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Laser path calculation method on triangulated mesh for repair process on turbine parts☆

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HIGHLIGHTS

- Apply geodesic methods in laser path generation for repair of turbine components.
- Improve MMP and FMM algorithms on STL considering requirements of laser process.
- Propose an approximate algorithm to rapidly generate laser paths within tolerance.
- Methods are applied to repair cases on tip, platform and aerofoil of turbine blade.

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ABSTRACT

Laser metal deposition is a very effective and precise technology applied by the manufacturers of turbomachinery parts to repair damages on parts in service or reclaim quality during manufacturing of new parts. The process chains to repair or refurbish turbomachinery parts are based upon a 3D laser scanning process which acquires digitalized models in the format of triangulated-meshes to represent the geometry of parts. This paper firstly studies a discrete geodesic method proposed by Mitchell, Mount and Papadimitriou (MMP) and based on this method proposes an optimized exact algorithm to generate precise laser paths on triangulated-mesh data of part geometry. Furthermore this paper presents an approximate method based on Sethian's Fast Marching Method (FMM) and constructs vertex-based geodesic distance field on triangulated-meshes to divide the part surface in equal-distant stripes morphed from boundary curves. These two methods are compared and error condition is evaluated. During the research the methods are implemented into an automated LMD process planning software, which is utilized into industrial applications and obtained satisfactory results. The results from application of LMD process planning software are also demonstrated in this paper.

1. Introduction

Defects like cracks, cavities, and voids are known causes of failure in turbomachine components (e.g. blade and blisk). These defects are caused by either a failure during manufacturing process or from deterioration after prolonged operation of turbomachines. Laser metal deposition (LMD) is an efficient method to repair such defects. It realizes the deposition of metal powder on part surface by the application of heat from a laser source. LMD is becoming a widely applied process in turbomachinery manufacturing industry to repair defects in order to extend lifetime of components and reclaim product quality by refurbishment.

In most practical applications of LMD process, material is first removed at the defected area by employing a suitable machining process such as milling. An accurate parametric geometric modelling of defected region is not possible. Therefore, a simplified geometric shape that bounds the defected area is used for computer aided manufacturing (CAM) planning of a machining process to remove material from defected area. An accurate geometric model of remaining part surface is absolutely vital for the effective planning of the LMD process. For this purpose an equally fine process of measurement that moves a 3D laser scanner over the surface of part to measure the part geometry within an interval of a minute or less is applied. A data model of point cloud is the outcome of the measurement. Afterwards available methods and software are applied to calculate a continuous surface geometric model of the remaining part surface consisting of a series of adjacent triangles with common vertices. This model is called a triangulated mesh of part surface. Fig. 1 shows the simulation of a process-chain for the

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Fig. 1. Process chain for the repair of a damaged turbine blade.

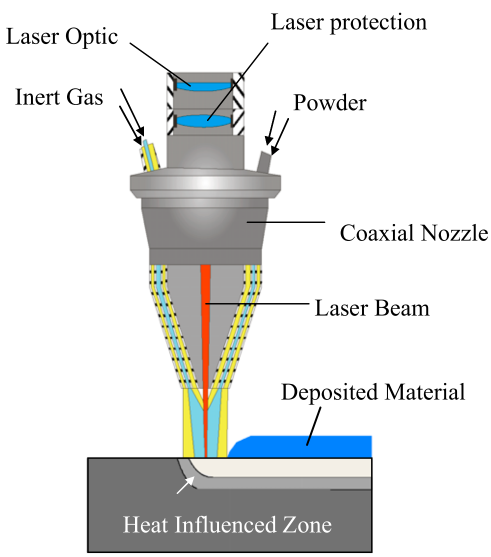

Fig. 2. Laser deposition process.

refurbishment of a blade of a turbine blisk (**Bl**ade **I**ntegrated Di**sc**) in which simulation of a 3D laser scanner being controlled by a 5-axis CNC machine followed by a simulation of an LMD process is depicted.

LMD process must be performed in a closed and fully automatic equipment in order to protect shop floor environment from the harmful effects of laser and the metal powder used during the process. An integrated laser machine system consists of a laser source, laser guidance and focus mechanisms, commonly named laser head, powder feeder and gas conveyor. In this paper we apply a powder feeder that feeds powder co-axial with laser beam and is integrated in the laser head. This type of laser nozzle achieves an isotropic distribution of metal powder on the part surface in movement. As depicted in Fig. 2 during the laser metal deposition process the heat from applied laser power melts part surface, the powder coming from powder feeder falls inside the molten pool of base metal and also melts. Upon cooling the powder builds up a deposit of the metal on the base surface. Repeated build up in several layers onto the part surface fills up a cavity area or builds up an extruded shape.

In order to establish a mechanically strong bond between base metal and deposited metal powder; relative movement of laser over parts surface, speed of laser travel, feed rate of powder and the power of laser are key factors to be controlled. These parameters are combined into a data structure and named laser path. An integrated laser machine receives laser path as input data to execute the LMD process.

In the following sections of the paper we discuss about the input data and approaches involved in the calculation of laser paths. The most significant input to the calculation is the format and accuracy of input geometry data that also determines and controls the process related factors. The input geometry in all repair and refurbishment applications is the triangulated mesh of part surface, outcome of 3D laser scanning measurement.

Triangulated mesh model of the geometry contains the polyhedral form of a free-form geometry model with faces, edges and vertices. Compared to CAD model, the mesh model cannot provide continuous and analytic information of part geometry, but only discrete data of geometric elements, and furthermore it contains fluctuation of the geometric positions due to the given data acquisition accuracy. Therefore the LMD planning process to calculate laser path for laser deposition has to handle the following aspects:

1. adaptive to various types of geometries
2. tolerant to certain level of noise in triangulated mesh model
3. fully automated calculation with minimum inputs
4. high calculation time-efficiency.

Under such circumstances a set of algorithms and numerical methods integrated in a LMD planning system have been developed which satisfy above specified requirements of a precise LMD process, and furthermore enable the automation of the process and also guarantee the result's quality by minimizing the influences of noises.

2. State of the art

In the field of laser processing technology, Keicher et al. introduced laser-aided direct metal deposition and analysed the materials and mechanical properties based on experiments with different laser set [1]. Shepeleva et al. examined laser cladding to treat the surfaces of turbine blades and compared the result in the substrate and cladded layers with that of traditional plasma cladding [2]. Mazumder et al. studied in the field of laser direct metal deposition with close loop control and demonstrated the whole process including CAD preparation and experiment procedure [3]. F. Klocke and C. Brecher from Fraunhofer IPT carried out research in scanner-based laser wire cladding with flexible adaption of specific requirements on variable parts' geometries, and laser deposition rate is enhanced and automated adaption of laser power regarding processing speed is achieved [4,5]. In [6] laser surface treatment technology with integrated computer aided technology has been researched by Fraunhofer IPT to improve the wear resistance and increase lifetime of deep drawing tools for automobile industry.

In the previous studies of CAM solution for polyhedral surfaces, Jianghuang Wu analysed the precision of milling tool's cut position on $\sqrt{3}$ subdivision surface and also presented a method to generate tool path for ball-end milling process [7]; Huan Qi and Magdi Azer describe a solution to create laser operation by defining tool path parameters based on laser technical requirement [8]; J. Radej, L. Budin and A. Milanovic examined the relation between the characteristics of triangulated mesh and accurate tool path calculation and in addition gave a method to partition triangulated mesh in order to create some basic geometries for tool path computation [9]. Another research conducted by Hongyun Du presented a geodesic path calculation method based on mesh topology, which outputs the shortest path on a mesh between two points [10]. However, these works cannot be directly applied to the laser cladding because they only partially cover the requirements of the use cases in this research.

In the field of computational graphics and topology, J. Mitchell, D. Mount and C. Papadimitriou initiated the research of discrete geodesic problems by introducing a number of lemmas that describe the geometric properties of triangle mesh and the geodesic path on discrete triangulated faces. Based on these lemmas, they proposed an algorithm (labelled "MMP") to calculate exact optimal geodesic path by constructing a data structure (so-called "*intervals*") on the edges of the triangles, which record