HOSTED BY
ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Journal of Computational Design and Engineering 2 (2015) 268–275

www.elsevier.com/locate/jcde

Five-axis finishing tool path generation for a mesh blade based on linear morphing cone

Rong Zhang, Pengcheng Hu, Kai Tang*

Hong Kong University of Science and Technology, Hong Kong

Received 4 March 2015; received in revised form 24 June 2015; accepted 24 June 2015

Abstract

Blisk is an essential component in aero engines. To maintain good aero-dynamic performance, one critical machining requirement for blades on blisk is that the generated five-axis tool path should be boundary-conformed. For a blade discretely modeled as a point cloud or mesh, most existing popular tool path generation methods are unable to meet this requirement. To address this issue, a novel five-axis tool path generation method for a discretized blade on blisk is presented in this paper. An idea called Linear Morphing Cone (LMC) is first proposed, which sets the boundary of the blade as the constraint. Based on this LMC, a CC curve generation and expansion method is then proposed with the specified machining accuracy upheld. Using the proposed tool path generation method, experiments on discretized blades are carried out, whose results show that the generated tool paths are both uniform and boundary-conformed.

Keywords: Five-axis tool path; Mesh; Blisk machining; Boundary-conformed; Linear morphing cone

---

1. Introduction

Blisk is an important component in aero engines. Because of their complex shapes, blades on a blisk are exclusively manufactured by five-axis machining for its unique advantage of large range of machinability and good machining accuracy.

Nowadays, tool path planning plays an important role with regard to computer-aided design, concurrent engineering and their related topics [1]. There are many existing methods for five-axis machining tool path generation, among which the most popular ones are the iso-parametric [2,3], the iso-planar [4–6] and the iso-cusp height [7–11] method. For these three methods, the tool path is generated based on the criterion of choosing a constant parameter in the machining process, i.e., either a constant u or a constant v in the parametric domain of the blade surface, a set of parallel planes with a constant step-over interval, or a constant cusp height between the neighboring Cutter Contact (CC) curves, respectively. These three methods can offer different CC curve patterns, among which the iso-parametric method is the most popular in blade machining, where the blade must be represented as a pure parametric surface. It is exactly because of this parametric representation, in which the boundary of the blade is naturally an iso-parametric curve, the iso-parametric method is able to satisfy the boundary-conforming requirement. Along with these three most common methods, there are also other machining methods aiming at achieving certain specific objectives in the machining process, e.g., good machining efficiency [12], good dynamic and kinematic behavior of the machine tool [13] and effective cutting conditions for the cutter [14], etc. However, all these methods require that the blade be represented as a pure parametric surface. Since for a blade model obtained via a 3-D scanning or CMM acquisition, it can only be represented by a point cloud or mesh, the above mentioned methods can be hardly used to machine the blade directly.

Towards the tool path generation for a discretized model (hereinafter referred as a mesh, since a point cloud can be easily constructed into a mesh), the most intuitive way is to

---

*Corresponding author. Tel.: +852 2358 8656.
E-mail addresses: rzhangab@ust.hk (R. Zhang), foxpcheng@gmail.com (P. Hu), mektang@ust.hk (K. Tang).
Peer review under responsibility of Society of CAD/CAM Engineers

http://dx.doi.org/10.1016/j.jcde.2015.06.013

modify the existing methods so as to find their application for a mesh model. With this strategy, the iso-planar method can be applied to generate tool path for a mesh model [6,15,16] because it is straightforward to calculate an iso-planar tool path by intersecting planes with the mesh. The iso-cusp height concept was also incorporated into the mesh model tool path generation [17,18] to shorten the total CC curve length. Unfortunately, similar to that in the parametric case, neither of these two adapted methods for a mesh blade is able to meet the boundary-conforming requirement. To address this conforming issue, Sun and Xu did a series of work [19–23] by re-parameterizing the mesh model into a parametric surface with a domain of a square or circular region, so did Oulee et al. [24]. By choosing iso-parametric curves in the re-parameterized domain, the boundary-conformed tool paths can be generated. The method can also be used to generate tool paths for compound surfaces. However, for this method, two sets of very large linear equations are required to be solved in the re-parameterization process, especially when the mesh is very dense, making this method very computational expensive and also prone to numerical instability. Instead of planning the tool path in the re-parameterized parametric domain, Yang et al. [25] and Li [26] directly carried out the calculation on the surface itself to generate boundary-conformed tool paths; but their methods are very complicated and difficult to implement.

To address the above mentioned issues, we in this paper propose a new method of 5-axis tool path generation for a blade represented by a mesh. This method is based on a concept called Linear Morphing Cone (LMC), which is defined according to the geometric properties of the blade on blisk. With the help of LMC, CC curves are constructed by intersecting the mesh model with the LMC. For a blisk with a cone-shaped hub, the proposed method can fulfill the boundary-conforming requirement while the specified machining accuracy (i.e., the cusp height) is upheld. The concept can also be easily extended to cases when the hub is represented by not a cone but a general revolution surface.

In the following part of the paper, the details of the algorithm of constructing the LMC will be introduced first, in Section 2; and then the tool path generation algorithm based on the constructed LMC will be presented, in Section 3; after that, experiments on two blade models will be described in Section 4; and finally we conclude the paper in Section 5.

2. Preliminary

2.1. Geometric property of blade on blisk

A blisk is usually composed of a hub with dozens of evenly distributed blades (sometime with splitters) mounted round it. Fig. 1 shows an example (of part) of a blisk with the hub and three blades. For the hub as shown in Fig. 1 (also the bottom surface of any blade), it is a surface of revolution and usually a lateral surface of a cone or cylinder. Also, for the top surface of a blade as shown in Fig. 1, it is always a surface trimmed from a lateral surface of another cone or cylinder. Thus, the two boundaries of the blade on blisk, as shown in Fig. 2, lie on two cones.

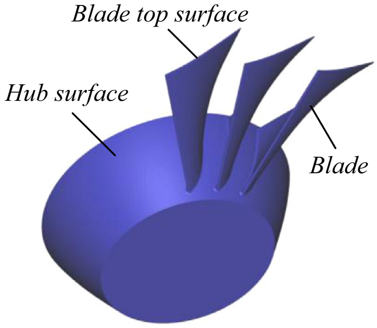

Fig. 1. Elements of a blisk.

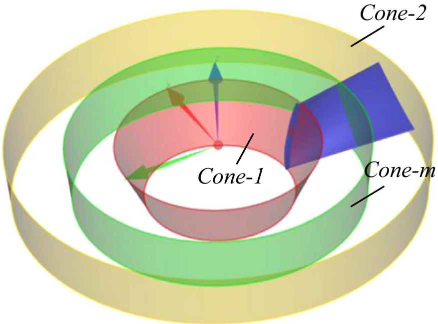

Fig. 2. Cones defined on a blade.

Note that cylinder and cone are similar to each other: both of their lateral surfaces are generated by revolving a line (also called generatrix line) around an axis for 2π degrees. Without losing any generality, we use *Cone*-1 and *Cone*-2 to denote the two revolted surface, as shown in Fig. 2.

Clearly, for a blade on blisk, *Cone*-1 and *Cone*-2 are defined according to its boundaries. The generated CC curves which are cone-conformed also conform to the two boundaries of the blade. For a cone-conforming (also boundary-conforming for a blade on blisk) tool path, the first and last CC curve should lie on *Cone*-1 and *Cone*-2, respective, while the rest of CC curves should be uniformly distributed between those two cones. Motivated by this simple fact, we can utilize the two cones, i.e., *Cone*-1 and *Cone*-2, to first generate a set of cones that linearly morph from one to the other, and then intersect them with the blade surface to generate the desired CC curves.

2.2. Linear morphing cone

For the blade model in Fig. 2, its coordinate system is defined in the center of the bottom plane, as shown in Fig. 3, where e_1 and e_2 are the bottom and top edge of *Cone*-1, respectively. Intersect e_1 and e_2 with the *X–O–Z* plane results in two points P_1 and P_2. Clearly, the line l_1 passing through P_1 and P_2 is the generatrix of *Cone*-1, as shown in Fig. 3. Similarly, the generatrix line l_2 passing through two points Q_1 and Q_2 can be found for *Cone*-2.