DEVELOPMENT OF A PRECISION RAPID METAL FORMING PROCESS

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Abstract

This paper presents the important issues pertaining to the development of a precision rapid metal forming process. A five-axis configuration provides a flexible building capability to produce free-form fabrication capability. The laser cladding process is able to produce functional mechanical parts and machining capability is able to produce industrial grade surface quality. A machine configuration that combines the laser cladding and CNC machining processes is presented. The related parameters and components are discussed.

Introduction

Due to the increasing complexity of certain part geometry, producing highly accurate functional models directly from computerized data is often very difficult using the available rapid prototyping (RP) systems. The laser metal forming process is a potential technique that can solve this problem. LENS (Laser-Engineered Net Shaping) is one developing Rapid Metal Forming (RMF) process that has demonstrated the feasibility of laser metal forming to produce near-net-shape metal parts [2, 3]. Some efforts have been dedicated to utilizing the existing laser cladding technique, which is an established method in surface coating of metal parts, to produce metal parts by a layer additive approach [1, 4]. The laser cladding process is able to produce fully functional mechanical parts. However, these parts usually pose inadequate accuracy compared to that of the CNC machining process. To address such issues, a machine configuration that combines the laser cladding and CNC machining processes is presented in this paper.

Rapid Metal Forming Process (RMF)

Rapid metal forming systems, especially those of laser-based energy sources, were reported by many authors [1-6]. These systems represent some current efforts to produce metal parts directly from CAD solid models. A number of studies on rapid metal forming with lasers were primarily concerned with the process parameters that determine the quality of the produced parts [1, 4, 6]. Most of these systems are still in the research and development stage.

The basic system hardware for a rapid metal forming process includes an energy delivery system (laser head, optics system), powder delivery apparatus (powder feeder, nozzle, carriage gas), and a Computer Numerical Control (CNC) table for x-y motion and z-axis vertical motion. The CNC table can have three-axis or multi-axis motion for enhanced flexibility that is needed in forming more complex parts [1, 2, 4-8]. *Figure 1* shows the basic system hardware required for a metal forming system.

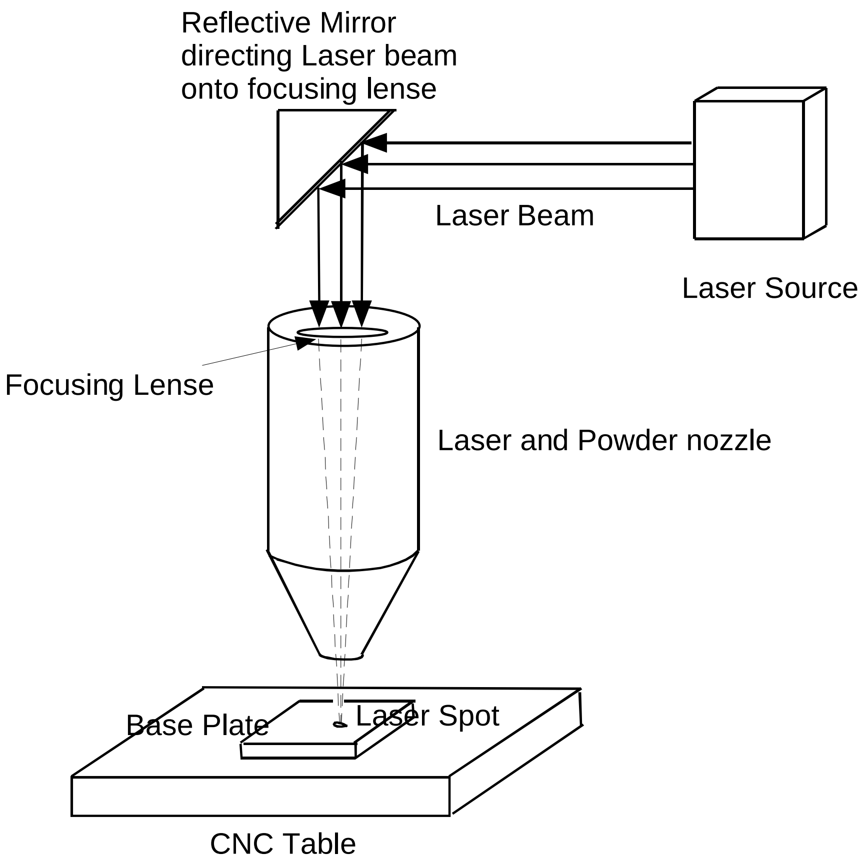

Figure 1. Basic System Hardware Required for a Metal Forming System

In addition to the basic hardware, a metal forming system also consists of control system hardware, a cooling system for the powder nozzle, and a base plate. Control system hardware includes sensors, CCD cameras, and a computer workstation. Online control is an integral part of a metal forming system. A cooling system is used for the powder nozzle because it is exposed to a thermal load by scattered and reflected laser radiation [4, 6, 9]. A base plate is normally used as a substrate on which metal layers are deposited until a complete part is formed. The base plate is removed by machining or by dissolving with certain chemicals, leaving the finished metal part.

Making Complex Part Geometry

A robust metal forming system should be able to create prototypes of any complex geometry that requires deposition at inclined angles or on curved surfaces. For example, a three-axis system cannot build multi-layer walls with 30° angles from the vertical plane as illustrated in *Figure 2*, and therefore, a more flexible system, such as a five or six axis machine, is required.

Support structure should also be minimized. Building in the vertical direction, the system cannot build a "T" shape structure without excessive support structure. However, a greater degree of freedom system with rotational axes in both the x and y directions, can build overhang geometry with minimum support structures needed.

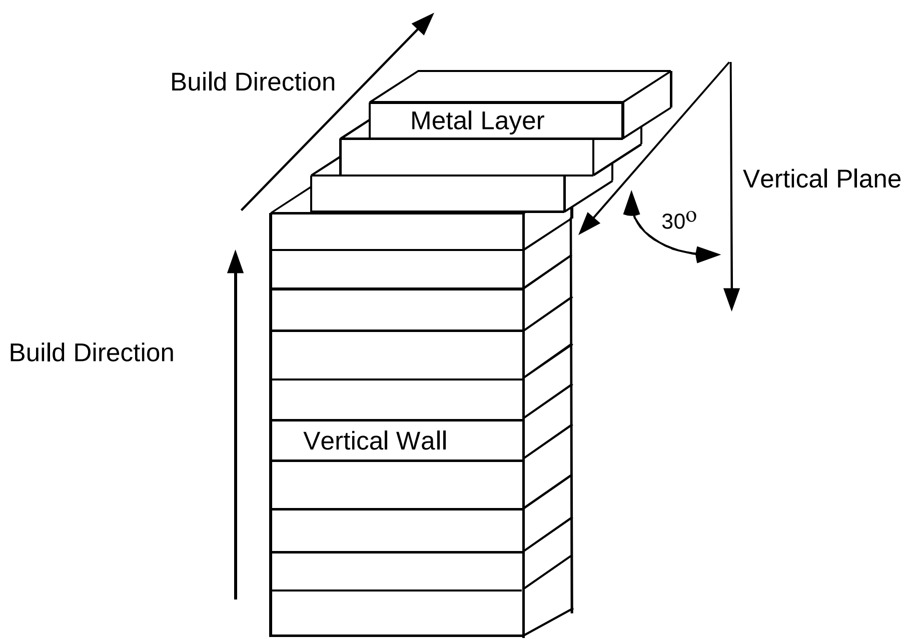

Figure 2. Multi-layer Walls at 30° Incline

Dimensional Accuracy Consideration

In a report on laser metal deposition system [10], a sample, as shown in *Figure 3*, is used to obtain a perspective of the dimensional accuracy of parts in the x, y, and z directions. Measurements taken in the x and y directions are within 0.002 inches (0.05mm) of the nominal dimension. The accuracy of the z dimension is typically within 0.015 inches (0.38mm) from nominal. The accuracy of the z direction is dependent on the build layer thickness. The thinner the build layer, the more accurate the part. The ability to build a part with variable layer thickness would improve the accuracy in the z direction. The surface roughness of the part is relatively rough compared to a machined surface. Surface roughness is a function of powder particle size, and the optimum particle size for the process produces a surface between 200-300 microinch average roughness (R_a). Therefore, in comparison with the current laser cladding processes, the machining process is able to produce parts with superior accuracy and surface finish with a broader range of materials.

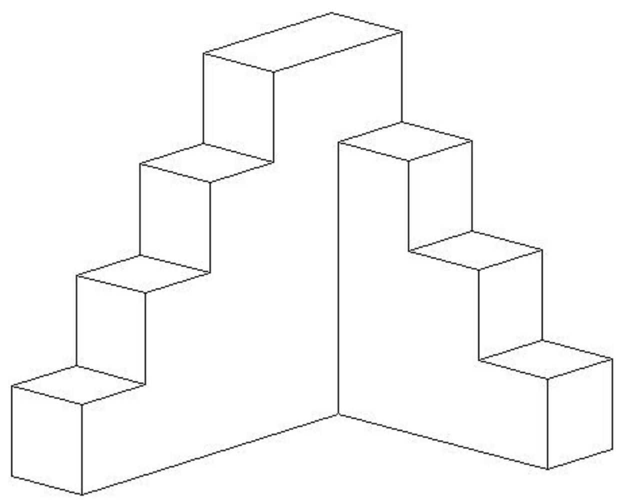

Figure 3. Geometry of the Sample in the Accuracy Testing [10]

LAMP Laboratory Process

There are some general challenges in the current SFF (Surface Free-from Fabrication) processes, such as to produce parts with the accuracy and surface finish required, to build parts with a wide variety of engineering materials, and to directly produce high-quality metal parts for production tooling applications. The automated CNC machining process can also be used as a rapid prototyping tool. Current CNC systems, however, are not extensively used for SFF because of the reasons such as the facts that skillful human intervention required to plan the operations and to operate the equipment, custom fixturing and special tooling often required, and inherent geometric limitations, as shown in *Figure 4*, hindering the process flexibility.

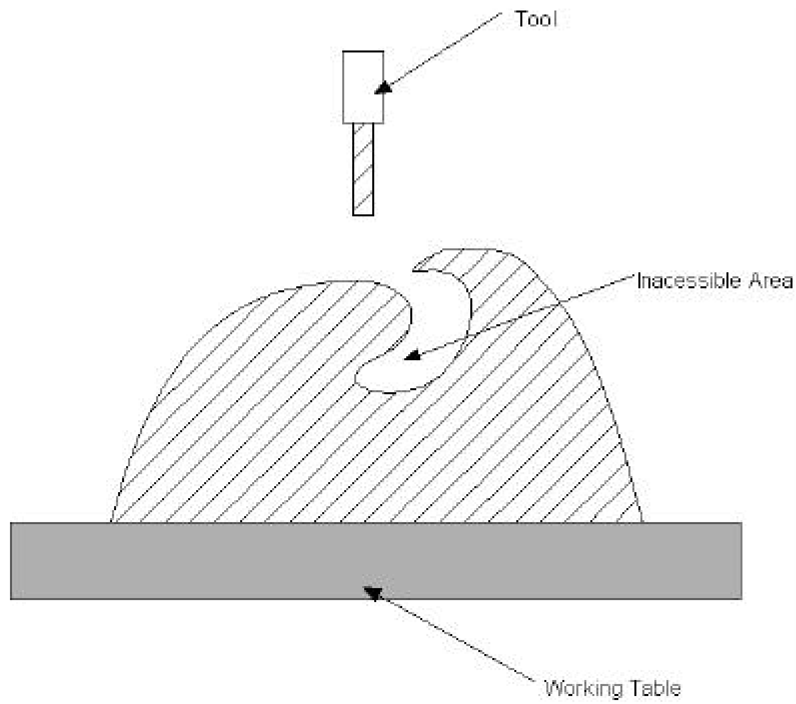

Figure 4 Geometric Limitation of the CNC Machining Processes

A combined system may have the advantages of both laser cladding and machining. It allows complex parts to be built with high accuracy. The schematic of the combined laser-based metal forming LAMP system is shown in *Figure 5*. The system includes two major subsystems: a laser deposition system and a CNC milling machine system. These two systems share the common xy translator and rotary-tilting table; however, they have independent z movement. The laser deposition system and CNC milling machine work in shift in a five-axis motion mode. The laser deposition system is divided into two independent systems: a laser system and a powder feeder. The laser system includes a 2,500W Nd-YAG laser, a laser beam delivery module, a focus optics module, a five-axis movement module, an optics protection module, *etc*. The laser system has a combined movement configuration, with z-motion from the motion of the optics, xy translation, and rotating and tilting of the workpiece. The other important subsystem of laser deposition is the powder feeder, which feeds powder into the melting pool formed by the laser beam.

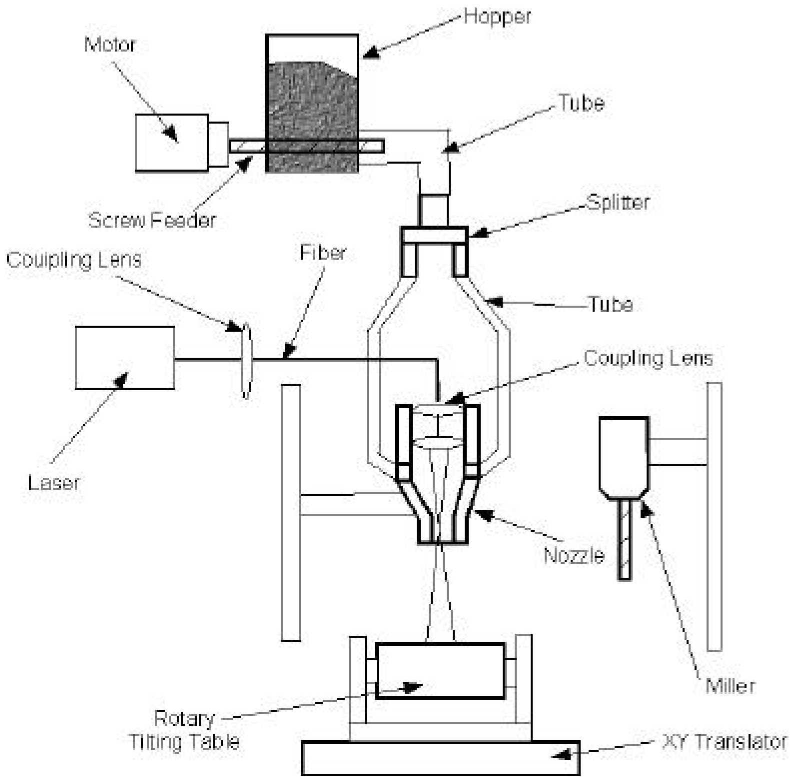

Figure 5. Schematic of the 5-Axis Material Deposition/Removal System

Conclusion

The LAMP system which features both material deposition and material removal processes and 5-axis capability will have the advantages of quickly producing functional parts with precision surface. The expected advantages of this process include 1) the capability to build complex parts including free form surfaces and thin walls; 2) much improved surface finish which is essential in tooling applications; 3) reduced structure support in building 3-D objects that is critical in making metal/ceramic parts; 4) Opportunities of reduced build time since thicker layers can be deposited and shaped by a machining process; 5) almost no limitation on material selection as long as the laser can melt the material in time; 6) capability of making perfect features such as holes and threads using machining processes; 7) Elimination of shrinkage factor in deposition process with the material removal process. This is not only useful in modern manufacturing environment in producing functional prototypes but also producing molds for mass production. The challenges, however, include the complexity in process planning and the system control.

Acknowledgement

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References

1. Koch, J.L. and Mazumder, J., "Rapid Prototyping by Laser Cladding," *The International Society for Optical Engineering*, vol. 2306, 1993, p. 556-eoa.
2. Keicher, D.M., Miller,W.D., Smugeresky, J.E. and Romero, J.A., "Laser Engineered Net Shaping (LENS): Beyond Rapid Prototyping to Direct Fabrication" , *Proceeding of the 1998 TMS Annual Meeting*, San Antonio, Texas, USA, p. 369 – 377
3. Beardsley, Tim, "Making Light Work: Blasting Metal Powder with Lasers to Make Precision Parts", *Scientific American*, August 1997
4. Kreutz, E. W., Backes, G., Gasser, A. and Wissenback, K., "Rapid Prototyping with CO_2 Laser Radiation," *Applied Surface Science*, vol. 86, 1995, p. 310-316.
5. Lewis, G. K., Nemec, R., Milewski, J., Thoma, D.J., Cremers, D., and Barbe, M., "Directed Light Fabrication," *Proceedings of the International Congress on Applications of Lasers and Electro-Optics*, 1994, p.17-26.
6. McLean, M. A., Shannon, G. J. and Steen, W. M., "Laser Generating Metallic Components", *Proceedings- SPIE The International Society For Optical Engineering*, Vol. 3092, 1997, p. 753-756.
7. Pelletier, J.M. and Sahour, M.C., "Influence of Processing conditions on Geometrical Features of Laser Claddings Obtained by Powder Injection," *J of Materials Science*, vol. 28, 1993, p. 5184-5188.
8. Calvalho, P.A, Braz, N., Pontinha, M.M., Ferreira, M.G.S., Steen, W.M., Vilar, R. and Watkin, K.G., "Automated Workstation for Variable Composition Laser Cladding-- Its Use For Rapid Alloy Scanning," *Surface and Coatings Technology*, vol. 72, 1995, p.62-70
9. Li, L., Steen, W. M., Hibberd, R. H. and Weerasinghe, V. M., "Real-time Expert Systems For Supervisory Control of Laser Cladding", *Proceedings of the International Congress on Applications of Lasers and Electro-Optics*, 1987, p. 9- 15.
10. Atwood, C., Griffith, M., Harwell, L., Schlienger, E., Ensz, M., Smugeresky, J., Romoera, T., Greene, D., Reckaway, D. (1998). Laser Engineering Net Shaping (LENS^{TM}): A Tool for Direct Fabrication of Metal Parts. ICALEO'98, Section E-1.