Manufacturing Letters 15 (2018) 1–4

Contents lists available at ScienceDirect

Manufacturing Letters

journal homepage: www.elsevier.com/locate/mfglet

Letters

Modeling of worn surface geometry for engine blade repair using Laser-aided Direct Metal Deposition process

Xinchang Zhang *, Wei Li, Wenyuan Cui, Frank Liou

Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology, Rolla, MO 65409, United States

ARTICLE INFO

Article history:
Received 30 June 2017
Received in revised form 19 September 2017
Accepted 25 November 2017
Available online 27 November 2017

Keywords:
Worn surface modeling
Blade repair
Direct metal deposition
Reverse engineering

ABSTRACT

Engine blade repair requires obtaining the worn area and generate corresponding tool path for deposition. In this paper, an automated worn surface modeling method was proposed to regain the missing volume of damaged blades. Reverse engineering was utilized to reconstruct models of blades. The reconstructed damaged model was best-fitted with the nominal model. Cross-section area comparison method was used to detect the damaged layers. Ray casting method was adopted to intersect the damaged layers to extract the missing volume. Tool path was generated and repair experiment was performed using Laser-aided Direct Metal Deposition process to validate the proposed method.

1. Introduction

Turbine and compressor blades are crucial components in modern jet engines to produce powerful thrust. The existence of unavoidable harsh working conditions including elevated temperature and pressure, impact with foreign objects (stones, bird, etc.), wear, corrosion and fatigue may damage blades prematurely [1,2]. The defects such as cracks on the blade tip and edge, distortion, creep and corrosion may significantly damage the aerodynamic performance of engines, therefore, reduce the fuel efficiency and cause safety problems [3]. Damaged blades should be replaced or repaired to maintain the crucial cross-section profiles. However, replacing damaged blades is not preferred since they are made of expensive materials, such as Titanium and Nickel-based alloys, which require special tools to fabricate [4]. Therefore, many studies have been focused on the strategies to repair worn blades using additive manufacturing (AM) [5–7] with its characteristics systematically discussed in [8,9].

An approach proposed by Jones et al. [10] integrates laser cladding, machining and in-process scanning in one machine. However, there is no discussion about how to compare the scanned model with the CAD model to generate the tool path. Also, using probe is not efficient to scan curved blades. To accelerate model acquisition process, a laser scanning system was used to capture surface points of a broken blade, which is then best fitted with the CAD model [11]. In order to extract the broken area, the distance from each of the scanned point to the nominal surface was calculated. However, the best-fitting procedure was not presented and the calculation process is time-consuming. Defect detection using Iterative Closest Point algorithm was proposed in [12] where the initially scanned data using laser scanner was registered on the CAD model. The method concentrated on point cloud matching while defect extraction was not discussed. He and Li [13] developed a curved surface extension approach to reconstruct the missing volume based on continuous curvature. This method, however, has limitations for constructing complex curved blade due to part to part defects variation.

In this paper, a worn surface modeling method is presented to regain the missing volume of damaged blades. Blade models were obtained using reverse engineering. Then the damaged model was best-fitted with the nominal model. After that, area comparison method was adopted to separate the damaged blade into intact and damaged sections. Ray casting method was used to extract the repair volume. Finally, repair experiment was performed to validate the proposed strategy.

2. General structure of worn surface modeling process

The proposed worn surface modeling process includes the following steps: (1) Model acquisition, (2) Model Best-fitting, (3) Damaged detection and extraction.

* Corresponding author.
E-mail address: xz25c@mst.edu (X. Zhang).

https://doi.org/10.1016/j.mfglet.2017.11.001
2213-8463/

2.1. Model acquisition

The model acquisition process is shown in Fig. 1. Because the dimensions of the blade are larger than the working space of the AM system, the blade was sectioned to a small piece using EDM. The sectioned blade was then fixed on a fixture and scanned using a high accuracy structure light 3D scanner (OptimScan 5M, Shining 3D) to reconstruct the nominal model. After that, the blade edge was cut using EDM to simulate the impact failure. Then the damaged blade was scanned to generate the damaged model. Because the blade surface was shiny, a developer (Spotcheck SKD-S2 Non-Halogenated Solvent Developer) was sprayed evenly on the surface of the blade prior to scanning. The models were output in STL format.

2.2. Model best-fitting

It was found that the reconstructed damaged model is in an arbitrary position and orientation with the nominal model (Fig. 2a). In order to reconstruct the missing volume, it is required to best-fit the damaged model with the nominal model. The model best-fitting process includes the following steps: (1) Surface best-fitting; (2) Convex-hull centroid best-fitting; (3) Cross-section best-fitting; (4) Model best-fitting.

Step 1: At first, points on the top surface of both models were obtained and two planes were fitted. The normal vectors of two planes were obtained, which is $\vec{n}_n = (v_{nx}, v_{ny}, v_{nz})$ for the nominal model and $\vec{n}_d = (v_{dx}, v_{dy}, v_{dz})$ for the damaged model. Both models were transformed so that the best-fitted planes are parallel to *xoy* plane. The normal vector of the *xoy* plane is $\vec{n}_{oz} = (0, 0, 1)$. This transformation can be represented in Eq. (1)

$$\vec{n}_n \cdot A = \vec{n}_{oz} \text{ and } \vec{n}_d \cdot B = \vec{n}_{oz} \tag{1}$$

Where $A(B)$ is the transformation matrix to transform the top surface of the nominal (damaged) model parallel to *xoy* plane. The aligned models were shown in Fig. 2b.

Step 2: In this step, both models were sliced with the same plane vertical to *oz* axis. This reference plane was selected so that it intersected with the damaged model at the undamaged section. The plane intersected with both models and the cross-sections were shown in Fig. 2d. The convex-hull centroid of the sliced layer of the nominal model is (x_n, y_n, z_n) and of the damaged model is (x_d, y_d, z_d). Translating vector is obtained in Eq. (2) to move the centroid of the damaged model to the corresponding centroid of the nominal model. All vertices of damaged models were processed with the translating vector in Eq. (3) and transformed models were shown in Fig. 2c.

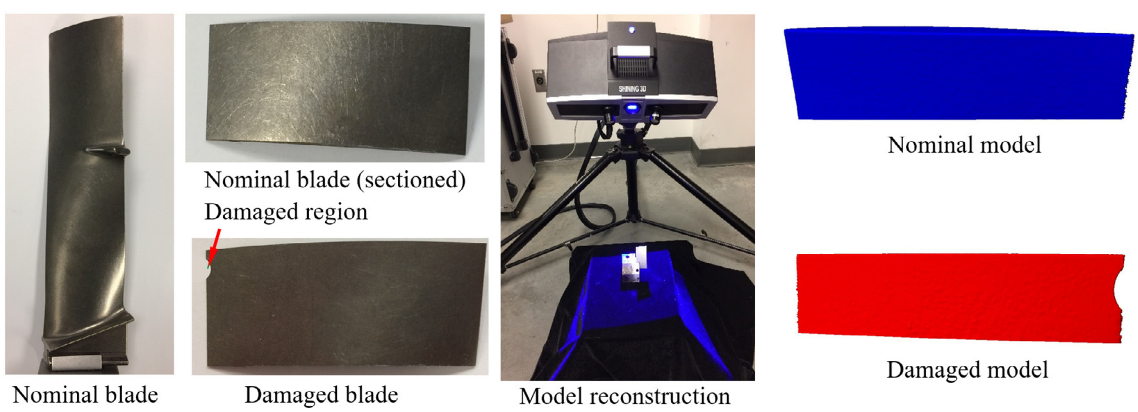

Fig. 1. Model acquisition process.

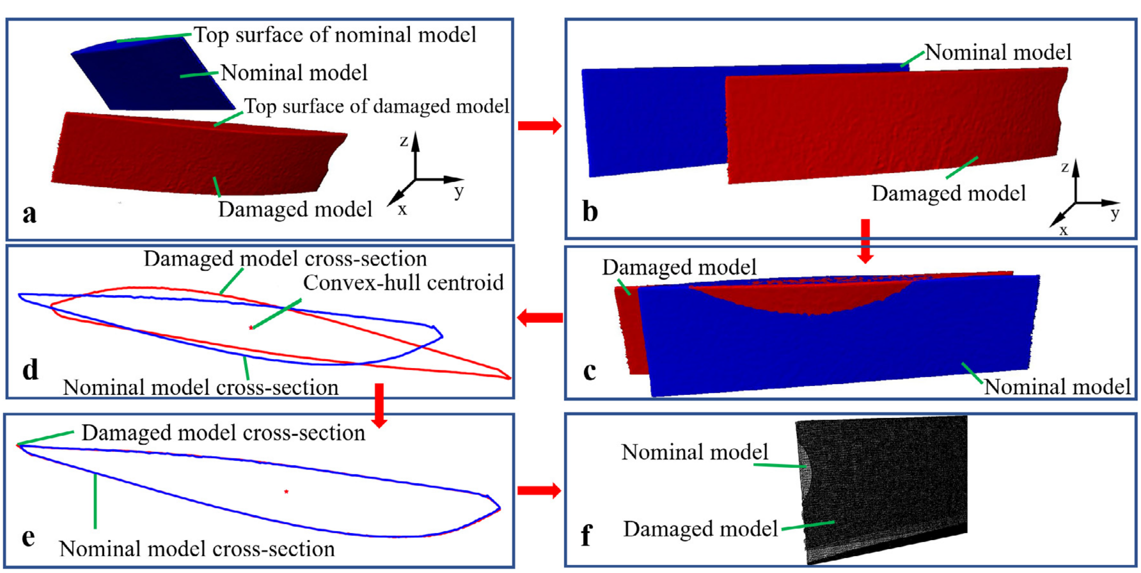

Fig. 2. Model best-fitting.