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A reverse engineering based approach for the repair of LP compressor fan blade

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Abstract
The aim of this research is to develop an adaptive machining strategy to restore worn fan blades. Since each worn fan blade has its unique profile, a reliable restoration model is essential and can increase the effectiveness and accuracy of the machining result. In comparison with other studies of reverse engineering which focus on enhancing the accuracy of the free-form geometry only with the surface scanning data, the approach introduced in this paper gives a different view in which the reversed engineered fan blade should be based on both its surface character and the design principle. The idea that is applied on the surface measuring strategy and data process algorithm is airfoil segment based which is the basic principle of the blade design. So, a reliable CAD model can be generated with the assist of the design principle. Moreover, this approach can further optimize the blade machining result. A computer simulation system was established. The test raw data was collected from a compressor fan blade which is available in aero engines. The simulation result showed that the restored area was in a reasonable shape and the rest of reconstructed geometry was in accordance with the real part with high accuracy.

Key words: Reverse engineering, Adaptive machining, free-form, CAD/CAM

1. Introduction

Reverse engineering (RE) is a process which produces a geometric model for the existing manufactured part. Unlike the conventional engineering which produces an artifact from a concept, in reverse engineering, a physical component can be measured, digitized, and then transfered into a model[1].

Great interest is given by MRO industry of the regeneration of jet engines because the maintenance and overhaul cost of engines takes up to 8% of the entire airplane operation cost. Within the maintenance cost, the cost for replacement of the worn blades accounts for about 50%[2]. Hence, to develop an optimal repair strategy which can restore the worn blades' functional property is a hot research topic in aerospace industry.

Many research studies have been conducted to improve the reverse engineered blades. Chen[3] proposed a modified adaptive model-based digitizing process (MAMDP) to design the CAD model of the turbine blade. This approach is CAD model based and the time cost in geometry construction for each surface patch is long. In the research of reverse engineering, Eyup Bagci[4] used CMM as the measurement technique to digitize the blade and generate the geometric model without the preliminary CAD support. The point cloud was collected and divided into different groups to generate surface paths. The surface continuity was be analyzed by iso-phote method. Reverse engineering also applied in wide chord fan blades' production of hot forming die sets[3]. Since the shape of the die deforms because of the thermal deformation during production, the idea of reverse engineering can trace the deformation of the die and repair it. The idea of the reverse-engineered turbine blades which based on design intent is proposed by Mohaghegh[5, 6]. The point denoising and 2D profile generation is according to the blade's design principle. This method beautifies the generated model at the expense of the accuracy.

This paper focuses on the repair of the leading edge of the Trent 800 low pressure fan blade of Rolls Royce. On-machine strain gauge probe measurement is adopted to digitize the surface. The design of the probing strategy and the leading edge geometry restoration are based on the blade geometry principle and repair specification. In the following subchapters, the principle of the blade airfoils will be presented. The advantage of the on-machine measurement method and the measurement and repair strategy will be explained. The analysis result of the constructed surface of the leading will be presented.

2. Design aspects of blade airfoils

Notionally, the shape of a blade is combined by a plurality of stacked airfoil segments which disposed circumferentially so that the leading edge can gain enough power when rotating. The stacked airfoil segments which viewed from a blade top and front are shown in Figure 1.

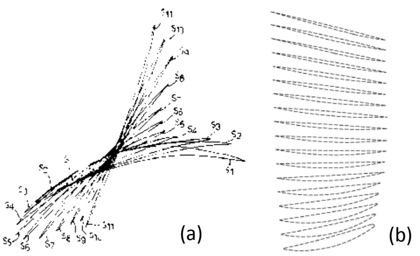

Figure. 1(a) Top view of the stacked airfoil segments for a blade[7]. 1(b) Perspective view of the stacked airfoil segments for a blade[8]

Basically, the shape of an airfoil segment has a leading edge (LE), a trailing edge (TE), a suction surface (SS), and a pressure surface (PS) (see figure 2.). The LE and TE are the arc of circles.

The profile of SS and PS are deriving from the camber line in the center.

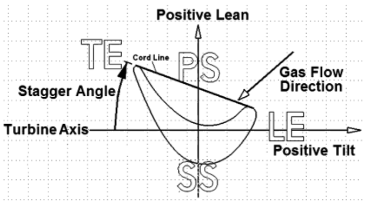

Figure 2. The geometrics of the airfoil segment[6].

The design of the probing tool path which used to collect the surface data of the compressor blade on both side of the leading edge and the profile restoration of the leading edge are relying on the basic principle of the blade.

3. Metrology

3.1. On-machine measurement

In this research, on-machine probing method is used to collect the surface data of the blade on both sides of the leading edge. The advantage of on-machine measurement is it hybrids both measurement and machining within one CNC machine so the two processes can integrate. This approach eliminates the operation of datum alignment for machining after measurement because the blade is fixed on the pallet from the start of the measurement until machining finished. So, this method is time efficient.

According to the blade definition in the previous chapter, blade surface probing points can be divided into several planes which parallel to the plane of the blade root. And since the shape of LE can be calculated from the profile of SS and PS based on the definition of the camber line, the probing points which positioned in the area near the leading edge is sufficient to gain enough references to trace the position of LE. Very limited probing points are needed in the measurement process. This method could compensate the drawback of the contact probe measurement.

3.2. Data process

After got the point cloud, points are grouped according to the plane they belong to. In each group, points are on the arc of SS and PS near LE. The curvature on SS and PS is small and from the visual point of view the two curves near LE is close to a straight line. Therefore the cubic spline interpolation can be adopted to generate the curves on SS and. Then, the area of LE can be predicted from the splines extrapolation. This prediction can be verified via probing on LE. The shape of LE is an arc of a circle which tangent to the splines on SS and PS. Then, the 2D shape of the airfoil segments can be created with known data and the 3D model of blade's LE is generated. The cutting tool path can be generated based on the new CAD model.

4. Surface test result

The free form test blade is a section of Trent 800 compressor fan blade provided by HAESL. The probe tool which mounted on the CNC spindle head is OMP400 a strain gauge probe provided by Renishaw which accuracy is 0.1μm. The CNC machine is Mikron HSM600U. The repairing simulation process mentioned on the previous chapter has been applied on this test blade without machining.

The new geometry model was checked by comparing a set of data randomly collected from the real blade surface with the CAD model. The planes which the randomly collected data belongs are in the middle of each two consecutive planes that used for surface measurement. The test is focusing on the surface accuracy near the joint curve of LE and SS/PS because the liable surface model ensures the accuracy of the repairing result. The CAD model of the measured area is shown in Figure 3. The test result (see Figure 4) shows that the point deviation is within $\pm$0.2mm. Among them, points which close to the joint curve has relatively high accuracy which deviation is $\pm$0.01mm and points which far from the join curve has lower accuracy.

This test has not considered the accuracy of the probe and the CNC machine and the measurement uncertainty. Further study should be conducted to improve the accuracy of CAD model.

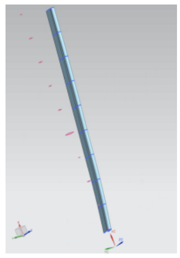

Figure 3. CAD model

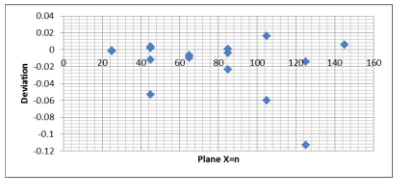

Figure 4. Check result

5. Conclusion

This case study presented a free-form blade machining approach which used the idea of blade design principle to create the measurement strategy and reverse modeling. The research focuses on repairing the worn LE according to its profile variation. The on-machine measurement method was adopted to digitize the surface character of both sides of LE which was used for the reference of LE prediction. The result shows that the machined LE has high surface continuity with SS and PS. Further study will be conducted to improve the measurement efficiency and adaptive capability.

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