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Automatic Process Planning and Toolpath Generation of a Multiaxis Hybrid Manufacturing System

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Abstract

With the integration of multiaxis layered manufacturing and material removal (machining) processes, a hybrid system has more capability and flexibility to build complicated geometry with a single setup. Process planning to integrate the two different processes is a key issue. In this paper, an algorithm of adaptive slicing for a five-axis Laser Aided Manufacturing Process (LAMP) is summarized that can generate uniform and non-uniform thickness slices. A method to build a non-uniform (thickness) layer that utilizes two processes is presented, and an overall algorithm for integration is described. The newly developed algorithm implemented in the process planning helps the hybrid system build parts more efficiently.

Keywords: *Layered Manufacturing, Hybrid System, Process Planning, Toolpath Generation*

Introduction

Due to global market competition, manufacturing companies are pressured as never before to develop new products as product life cycles shorten. This trend can be seen in almost all manufacturing companies in the world. The science and technologies that can greatly reduce time to market will be critical for any company to be competitive in the 21st century. Since its appearance in the mid 1980s, Layered Manufacturing (LM) has given industry an approach to achieve the goal of providing better quality products in a shorter time and at a lower cost. This process quickly produces a part by depositing material on substrates, layer by layer, directly from a CAD model.

Recently, the focus of researchers has shifted to metal direct deposition systems to obtain fully functional parts. A high-powered laser is utilized in the process to melt metal powder, layer by layer, to form an expected geometry. Laser-engineered net shaping (LENS) (Keicher et al.1998) and the directed light fabrication (DLF) system (Milewski et al. 1998) were developed at Sandia National Laboratory and Los Alamos National Laboratory, respectively. Mazumder et al. (1997) has also conducted research on metal-related forming systems. One of the primary disadvantages of a metal deposition system is that the accuracy and surface quality may not be adequate. The surface finish for a LENS fabricated part without additional processing is about 432 µ inches. Although LENS utilizes a laser-glazing technique to improve the surface finish to 74 µ inches, the processing speed is slow.

In a conventional 2.5-D laser deposition process, another major concern for the metal LM system is that support structures are needed to prevent an object from toppling over and to support material that would fall (Allen and Dutta 1995). Often, support materials for functional metal parts are not feasible. Moreover, deposition of the support material for metals leads to poor surface quality at the regions in contact with the support structure, and it increases the building time of the part and necessitates time-consuming post processing (machining or chemical process).

A machining (material removal) process can achieve a much better surface quality than the LM process; therefore, it can be used as a finishing operation to improve overall surface quality from the LM process. In a traditional 2.5-D metal LM system, the building direction is fixed with respect to the workpiece. If the building direction can be changed during the deposition process, some support structures can be eliminated by rotating the workpiece to a different building direction. It will be very helpful to integrate multiaxis deposition and machining processes to obtain the benefits of both processes.

The Laser Aided Manufacturing Processes (LAMP) Laboratory at the University of Missouri-Rolla (UMR) is developing an integrated system as discussed above. With a five-axis deposition process integrated with five-axis machining, some obstacles that occur in a traditional 2.5-D metal LM system can be removed. LAMP integrates the deposition process and the machining process together on a five-axis CNC machine. It includes two major systems: a laser deposition system (Rofin-Sinar 025) and a CNC milling machine system (Fadal VMC-3016L). The laser deposition system and the CNC milling machine work in shifts in a five-axis motion mode. The laser deposition system consists of a laser and a powder feeder. The working area is in a protective argon atmosphere to prevent oxidation. The net shape of the workpiece is formed by multiaxis deposition with layers of nonuniform or uniform thickness. Later, a five-axis CNC machining process is used to obtain an accurate profile of the part. With multiaxis capability, minimal support structures are needed, and the internal structures can be built with integration of the deposition process and machining process. Also, considerable lead time is saved and machining accuracy is achieved.

With an integrated system, the process becomes much more complicated than with regular systems. It is necessary to define motion code and sequence carefully for both processes in order to build parts efficiently. The major objectives of process planning for the LAMP system include: adaptive multiaxis slicing; defining positions of the nozzle and tool for deposition and machining processes, respectively; defining the sequence of two processes; and finding possible building solutions for a given part. The multiaxis adaptive slicing algorithm is discussed in another paper (Zhang and Liou 2001) and summarized here. The purpose of this paper is to discuss the integrated procedures for both processes.

Related Work

Previous work on process planning on the LM system involved little cooperation with the machining process. Most work only relied on 2.5-D adaptive slicing to improve surface quality. However, some systems and research have utilized the machining process in deposition to improve overall accuracy.

The Sanders prototyping machine uses an end-milling cutter to mill off the extra material deposited on each layer to maintain accuracy in the z direction. There is no surface machining to eliminate the step-case effect. The five-axis milling in shape deposition manufacturing (Merz 1994) is utilized to maintain the exterior contour. The layer thickness is uniform and the toolpath is generated for (NC) machining separately. Contour crafting uses an arrangement of trowels to shape the exterior contour of the layer, and material is filled in solid interiors layer by layer (Khoshnevis 1997). Currently, only planar trowels are used to form an approximation of the exterior of the layer.

Pinilla, Kao, and Prinz (1998) proposed a method to decompose a part into several manufacturable components, and every component is built up using the LM process. The machining process is carried on to improve the final part surfaces, which are identified in part decomposition, and the part is transferred between LM and machining workstations. However, no toolpath generation algorithms are discussed.

Kulkarni, Prasharnt, and Dutta (2000) presented a system to integrate layered manufacturing and material removal processes. Single and multipass machining toolpaths are used with the deposition layer with an adaptive thickness together to improve the efficiency and accuracy of the system. The machining toolpath is computed based on cusp height of the deposition layer. Also, a trowel tool is analyzed to sculpt the curve surface for the contour crafting process. This method is limited to 2.5-D problems, and the authors assumed that only stair-stepping caused from the LM process affected the final surface quality.

A five-axis machining process is used to improve the geometry accuracy and overall quality from the SWIFT process (Taylor et al. 2001). Two different algorithms are described for both situations—a simple one is designed for a single-edge contoured edge and a more complex one is presented for five-axis machining within a slice. No integration issues are discussed by the authors.

This paper presents a method that integrates the multiaxis-deposition LM process with the machin-