Workpiece Alignment for Hybrid Laser Aided Part Repair Process

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Abstract

Work piece alignment is a key issue for hybrid laser aided part repair, a process utilizing both machining and laser deposition. Proper alignment can greatly improve the accuracy of the repair process. This paper introduces a method for aligning a physical work piece and a CAD model using a Renishaw touch probe and software tools. Also discussed is a model for computing 5-axis CNC positions based on a desired work piece orientation.

Introduction

Laser Aided Manufacturing Process (LAMP) part repair uses laser deposition process and machining to restore a damaged metal part to near-original condition. The LAMP repair process is a hybrid repair process. The damaged portion of the work piece is first machined, both to remove damage and to make a surface suitable for laser deposition. Then metal powder is laser deposited at the damaged location. Finally, the work piece is finish machined back to its original condition.

Alignment of the work piece becomes highly critical in this application. Poor alignment might result in deposition or machining at the wrong location or even damage to the deposition system itself. The strategy for alignment is as follows. A Renishaw touch probe is used to get the point cloud data from the work piece. This data is then used to orient the work piece in a direction we want before machining away the damaged portion. After machining, the touch probe is used again to calculate the orientation of the work piece. Then, The LAMP system is used to repair the part. The work piece is again probed to make sure that the finished part has the required accuracy.

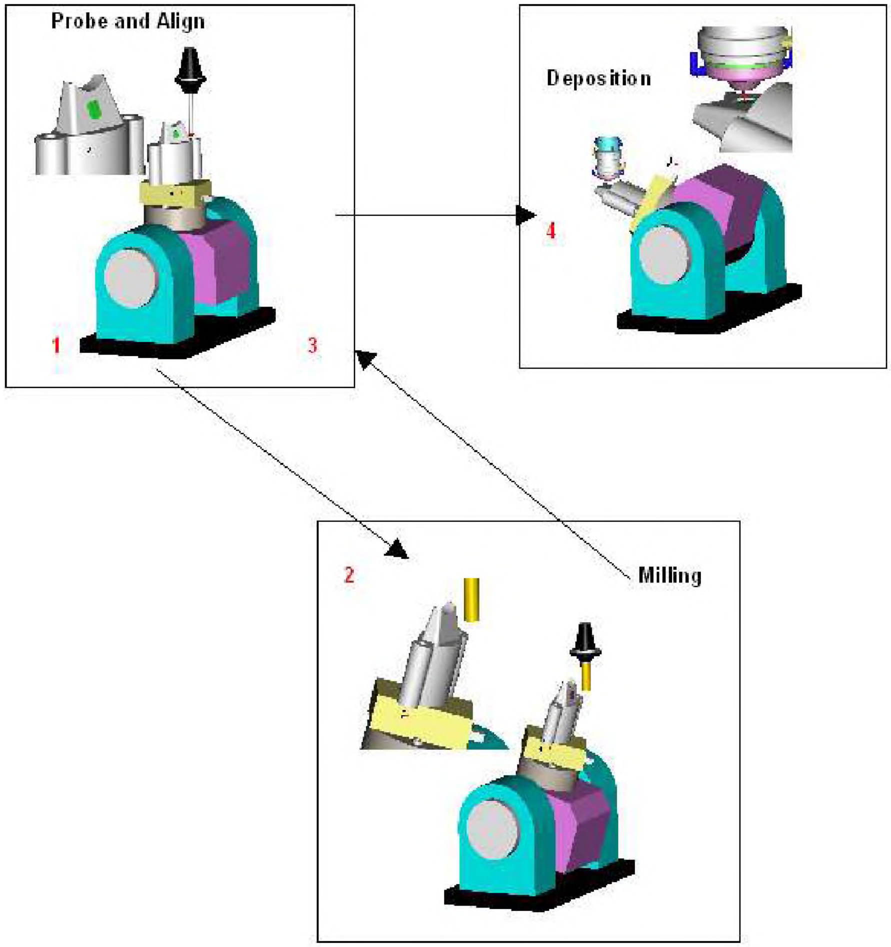

Figure 1 – Repair Process

Equipment Overview

Laser Metal Deposition (LMD) is a layered manufacturing process where metal powder is focused into a melt pool created by a laser incident on a substrate. The advantage of this process is that complex geometries can be constructed with near net shape. The LAMP system at the University of Missouri Rolla is comprised of a 1.4 KW Nuvyonx diode laser (808 nm) with integrated 5-Axis FADAL CNC with a maximum spindle speed of 7500 RPM. Powder is delivered by a Bay State thermal spray powder feeder

Figure 2 – LAMP Process

The 5-axis CNC has the capability of producing overhang parts and does not use support material. Use of support increases the build time of the part and requires a time consuming post-processing. With a five-axis deposition integrated with five-axis machining, these obstacles are removed

Alignment Methodology

The FADAL CNC is a five-axis one with three linear axes, X, Y, and Z and two rotary axes, A and B. In laser deposition the flatness of the substrate is a priority for good deposition. The A and B axes of motion are combined together to get a C axis of motion which makes the surface for deposition level. Data obtained by probing the surface to be deposited is used to calculate the A & B angles needed. The calculations for getting the A and B angles are shown below in Figure 3.

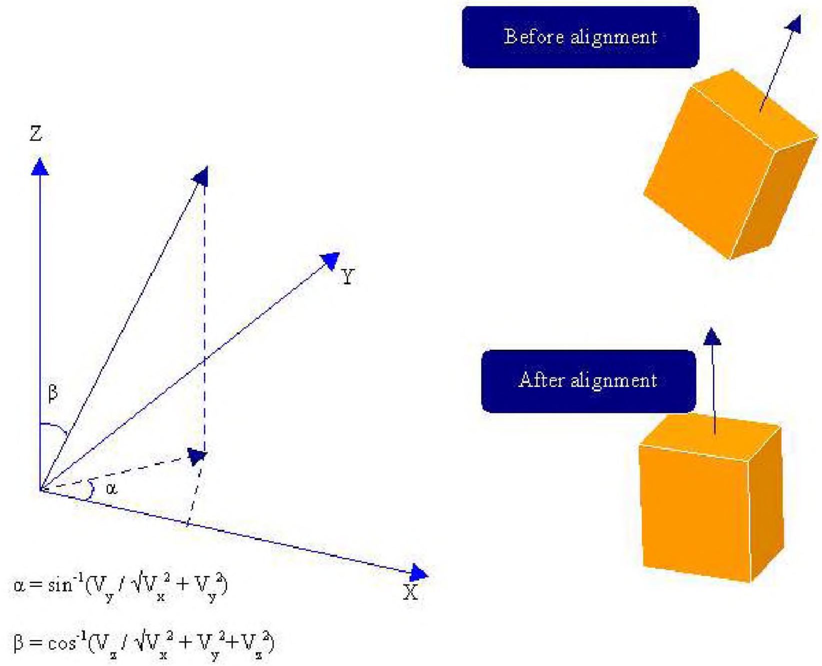

Figure 3 – Surface Leveling

The solution obtained for leveling a flat surface from a combination of A and B axes motion is a unique solution. Any further rotary motion in either A or B directions will affect the level of the substrate.

The process planning of LAMP repair process is based on the CAD model of the workpiece. The aim of alignment is to make sure that the coordinate system of the CAD model and workpiece match, so that the position and orientation of the workpiece is known.

After affixing the work piece in the vise, the top surface is probed and the data is used to level the surface using a combination of A and B rotary motions. Any further rotary motion will change the orientation of the surface. So, for the CAD model to match the work piece orientation, the CAD model has to be rotated and not the work piece. The YZ plane of the work piece is then probed. The data obtained is used to calculate the equation of the plane. The corresponding plane is then identified in the CAD model,, as highlighted in Figure 5. The angle between the two planes is calculated via Equation 1. It doesn't matter if the XZ plane is probed instead of the YZ plane as the workpiece is a rigid body.

If n_1 and n_2 are the normal vectors of two planes, the angle between them is given by:

$$\cos(\Theta) = \frac{n_1 \circ n_2}{|n_1| \cdot |n_2|} \tag{1}$$

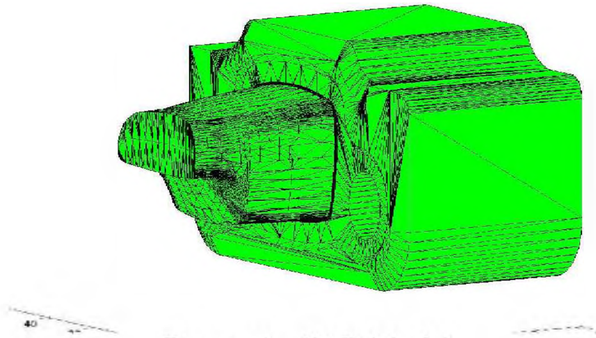

Figure 4 - CAD Model

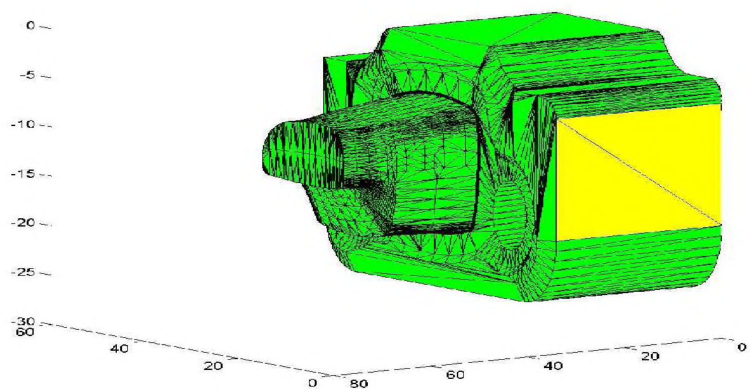

Figure 5 - CAD Model with the YZ plane highlighted

The CAD model is then rotated to correct the misalignment. The angle between the two planes is again calculated to make sure that the CAD model and the work piece orientation match.

This algorithm can be used only for parts with at least two non-parallel flat surfaces accessible to the touch probe. Parts not meeting this criteria require a more complex and computationally expensive surface fitting algorithm, which will be a part of a future work.

The levelness of the substrate is important in this algorithm. The solution for attaining that objective is a unique one. Hence, a coordinate transformation is imperative for process planning. For example, if a 1in square patch is needed on the surface of a part, but the part is rotated by 45 degrees in both the A and B axes, then the transformation would provide the coordinates of the patch in the tranformed state (Figure 6 and Table 1). The Octave code for this transformation is attached in Appendix 1

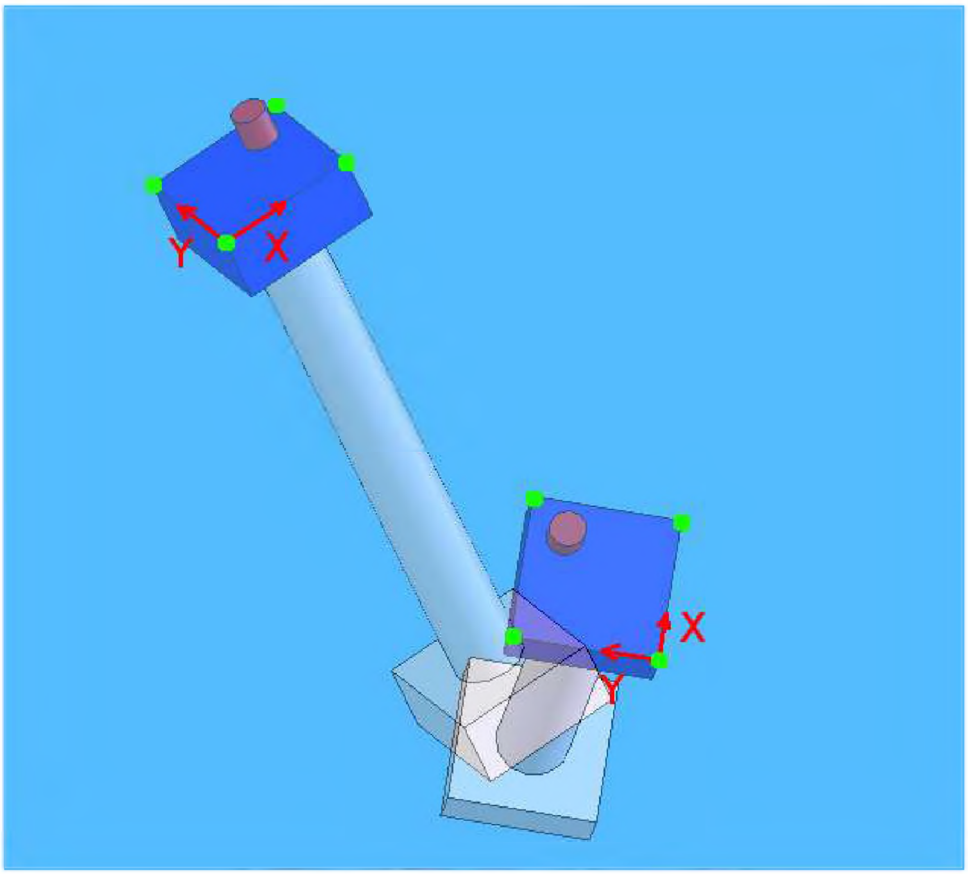

Figure 6 -Transformation example

Table 1 – Transformation Coordinates

Point	Pre-Rotation	Post-Rotation
1	0,0,0	2.53553,0.41421,-1.46447
2	0,1,0	2.03553,1.12132,-0.96447
3	1,1,0	2.5355,1.8284,-1.4645
4	1,0,0	3.0355,1.1213,-1.9645

Conclusions

Alignment is a critical for a viable part-repair process. Using touch probe data, it is possible to align a part with atleast two non-parallel flat surfaces. The levelness of the substrate is important to the deposition process and critical for the machining process. The algorithm discussed in the paper takes this into account. Without precision alignment of workpiece, an efficient part-repair process becomes impossible. The coordinate transformation discussed in the last part of the paper is imperative for successful process planning.

Acknowledgments

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Appendix 1

Octave code for coordinate transformation

```
function W=fiveaxiscoords(Xp,Yp,Zp,A,B,Pzerox,Pzeroy,Pzeroz)
phi=A/180*pi();
theta=B/180*pi();
RA=[cos(phi) -sin(phi) 0 0;sin(phi) cos(phi) 0 0; 0 0 1 0; 0 0 0 1];
RB=[cos(theta) 0 sin(theta) 0 ;0 1 0 0; -sin(theta) 0 cos(phi) 0; 0 0 0 1];
Pzero=[Pzerox;Pzeroy;Pzeroz;1];
Tpc=[1 0 0 Xp;0 1 0 Yp;0 0 1 Zp;0 0 0 1];
Wzero=[1 0 0 -Pzerox;0 1 0 -Pzeroy ;0 0 1 -Pzeroz;0 0 0 1];
W=Wzero*RB*RA*Tpc*Pzero;
```