Shot Peening Method for Aerofoil Treatment of Blisk Assemblies

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Abstract

Todays advanced compressor designs 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 laser shock peening, ultrasonic peening, deep rolling and shot peening wet and dry with glass or ceramic media shot peening with steel media is the technology used most. However, depending on the size of the component accessibility might be limited and the set-up of economical production techniques can be challenging for blisk aerofoil shot peening.This paper gives an introduction into blisk aerofoil shot peening using specially designed caliper nozzles as a solution for introducing uniform residual compressive stress conditions as well as consistent shot peening coverage levels.

Keywords Shot Peening, Fatigue Strength, Residual Stress; Surface Roughness

Introduction

During the last 15 years aircraft engine compressors have been significantly improved aerodynamically. The design and material changed to provide 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 1990s almost exclusively in military applications are now used in huge quantities in civil jet engines as well. The compression ratio has increased, while the component weight was reduced simultaneously. These performance improvements were achieved amongst others by changing the design philosophy from a conventional bladed bolted rotor with inserted blades to an electron beam welded blade integrated disc design (blisk) (Fig.1). The conventional single compressor blades of bladed rotors are mounted on the circumference of the compressor disc by using fir tree or dovetail joints. The blades and discs of a blisk are made out of a single piece, e.g. 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 state of the art today. These materials became necessary caused by the steadily rising engine temperature caused by the increased compression ratio. As a result of the elimination 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 minimized.

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. Steel media shot peening is a standard technology used. Alternatives are ultrasonic shot peening, laser shock peening, deep rolling and wet and dry shot peening with glass or ceramic. However, caused by the very limited accessibility for nozzles and flow limitations of the peening stream, only a few production techniques are economically applicable for blisk shot peening [1].

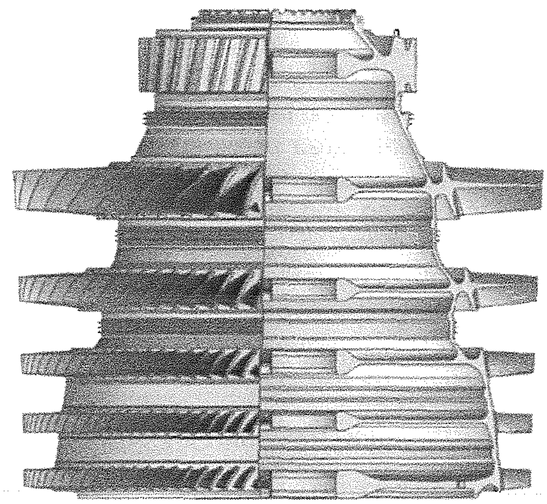


Fig.1: Rolls-Royce high pressure compressor blisk-rotor [3]

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 both sides (suction and pressure side) consistently with standard external peening nozzles – like peening of conventional blades–. Furthermore it is important to treat the area of the blade fillet with uniform coverage rates and 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 edge radii are changed by the direct impact of the aggressive peening stream. 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. Caused by the design of the nozzle outlet the shot peening stream hits the surface almost perpendicular. A higher impact angle of the shot results in higher contact area between shot and surface and by that in a lower plastic deformation. In combination with the shot peening parameter used this leads to an almost homogeneous surface roughnes (Fig. 4).

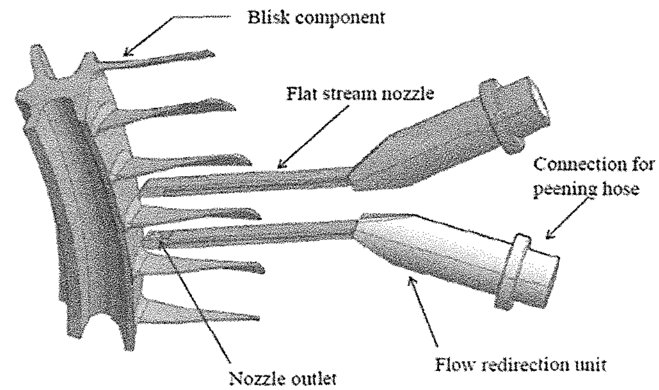


Fig.2: Scheme of a calliper nozzle for shot peening of aerofoils [2]

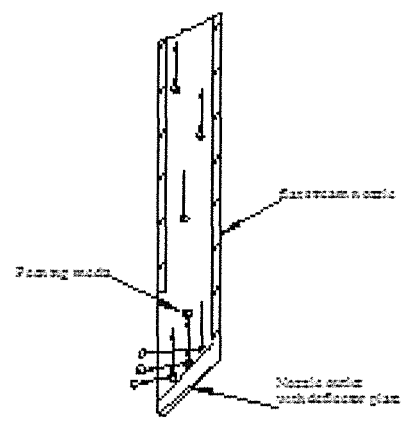
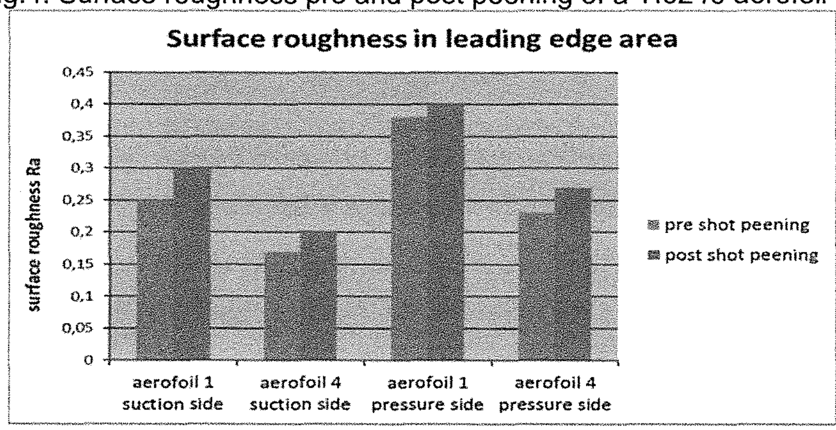


Fig.3: Nozzle outlet [2]

Fig.4: Surface roughness pre and post peening of a TI6246 aerofoil [3]



Caused by complex twisted 3D shapes of the actual blade design at least a 5-axis movement is required to follow the complex blade shape. The blades are peened from the blade root to the tip in parallel nozzle paths. The simultaneous treatment of suction and pressure side of the blade enables a treatment with minimum 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. Due to these machine settings the media speed is low and abrasion of peening tools is nearly negligible due to the round shape of the media. Due to the small distances between the blades of compact compressor rotors, it is possible that the nozzle is only 2 to 3 mm away from the surface. Therefor reproducible 5-axis movements and stable process parameters at low treatment pressures are required for a controlled shot peening process. Although the peening pressure is not greater than 1,5 bar, compressive stresses are obtained as shown in figure 5 without deforming the sensitive blades. See figure 6.

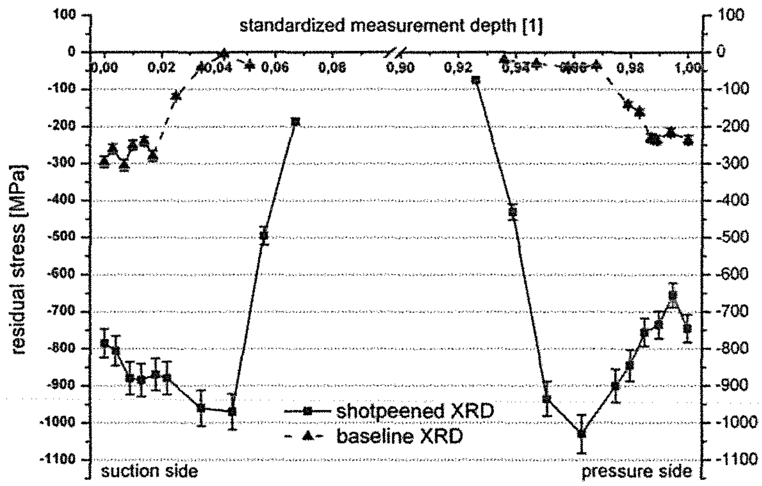


Fig.5: Residual stresses in Inco 718 aerofoil [3]

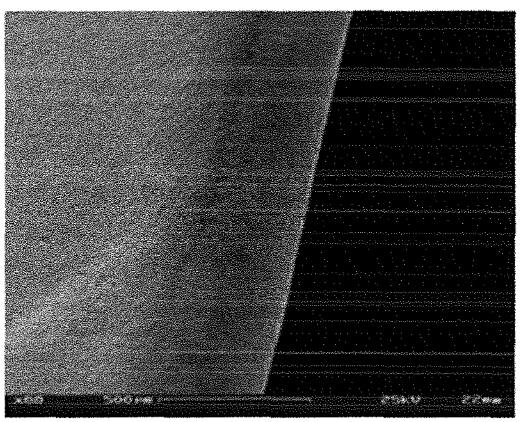


Fig.6: Leading egde post peening

With this process it is possible to peen even very small leading and trailing edges as well as fillet radii individually without using further 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 randomly (very low ricochets). Other components respectively blade geometries can also be shot peened with the same tools after the nozzles path is programmed accordingly. Individual blade peening for repair application is also possible.

It must be noted that a conventional teach in programming is not feasible for such complex tool movements. Offline programming using the 3D CAD model of the component and the machine and an implementation onto the machine using a CAD-CAM system creates an optimum nozzle path according to the freeform blade shape. See figure7. For verification of the machine parameters the known and established Almen-strip-method according to 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 kept constant throughout the entire process.

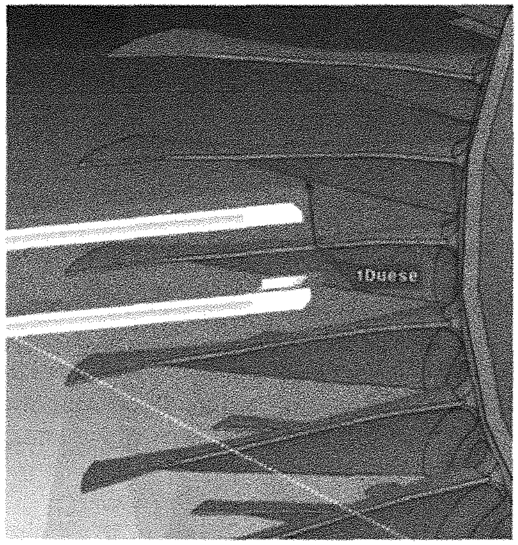


Fig.7: Nozzle path are programmed using 3 D component model

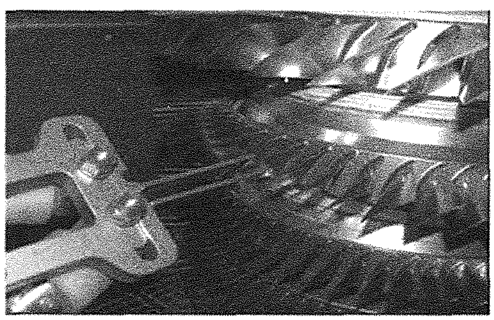


Fig.8: Peening of a 4 stage blisk rotor

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 standard shot peening nozzles. A customized nozzle design is shown, which successfully allows efficient shot peening in manufacturing and repair applications of blisks. The application of this technology is now in use on different engine types in Rolls-Royce.

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