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Shot Peening Method for Aerofoil Treatment of Blisk Assemblies

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Abstract

Advanced compressor designs today often include blade integrated disc (blisk) rotors, with high demands on aerodynamic performance, resistance against high load levels and foreign object damage (FOD).

To increase the high cycle fatigue (HCF) strength, compressive residual stresses are introduced into the surface and subsurface layer of aerofoil, fillet (transient area between aerofoil and disk) and annulus (intermediate area between aerofoils). For generating compressive residual stresses several different industrial production processes are used, beside ultrasonic shot peening, laser shock peening, deep rolling and shot peening wet and dry with glass or ceramic media is shot peening with steel media the mostly used technology. However, depending on the size of the component accessibility for tools might be limited and the set-up of economical production techniques challenging for blisk shot peening.

This paper gives an introduction into blisk shot peening, a sophisticated mechanical surface technology for treating aerofoil surfaces of blisk rotors using special designed calliper nozzles as solution for introducing uniform residual compressive stress states, as well as consistent shot peening coverage levels.

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Introduction

During the last 15 years aircraft engine compressors have been significantly aerodynamically improved. The design and material changed to higher performance, thus causing higher thermal and mechanical loads. Lower surface roughness and elliptical leading edge profiles are two determining factors increasing operation efficiency, the fatigue strength and the durability of the component which specify the stability of the whole engine performance.
Designs and materials that were used in the 1990th almost exclusively in military applications are now used in huge quantities at civil jet engines as well. The compression ratio has increased, while the component weight was reduced simultaneously. These performance improvements were achieved among other things by changing the design philosophy of a conventional bladed bolted rotor with inserted blades to an electron beam welded blade integrated disc design (blisk) (fig.1).

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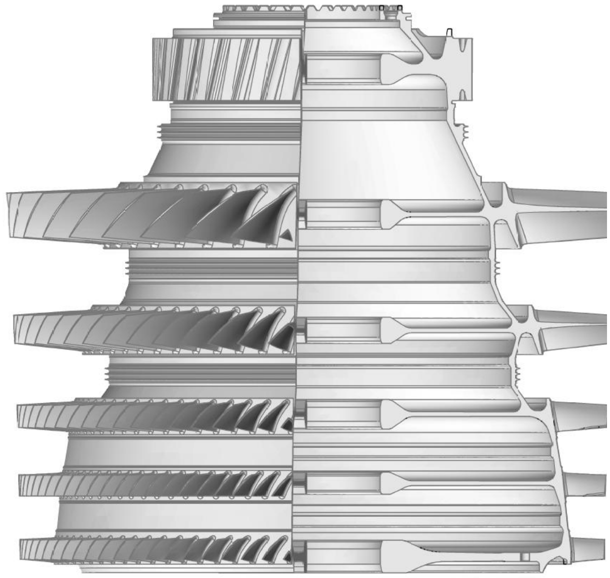

Fig.1: Rolls-Royce high pressure compressor blisk-rotor [1]

The conventional single compressor blade of bladed rotors are mounted on the circumference of the compressor disc by using fir tree or dovetail joints. Blades and discs of blisk are made out of one piece, by milling them from solid. With this design it is possible to place a higher number of blades on the circumference increasing the compression ratio while simultaneously reducing the weight in the interior area of the disc. High-strength materials like Ti64, Ti6246 and IN718 are today state of the art. These materials became necessary caused by the steady rising temperature due to the increase of the compression ratio.

As a result of the saving of the blade coupling the space between two adjacent blades is reduced significantly and the dampening effect between blade root and disc slot coupling is gone.

The conventional discs are primarily loaded by low cycle fatigue (LCF), forged or milled blades are loaded by high cycle fatigue (HCF).

In order to allow cost effective manufacture of these compressor blisk designs further manufacturing technology developments were required. Today it is state of the art to produce compressor blisks in large quantities economically by using 5-axis milling or friction welding operations. Caused by extreme operating conditions these components experience strong HCF loads as well as external influences like foreign object damage (FOD) in the blade area. These heavy loads at operating temperatures up to 600°C require appropriate counteractions. To obtain a higher strength, compressive residual stresses are introduced into the surface layer of the blade and fillet. For obtaining compressive residual stresses several different industrial production processes are used, beside ultrasonic shot peening, laser shock peening, deep rolling and shot peening wet and dry with glass or ceramic media is shot peening with steel media the mostly used technology. However, caused by the very limited accessibility for tools and flow limitations of the peening stream only a few production techniques are economically applicable for blisk shot peening.

Conventional Peening Method

Conventional shot peening is ideal for peening individual blades. Today the peening process is very productive and the key process variables are fully understood and under control. In continuous flow or satellite machines both the blade root and the aerodynamic area are shot peened. Steel media is used for blade root and glass or ceramic media for the blade surface. Accessibility for the peening stream is nearly unrestricted in this shot peening process.

Peening the blades of compact blisk or blisk rotors requires a new approach in the field of shot peening treatment. The high number of blades on the disc circumference results in a strong mutual overlap. It is almost impossible to peen with standard external peening nozzles – like conventional blade peening – both sides (suction and pressure side) consistent. Furthermore it is important to treat the area of the blade fillet with uniform coverage rates and equal intensity levels. For achieving the required intensities with this method, relatively high peening pressure is necessary and the possible impact angle of the peening stream is inappropriate. It is not possible to avoid impact angles of about 45°. This increases the surface roughness, the shape of the blade is affected and small aerodynamically necessary edge radii are deformed by the direct impact of the aggressive peening stream. Furthermore this increases the surface roughness and can induce residual tensile surface stresses. Caused by different impact angles and the direct or indirect impacts (ricochet) of the peening media onto the component surface, an individual blade can be peened with different intensities and levels of coverage

Nozzle design and application

These limitations lead to the development of a new nozzle design which enables simultaneous uniform peening of the suction- and pressure side of the blade.

To achieve this, new ways of shot peening had to be found. Special nozzle shapes, precisely adjustable KPV`s (Key process variables) and reproducible nozzle movement paths in the range of +/- 0.1 mm have to be ensured. Simultaneous peening of the suction- and pressure side of the blade is possible with a nozzle design as shown in figure 2 and 3.

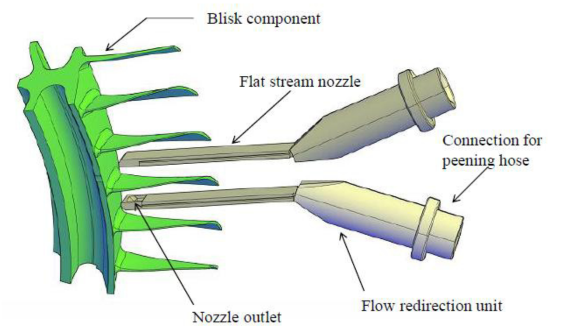

Fig.2: Scheme of a calliper nozzle for shot peening of aerofoils [1]

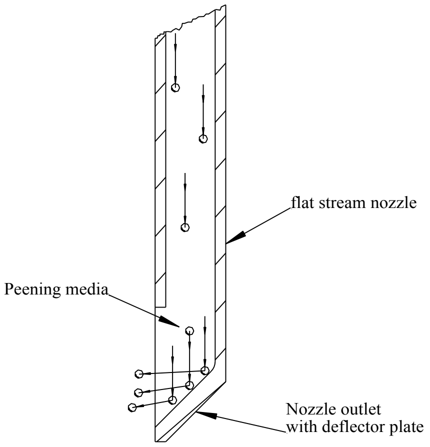

Fig.3: Nozzle outlet [1]

Caused by the design of the nozzle outlet the shot peening stream hits the surface almost perpendicular. The higher the impact angle of the shot the higher the contact area between shot and surface and the lower the plastical deformation.

This leads affected by the used shot peening parameter to an almost steady roughness (Fig. 4).

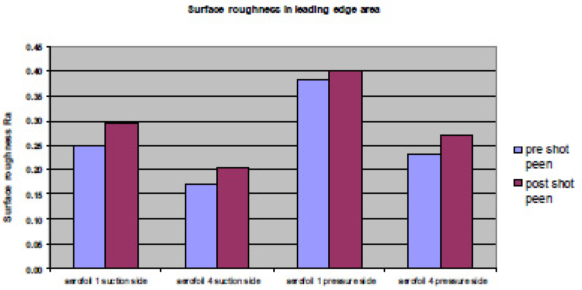

Fig.4: Surface roughness pre and post peening of a TI6246 aerofoil [1]

Caused by complex twisted 3D shapes of the actual blade design only and at least a 5-axis movement is capable to follow the blade shape. By individual parallel nozzle paths the blades are peened from the blade root to the tip. The simultaneous treatment of suction and pressure side of the blade enables a treatment without any deformation of the component. In order to ensure a uniform flow of media, the shot peening media dosage and the pressure control units have to be calibrated and the peening hoses have to be adjusted to achieve these. Due to these machine settings the medium speed is low and caused by the round medium shape abrasion of peening tools is nearly negligible. Because the distances between the blades of compact compressor rotors are very small, it is possible that the nozzle is only 2 to 3 mm away from the surface. All this, reproducible 5-axis movements and stable process parameters at low treatment pressures are required for those sensitive shot peening processes. Although the peening pressure is not greater than 1,5bar, compressive stresses are obtained as shown in figure 5 without deforming the sensitive blades. See figure 6.

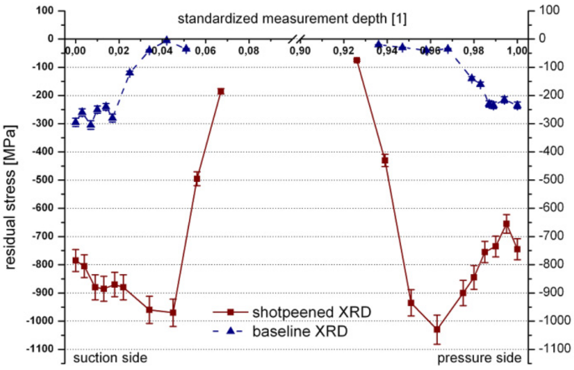

Fig.5: Residual stresses in Inco 718 aerofoil [1]

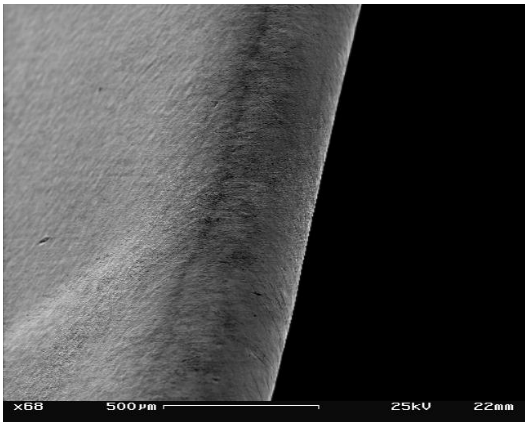

Fig.6: Leading egde post peening [1]

With this process it is possible to peen very small leading and trailing edge as well as fillet radii individually without using special equipment. Another advantage of this new shot peening method is that the shot peening media hits the surface in a controlled way and not chaotically (very low ricochets). Other components respectively blade geometries can also be shot peened with the same tools after the nozzles path is reprogrammed accordingly. Individual blade peening for e.g. repair is also possible.

It must be noted that a conventional teach in programming is not feasible for such complex tool movements. Offline programming on the basis of the CAD model of the component and the machine and an implementation via CAD-CAM system into the machine creates an optimal nozzle path evolution according to the freeform blade shape possible. See figure7.

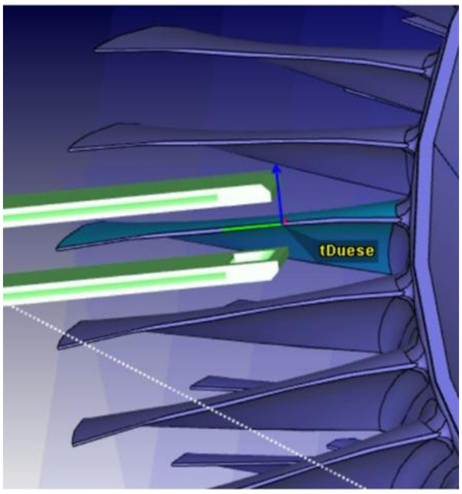

Fig.7: Nozzle path are programmed using 3 D component model [1]

For verification of the machine parameters the known and established Almen-strip-method according SAE J 442 specification is used. As the defined nozzle movement is parallel to the surface, the development of intensity curves and the intensity verification can be done on a standard Almen-strip-holder. No complex and expensive multi sample holders have to be designed, manufactured and treated because the component, Almenstrip – peening nozzle orientation is permanent the same.

Fig.8: Peening of a 4 stage blisk rotor [1]

Summary

The presented method of advanced blisk shot peening describes a process specially designed for blisk geometries which are likely to distort and show limited accessibility for shot peening nozzles. A customized nozzle design is shown, which successfully allows efficient shot peening in manufacturing and repair applications. For five years this application is in successful use for different engine types in Rolls-Royce.

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