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Geometric error analysis of compressor blade based on reconstructing leading and trailing edges smoothly

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Abstract

In the process of blade design, the shape of blade, which causes great influence on aerodynamic performance, is the most difficult part for designer. The shape of blade changes because of the cutting force, residual stress and deformation. To analyze the precise error of this, this paper presents a new algorithm for reconstructing cross section curve of blade from measuring points. The Gauss-Newton method and dichotomy are used to fit the circle of leading and trailing edge, which is the most important part of blade. Then the deformation error, contour error and parameter error are calculated with relative algorithm based on the new cross section curve. Also, a series of points and a blade model are utilized to demonstrate the effectiveness of this novel algorithm on reconstructing cross section curve and analyzing machining error.

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Keywords: cross section curve reconstructing; leading edge fitting; blade error analyzing.

1. Introduction

As the hardest machining components among the aviation industry, aero-engine is used in the field of Nation Defense widely, and plays an important role in commercial areas. As an important part of the aero-engine, the blades are particularly important for jet engines, in order to satisfy the mechanical property, structure design and aerodynamic performance, blades need to be obtained with high manufacture precision.

Just as the history which is the development of blades shows, the development of new materials and manufacturing techniques makes blades more durable and lighter. Scholars have been studied in this area for many years. Such design improves the performance of gas turbine engine significantly, and makes a great contribution to obtain a higher contribution ratio and lower fuel consumption [1].

In the process of blade design, the shape of blade, which causes great influence on aerodynamic performance, is the most difficult part for designer. It is used to change the direction of the air flow. Moreover, for the fan blades and compressor blades, it also plays a role of boosting and decelerating. In evaluation of the aerodynamic performance of blades, improving the efficiency of air compressing, reducing the consumption of secondary flow and increasing stall margin are very important for aerodynamic performance. The goal of any blade-design method is to find a geometry that satisfies flow requirements with minimum loss, tolerable mechanical stresses, minimum disturbances downstream and upstream, and in the case of compressors adequate stall margin, among others. The design of blade geometries is a very important step for the design of efficient turbomachines, as the blade design process directly influences the blade-row efficiency and thus the overall machine efficiency.

Many researchers have studied on aerodynamic performance of blade influenced by the geometric precision of leading and trailing edges. Hamakhan [2] redesigned the original shape of the blade. Aiming at the shape of the original leading edge, he sharpened the edge and ensured the smooth attachment under the premise of constant chord length. After testing the aerodynamic performance of the blade under different attack angle (-10°, -5°, +5°, +10°), he found that the

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blade with slender leading edge did a better job in avoiding flow separation.

In the same way, Yin [3] proposed a method of continuous curvature leading edge of compressor blade. Based on cubic Bezier spline, the design only required three independent variables. Compared with circular and elliptical leading edge, the working range is enlarged by 1.2° and 2.5°, respectively. Thus the improvement of efficiency and working range was achieved.

Therefore, precise modeling technology is very important in machining and subsequent measuring. The main purpose of reconstructing cross section curve of blade, which is the curve fitted by measured points from machined blade, is to extract the shape parameters which will be compared with the theoretical parameters later. Combined with aerodynamic performance experiment, we can analyze the influence of processing error on the aerodynamic performance and aerodynamic sensitivity at different parts of the blade [4].

In this paper, based on process of the data measured in the process of machining blade, a new blade cross section curve reconstruction algorithm is proposed. Under the condition of precise measurement, this algorithm can obtain minimum fitting error while satisfy the smoothness and continuity of cross section curve as far as possible. Then the aerodynamic performance can be analyzed in the future based on the error analysis.

2. Parameters of blade

In general, the fan blades and compressor blades are the most important parts in aero-engine. Although they are in different size, substantially they contain different cross section curves, which are the basic airfoil bended by mean line. Because of the free-form surface, the structure of the blade is very complex. In order to grasp the shape of blade precisely, the designer needs to design a reasonable mean line to meet the aerodynamic characteristics of the blades. Then the original airfoil, which is symmetrical not bended, is selected to obtain thickness distribution function of airfoil. After that, different thickness is superimposed to the both side of mean line. All these theories produce one cross section curve of blade. The other cross section curves of blade are calculated from different aerodynamic performance corresponding to the height. Finally, with all these curves stacked in a stacking line, the geometry of blade is generated. Therefore, mean line and thickness distribution are the most important parameters. All these settings are to design better parameters of airfoil which determine the aerodynamic performance of blade. The geometric profile is shown in Fig.1 and some parameters of airfoil are shown in Fig.2.

2.1. Geometric profile

1. Leading edge surface. The region contacted by free stream first used to divide free stream into different surfaces.

2. Suction surface. Named as convex surface. The flow accelerates on this surface and produce a low pressure.

3. Pressure surface. Named as concave surface. The pressure here is much higher than suction surface region.

4. Trailing edge surface, where flow from suction surface and pressure surface join together.

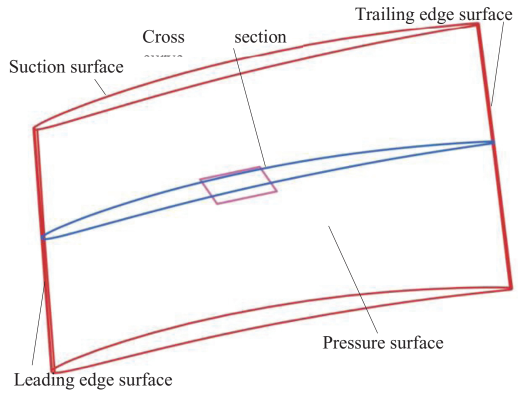

Fig. 1. The introduction of blade terminology

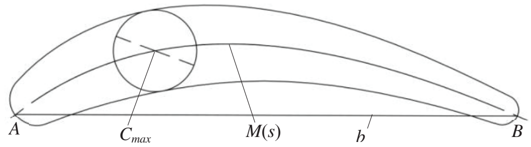

Fig. 2. Sketch of cross section curve parameter

5. Cross section curve. An intersection curve produced by a plane and blade model, which consists of four curves.

2.2. Parameters of airfoil

1. Mean line $M(s)$.

A continuous curve formed by the center points of inscribed circles of cross-section curve. It is the datum of blade design, which changes the direction of flow.

2. Leading edge point *A* and trailing edge point *B*.

The separation point of free steam when attack angle is 0 is the leading edge point. The flow converges at the point of trailing edge is the trailing edge point.

Extending mean line and getting two intersection points from leading edge curve and trailing edge curves. They are the Leading edge point *A* and trailing edge point *B* respectively.

3. Chord *b*.

The longest line of cross section curve, which is the line between leading edge point and trailing edge point. According to the definition of chord, the length of chord is easy to get.

4. Maximum thickness C_{max}.

The value of thickest airfoil, which can be expressed as the double radius of maximum inscribed circle of cross section curve.

3. The algorithm of reconstructing cross section curve

Calculating parameters is an important step for error analysis, which is based on cross section curve of airfoil. For design model or theory model, cross section curve is a lap of curves from the section of blade model. With regard to measuring data, the cross section curve is not existed. For