material. In a process like engraving, the energy directed by the laser at the

material is lower, enabling limited surface ablation, where material is removed layer by layer. As for additive laser manufacturing, the laser melts or sinters the material powder in very controlled way, to form thin layers, that stack up and form the 3D model [7]. In engineering, metals are of particular interest due to their mechanical, thermal and electrical properties, therefore understanding their interaction with lasers can prove useful in modern manufacturing. For instance, metals have many available energy states, these states allow electrons on the surface of the material to transition from an energy state to another. The excitement of these electrons depend on the wavelength of the light beam and the crystal structure of the metal involved, the higher the energy of the light, the better the penetration, therefore the more electrons it can interact with [8].

Laser Printing in Manufacturing

3D laser printing, also know as additive manufacturing, involves using laser beams to selectively fuse powdered material to create three dimensional objects. The most common laser manufacturing technology is Selective Laser Sintering (SLS). This process utilizes high laser beams to raise the temperature of the powder above the softening or melting temperature of the material, and its success depend on adequate absorption of the laser energy. The sintering happens between two solid particles at elevated temperature by forming a neck between these individual particles due to diffusion of atoms along the surface, the grain boundaries or other paths [9]. The most common process in additive manufacturing is Laser Powder Bed Fusion (LPBF). During the process, a powder bed fusion system is enclosed in a chamber with an inert gas, the scanner locates the area to sinter through a three-dimensional CAM file, and directs a heat source, the laser, to a particular area of the surface of the powder evenly distributed on the bed of the printer, as seen in figure 1. Once the layer is completed, typically 10 to 50 μ m thick, the bed of the printer is lowered using a vertically travelling piston to complete the following layer, and the process is repeated until the part is completed [10].

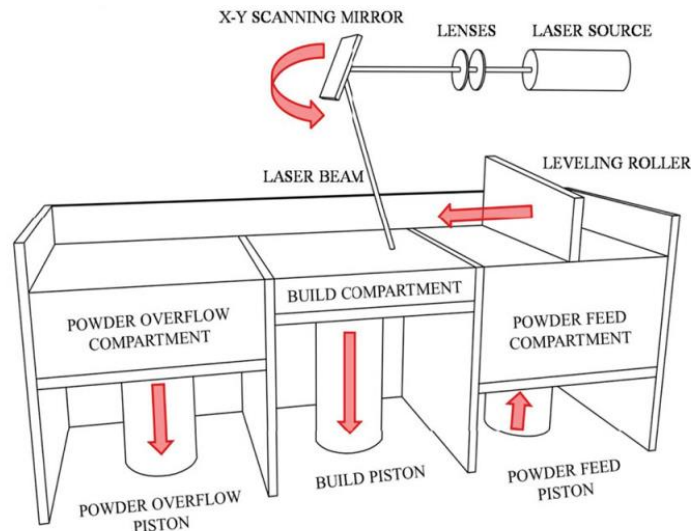


Figure 4: Laser Powder Bed Fusion [10]

Advantages and Limitations of Laser Printing

Laser printing technologies offer several significant advantages in manufacturing. One of the key benefits is precision. Lasers can focus energy on extremely small areas, allowing for detailed work that is difficult to produce using other methods. Another advantage is the possibility to create complex parts, that would be difficult to produce using subtractive manufacturing, forging, or casting. For example, parts that have internal complex channels, or parts with lattice or honeycomb structures on the inside for weight saving applications. Additive manufacturing in general helps reduce assembly work in its production, where a system in its entirety may be made in one part, therefore reducing manufacturing and labor cost. Additionally, the designer can be creative in more ways in their design process, utilizing the broader spectrum of manufacturability that additive manufacturing proposes, and allowing for more innovative solutions [12].

Despite its many advantages, laser printing in manufacturing does have its limitations. One of the primary drawbacks of is the high cost of equipment, since industrial-grade laser printers are expensive to purchase and maintain. Laser printing machines utilize cutting edge technologies such as specialized high energy lasers, precision sensors, and performance cooling systems. Not to mention the added cost of high skilled labor to operate and maintain the equipment [11]. Additionally, parts made with laser printing inherently exhibit various types of defects, that may hinder their use in some applications. The presence of porosity and cracks, high residual stresses and varying phases and grain structures are a direct cause of local heating and cooling that the part undergoes in the process, these defects can alter or even degrade the mechanical properties of the materials [1]. Yet, extensive research is undergoing to better control and understand the process. Additive manufacturing as a production method is still in its infancy, the technology as it exists today will struggle to financially compete with more conventional methods of manufacturing for high volume industrial production.

Applications in Industry

Laser printing technology is used in a variety of industries, each benefiting from its precision, speed and versatility. For instance, selective laser sintering is used to build light weight bracketry with complex geometries, as shown in figure 2 bellow. A particular example of these applications in aerospace is GE's jet engine nozzles that are completely made using laser printing. By 2018, their factory in Auburn Alabama, has reached a production volume of 30,000 jet engine fuel nozzle tips using their laser printers [13].



Figure 5: GE's Jet Fuel Nozzle [16]



Figure 6: Zygomatic Bone Implant [17]

Health professionals have also seen the benefits that Laser printing can bring to the orthopedic practice in medicine, where laser printing has made it possible to design patient-specific implants to better fit patient needs in more complex cases, as seen in figure 3 above, the craniomaxillofacial implant of a zygomatic bone printed using additive manufacturing. Patient-specific implants reduce the risk of infection, shorten the recovery time, and match the patient's anatomy with excellent precision [14].

Conclusion

In conclusion, laser printing principles and techniques have fundamentally revolutionized the landscape of modern manufacturing. The unique capabilities of lasers to precisely cut, engrave, and build complex three-dimensional objects make them an important competitor in manufacturing processes. The laser printing technology offers numerous advantages, including flexibility, efficiency, precision, while minimizing material waste and enabling rapid prototyping. However, the high cost of equipment and skilled labor, the production volume, and the inherent mechanical defects present, may hinder their broader use and present challenges that need to be addressed as the technology evolves. Looking ahead, the future of laser printing in manufacturing holds significant potential for growth and innovation. The research and development of the technology will expand the range of materials, while addressing some of its technical challenges, and broaden its use in many applications. Additive manufacturing appear to be the next generation of manufacturing technologies, paving the way for more efficient, and environmentally friendly production methods.

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