Motion Planning for Cladding Operations in a 5-axis LENS™ Machine

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ABSTRACT

This paper presents a motion planning approach for some basic part shapes that require 5-axis motion control in a LENS™ machine. The paper discusses an approach that allows a cladding layer to be deposited on a cylindrical or a semi-spherical part for re-build operations. For cylindrical parts, the deposited layer could take the form of a tube, a spiral, or stepped/tappered tube. The approach allows arbitrary values for the parameters of these layers, and automatically translates the part parameters into a motion control program to run the LENS™ machine. The developed methodology was tested on an Optomec 850 machine, and the results were successful.

INTRODUCTION

The Laser Engineered Net Shaping (LENS™) process developed at Sandia National Laboratories and commercialized by Optomec Design Company of Albuquerque, New Mexico, is one of the first successful techniques for direct metal deposition. The LENS™ process distinguishes itself from the stereolithography process and other common rapid prototyping processes in the following ways:

1. The LENS™ process fabricates metal and/or ceramic parts rather than polymer parts.
2. Parts are built by fusing powdered metals and ceramics with a high-powered laser, directly creating dense metal and ceramic parts in the LENS™ machine without need for post-processing in a furnace.
3. Parts are built on a base and unsupported overhangs cannot be built. Only upward-facing features can be built unless the part is manipulated with multi-axis control.

A LENS™ machine delivers powder directly to the beam/powder interaction region on the substrate. A high-powered Nd:YAG laser melts the powder, solidifying it to the substrate. The LENS™ machine scans the entire x-y cross-sectional slice from the CAD model, steps in the z-axis, and then repeats the process over again until the part is fabricated.

This paper discusses a method to plan the motion of a 5-axis LENS™ machine that allows a cladding layer to be deposited on a cylindrical or semi-spherical part. For cylindrical parts, the deposited layer could take the form of a tube, a spiral, or stepped/tapered tube. The capability to deposit the cladding layers is important in part rebuild operations.

Very little work has been reported in the literature on motion planning of multi-axis LENS™ machines. In addition, no work has been reported yet to automatically control, based on the solid model alone, deposition for more than 3 axes of motion. Researchers at at Sandia [1] have reported on the use of a six-axis robot to hold and manipulate a part during deposition. Lockheed Martin, which owns an Optomec LENS™ machine, has reported [2] on the use of a six-axis articulated robot that carries the deposition head.

APPROACH

The approach that was followed was to develop a motion planning methodology that works for a class of parts, but allows arbitrary values for the dimensions of these parts. All the parts that were considered require three or more axis of motion to produce the desired geometry. The part shapes that were considered include: a cantilevered cylindrical geometry, cantilevered spiral geometry, a cantilevered stepped/tapered cylindrical geometry, and a spherical geometry.

The Optomec-850 machine has 5-axis of motion arranged in two groups (see Figure 1.) The first group consists of three linear motion stages stacked together to form an XYZ positioning system. The laser deposit head is mounted at the end of the X-motion axis. The second group consists of two rotary stages, mounted on the top of each other. The lower stage (stage E) rotates about a horizontal axis, while the upper stage (stage F) rotates about a vertical axis. The part sits on the top of the upper stage. For 3-axis fabrication, the two rotary stages remain stationary with the upper stage top surface oriented horizontally.

As a first step in this process, a kinematic model of the Optomec-850 machine was first obtained. The model involves assigning coordinate systems to the various components in the system, and then obtaining the necessary equations that give the proper location and orientation of the laser deposit head relative to the part. Fig. 1 shows the coordinate systems that were assigned.

Geometry Modeling

Figures 2-5 define the parameters of the shapes that were considered. Some of these parameters include part radius, and clad length. To make the parameter specification problem easier, it was assumed that the machine operator would first position the laser head at the points indicated by “Zero Position” in the figures. In this way, the location of the part relative to the machine reference system is automatically obtained. The "Laser Gap" is a user-defined parameter that sets the spacing between the laser head and the workpiece. Additional parameters that the user specify but are not shown in the figures include the clad layer thickness, the deposit thickness layer, and the deposit layer width. The last two parameters are dependent on the laser and feeder settings for the machine. As an additional feature, the operator is allowed to specify the scanning mode during deposit, i.e., whether to perform the scanning in all layers in the same direction or in alternate directions.

Note that for all the shapes considered here except the spherical shape, the cylinder axis can be set to be the x or y-axis depending on the orientation of the stages. Note also that for the stepped/tapered case, some combinations of the segment lengths and heights make it impossible for the laser head to reach all the surface areas of the part without a collision. In this case, the software will skip these inaccessible areas.

Translation into Motion Controller

After the coordinates of the motion paths are obtained, the data is automatically transferred into a motion control program to run the Optomec-850 machine. The Optomec-850 machine is controlled by a GALIL [3] motion control card. Hence all the control commands need to be translated into the specific format of the card. To make the translation task easier, the motion controller program was split into several basic modular basic units, and only the units that need to change because of the particular geometry were changed.

RESULTS

A visual basic program was written to implement the above methodology. The program allows the user to select the particular part that need to be cladded, and to set the appropriate parameters for that geometry. The program then automatically computes the motion paths of the machine, and translates them into a control program in the motion controller format. All the above shapes were tested in the machine and the results were successful.

CONCLUSIONS

An approach to plan the motion paths for a 5-axis LENS™ machine is presented in this paper. The approach is specific to certain part shapes, but allows variation in the parameters of these parts.

REFERENCES

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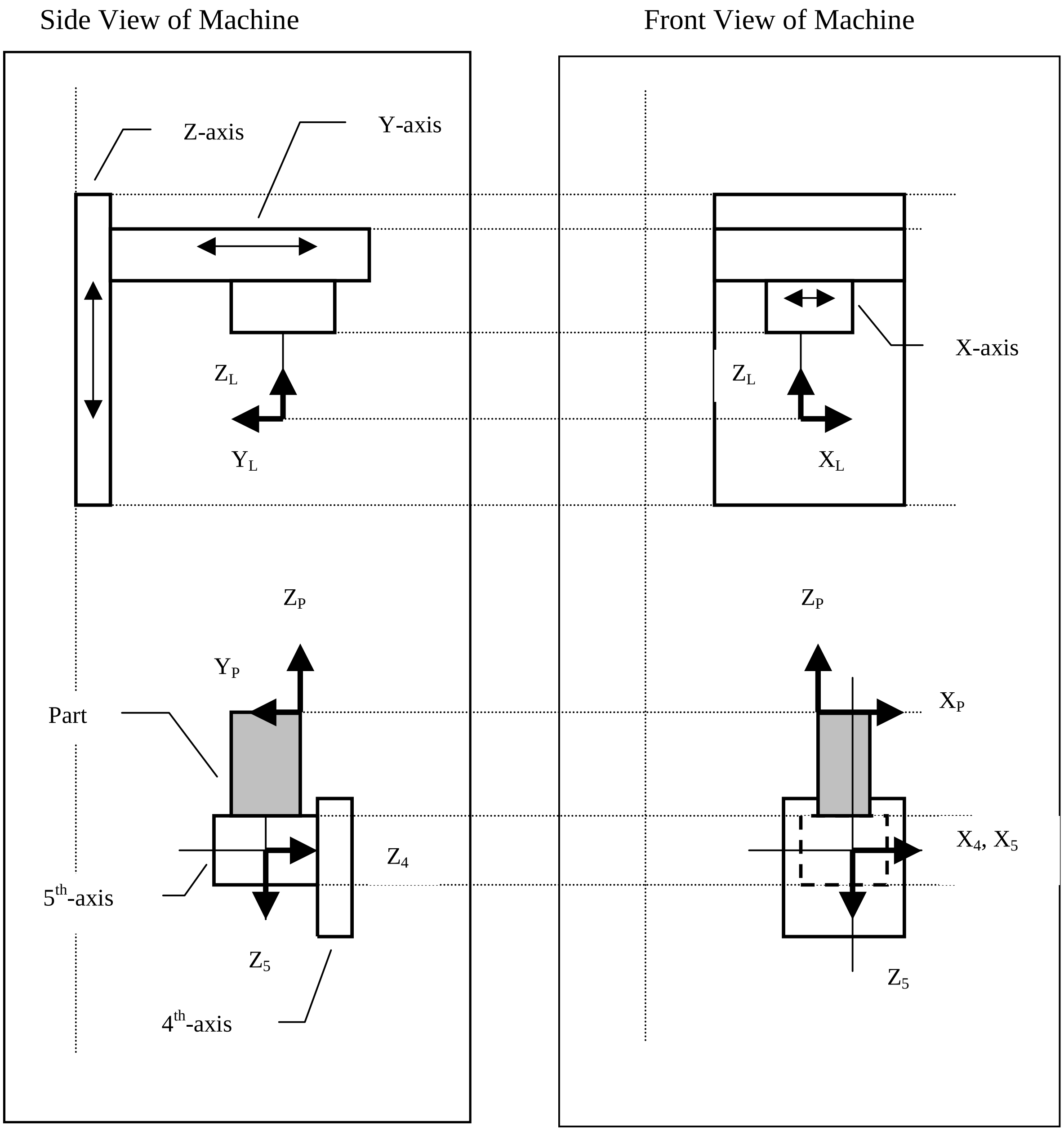
2. "Rapid Manufacturing Technologies". *Materials & Processes*, Vol. 159, Issue 5, May 2001.
3. "DMC-1700 User Manual", Galil Motion Control, Inc., Mountain View, CA 1998.



Notation:

P: Part
L: Laser
4: Horizontal Rotary Axis (E)
5: Vertical Rotary Axis (F)

Fig. 1 A schematic of the 5-axis LENS™ Machine

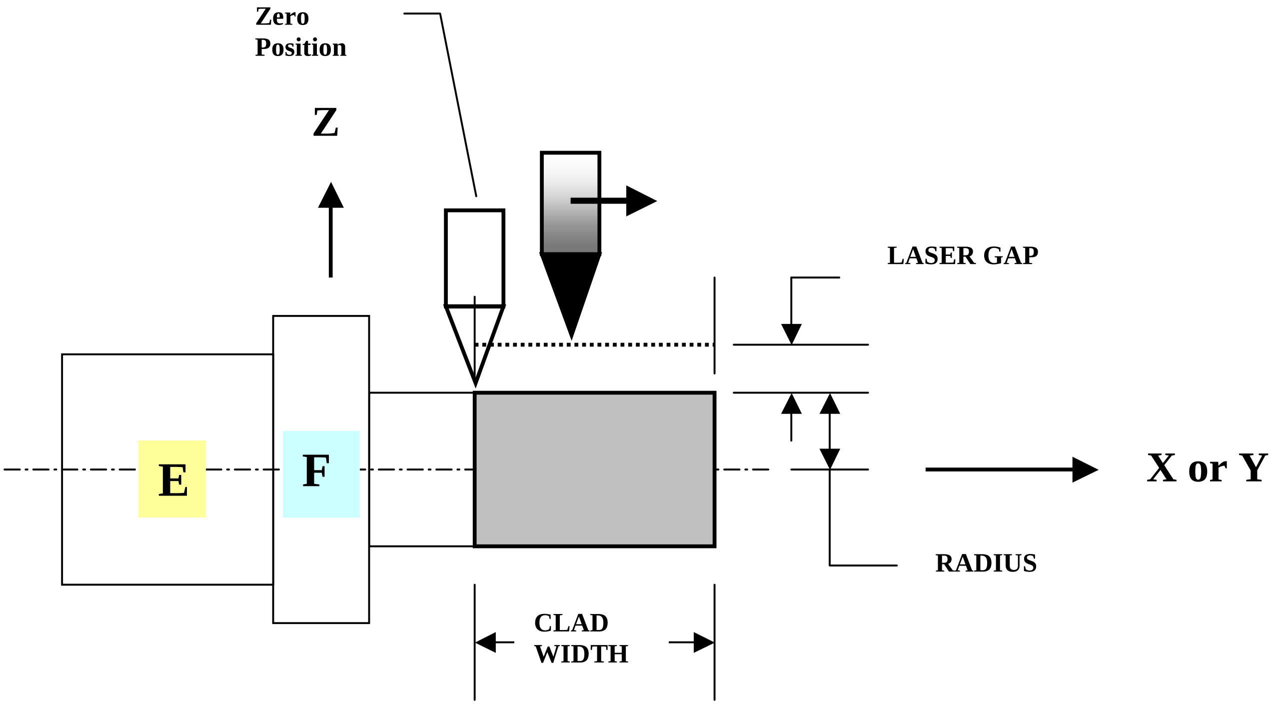


Fig. 2 Cantilevered Cylindrical Geometry

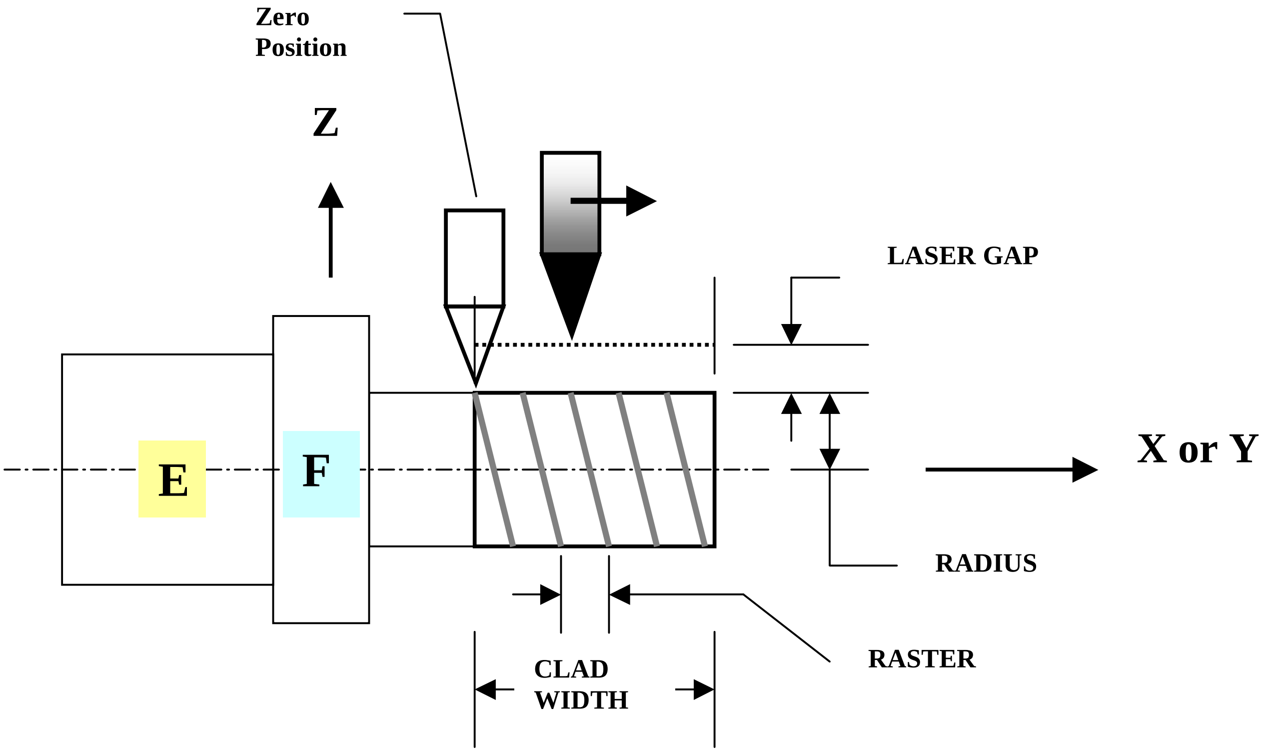


Fig. 3 Cantilevered Spiral Geometry

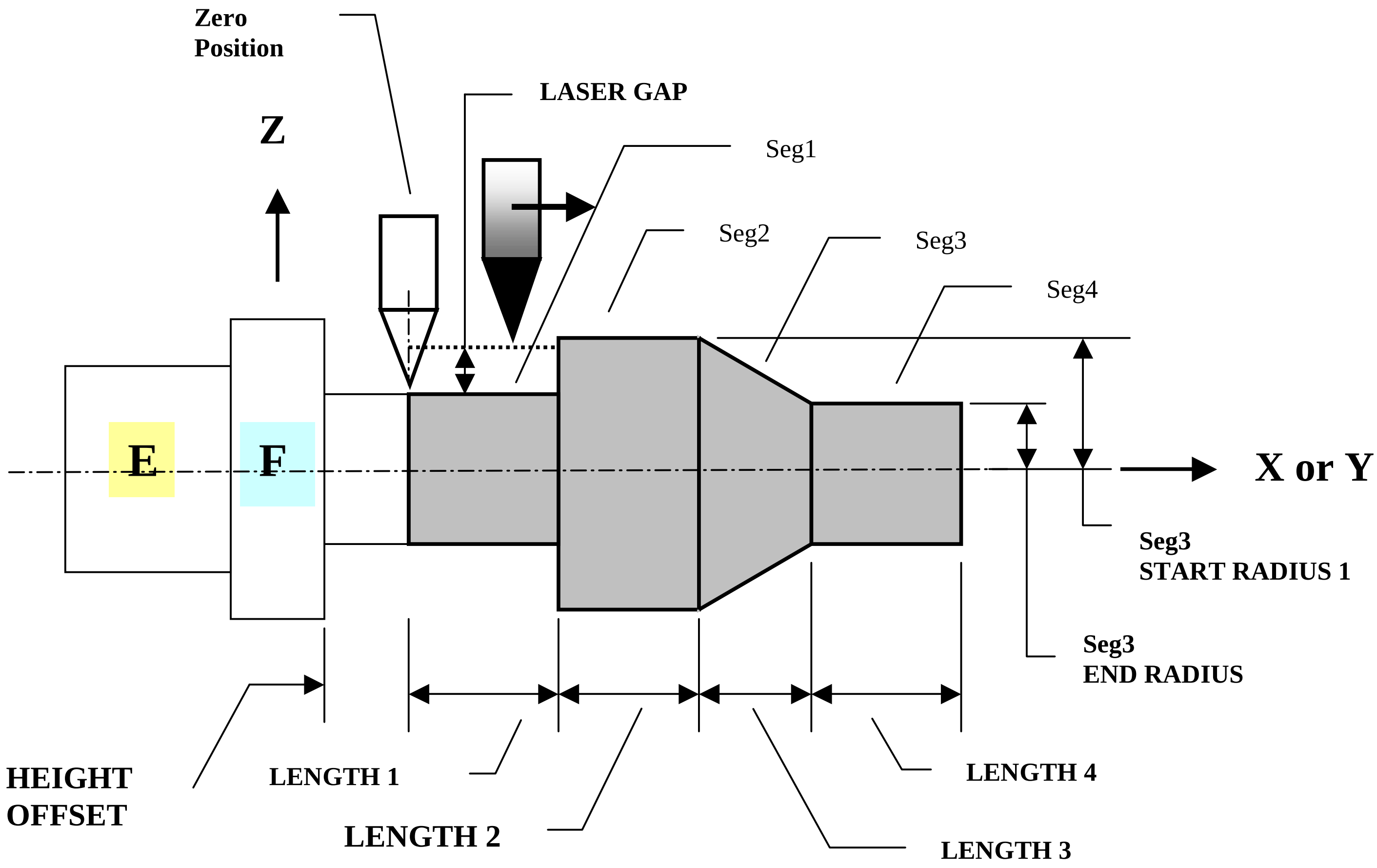


Fig. 4 Tapered/Stepped Cylinder Geometry

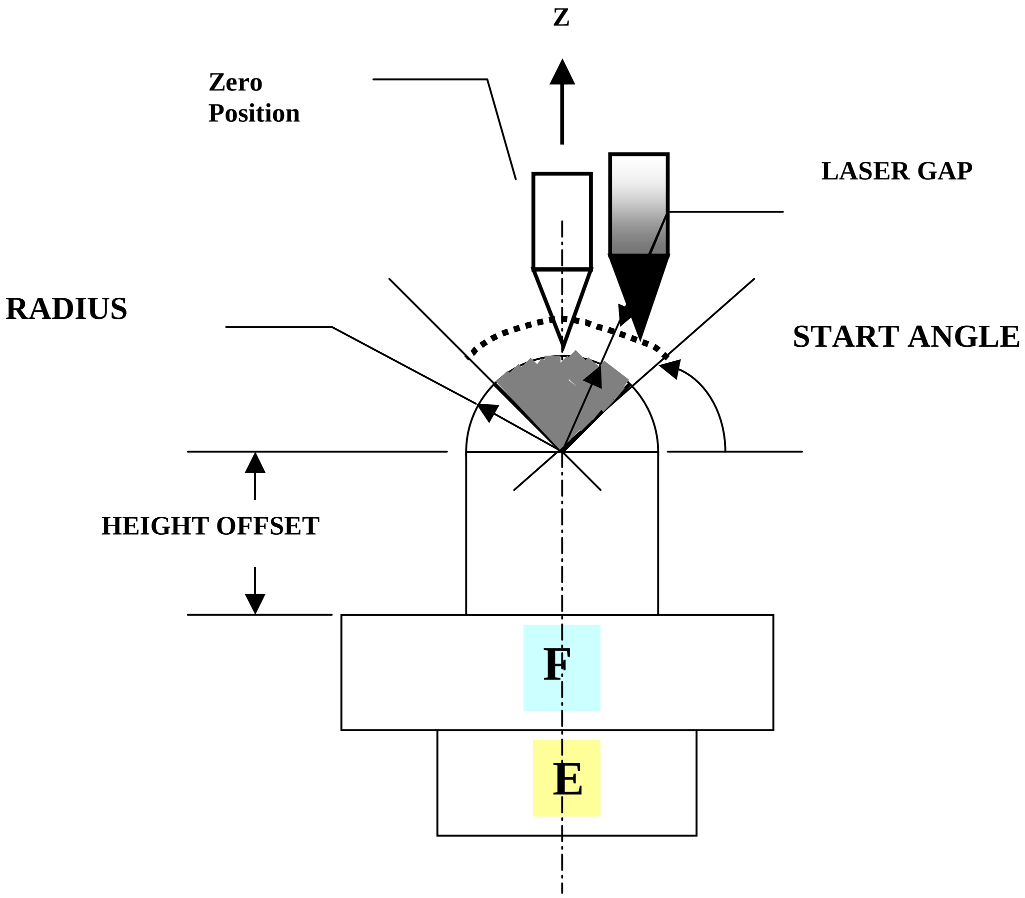


Fig. 5 Spherical Geometry