DEVELOPMENT OF LASER NON-CONTACT MEASUREMENT FOR TURBINE BLADE PROFILE

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Abstract: Blade is a key part that widely used in aero industry. Measurement of blade profile is very important for the quality acceptance of the blade. Development of laser non-contact measurement for turbine blade profile is presented. The laser profile measurement system is based on coordinate measuring machine. It adds r axis and CCD laser displacement sensor. Measured result was compared with CMM, the accuracy is good enough to profile measurement. It can be used to measure turbine blade profile rapidly and accurately.

Keywords: blade; profile error; laser measurement; no-contact measurement; development

1. Introduction

Blade is a key part that widely used in aero industry. Blade surface is designed by computing load of gas dynamics. In general, the profile of blade is non-regular free-form surface, which is formed by fitting several section curves, also called design curves. Working ability was decided by its geometric and size. Quality of profile affect second flow lost rate of engine and energy transfer rate. So measurement for turbine blade profile is very important [1].

There is a variety of profile measuring techniques in application in the past, such as template profile method, automatic draw-curve method, projection method, electric sense method, coordinate measuring method. Recently, there are some new method for measurement of turbine blade profile, for example, machine vision measuring method [2], four coordinate laser measuring method and laser scan measuring method.

Template profile method was used in first class inspection during blade production process. It is of lower precision and efficiency, can't give out error number. Automatic draw-curve method, projection method, electric sense method and coordinate measuring method are of high precision but of lower efficiency, the machines are very big and require a strict environment. Because of the big size of electric sense, it is impossible to arrange many electric senses closely, so some region can't be measured.

We developed a laser no-contact measurement system for blade profile in the purpose of achieving rapid and accurate measurement.

2. System description

The laser no-contact measurement system is base on coordination measuring machine. A precise rotating r axis and CCD laser displacement sensor are added. Z axis is on y axis, r axis is on x axis, as show in fig.1. X, y and z moveable axis are vertical to each other. Laser measuring device is located on z axis, blade is placed on the rotating platform with a fixing tool. By using laser measuring device to read displacement of measure points in real-time, we can get profile error of blade section.

Building up of measuring coordinate is one of the basis for profile measurement. Measuring coordinate transfer relationship is show as Fig.2.

There are five coordinates (Σ_i, i = 0~4) in measuring system, Σ_0 is blade design coordinate; Σ_1 is measuring tool coordinate; Σ_2 is rotating coordinate; Σ_3 is mechanism coordinate; Σ_4 is laser measuring coordinate. We can build up relationship between blade theory coordinate and laser measuring coordinate by computation. Profile error can be worked out from laser measuring data and coordinate relationship rapidly.

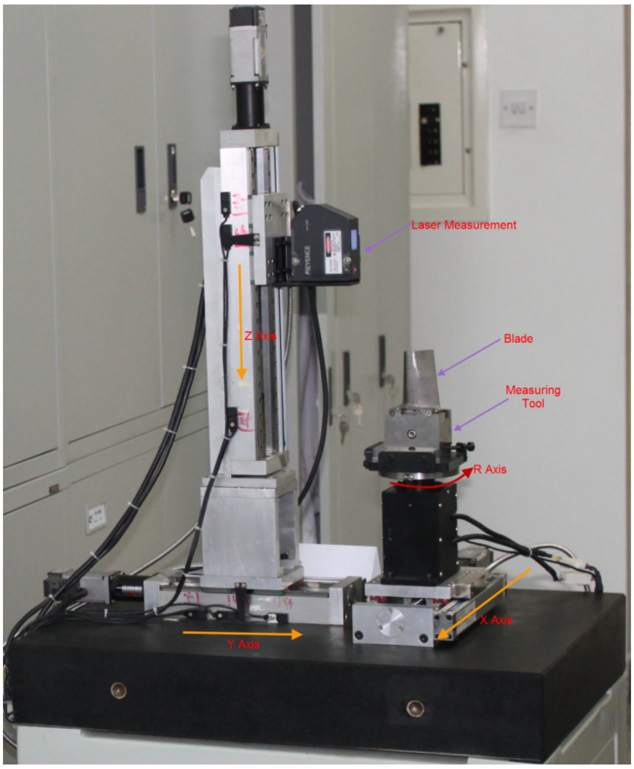

Fig. 1 Laser non-contact measuring system

Blade design Coordinate XYZ axis ⇒ Measuring tool Coordinate XYZ axis ⇒ Circumrotate Coordinate R axis ⇒ Mechanism Coordinate XYZ axis ⇒ Laser measuring Coordinate XYZ axis

Fig. 2 Measurement system coordinates

3. Key factors

3.1 Scanning Trace computing

Before using laser non-contact system to measure profile of blade, we should compute out space location of laser measurement from blade design data to establish the scanning trace of the measurement.

We select LK-G80 CCD laser displacement sensor as laser measuring device, the measuring range is

80±15mm, angle between laser beam and normal vector should less than 7.5°. So normal vector calculating must be precise.

The design data of blade section profile is inversely constructed as specified B-spline interpolation. We can get the normal vector of measure points, turn design coordinate around r axis to let normal vector parallel with y axis of laser measuring coordinate, then move x axis to position current measure point on y axis. Move y axis to allow laser measuring distance within the measuring range. Move z axis to section height. Read displacement with laser measuring device. The position deviation between measured data and design data is calculated by iterative closest point algorithm to realize optimal matching. Profile error is least distance projection on normal vector [3]. This least distance can be rapidly calculated by searching for corresponding area of measure points on design data, and then the profile error of blade section can be accurately calculated through measurement system coordinates relationship and normal vector.

3.2 Automatic matching

Affected by blade real profile, measuring tool, mechanism system etc, measuring data had some moving and rotating warp with design data, so it can't be compared directly. We can get moving and rotating warp by using iterative closest point algorithm [4, 5, 6] to realize optimal matching, then calculate the position deviation between measure points and design data.

3.3 Error analyze

Error source of laser non-contact measurement system includes mechanism error, laser measuring error, trace computing error and random error etc [7]. Orientation and verticality of x, y, z, r affects mechanism error. Laser measuring error is including linearity and lean angle; Trace computing error is including normal vector computing error and projection error; Random error is including environment temperature, humidity, atmosphere pressure, electric- magnetism, vibration etc random changing reason. Laser non-contact measurement system error can be reduced by comparison of CMM measurement and error correct method [8].

4. Experiment results

We use laser interferometer to inspect mechanism repeat accuracy. The results show as follows: X, Y, Z axis repeat error less than 0.003mm; R axis repeat error less than 0.01°; X, Y, Z axis move rang is 110×100×270mm. Laser measuring repeatability is 0.02μm, linearity is ±0.015mm. Inspecting time is about 3 min per blade, for 5 sections and 70 points per section.

In order to verify the accuracy and validity of laser non-contact measurement system, we compared laser measurement data with CMM measurement data. One example of the section profile comparison results on the same blade and fixing tool is shown in fig.3 and fig. 4. Other results of comparison are also similar.

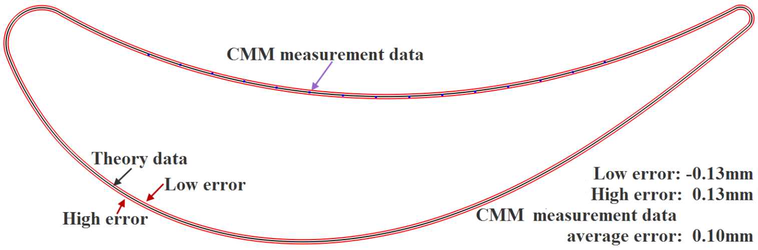

Fig. 3 CMM measurement data

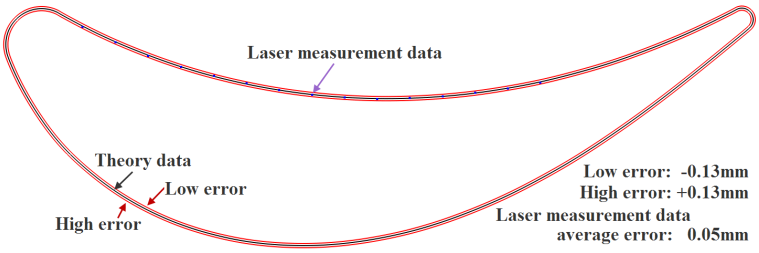

Fig. 4 Laser measurement data

Average error between CMM measurement data and design data is 0.10mm, so we know that the real blade profile is greater by 0.10mm than the designed profile. Average error between laser measurement data and design data is 0.05mm, so that the laser measurement blade profile is less by 0.05mm than real blade profile. System error is less than ±0.05mm, it is acceptable for blade profile inspection. It is possible that the system error be reduced to 0.02mm by further error correction.

5. Conclusions

Laser non-contact measurement for turbine blade profile is established based on coordinate measuring machine. The comparison of measured result with CMM shown an accuracy good enough for blade profile measurement. The system can be a useful tool for blade profile control during blade production process.

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