A Shot Peening Method for Aerofoil Treatment of Blisk Assemblies

This report gives an introduction into the sophisticated mechanical surface technology for treating aerofoil surfaces on blade-integrated disc rotors. The invention of the described caliper nozzles (fig.2) solves the difficulty of introducing uniform residual compressive stress states, as well as even coverage levels.

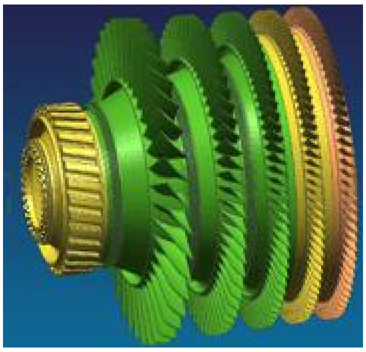

Fig. 1: Five stage compressor blisk drum

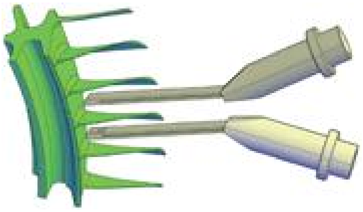

Fig. 2: Peening tool

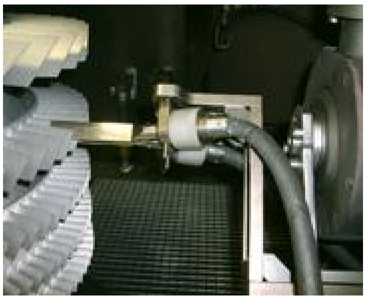

Fig. 3: Example of an application

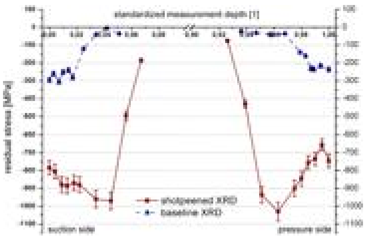

Fig. 4: Achieved residual stress profile

During the last decade, aircraft engine compressors have been aerodynamically improved. The designs and materials 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 1990s almost exclusively in military applications are now used in civil jet engines as well. The compression ratio has increased, while the component weight has reduced simultaneously. These performance improvements were achieved among other things by changing the design philosophy of a conventional bladed rotor with inserted blades to a bladed integrated disc design (blisk) (Fig.1). The individual compressor blades of bladed rotors are mounted on the circumference of the compressor disc by using fir tree or dovetail joints. Blades and discs of blisk rotors are made out of one piece, either milled from a solid block or friction welded. 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 Ti6246 and IN718 are state of the art today. These materials became necessary owing to the steadily 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.
Conventional discs are primarily loaded by low-cycle fatigue (LCF). Forged or milled blades are loaded by high-cycle fatigue (HCF).

For manufacturing these new designs, cost-effective further developments of manufacturing technology programs were necessary. Today, it is state of the art to produce compressor blisks in large quantities economically by using 5-axis milling or friction welding operations. Owing to 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 in place, such as glass-, ceramic-wet-peening, ultrasonic shot peening, laser shock peening and deep rolling. However, because of the very limited accessibility for tools or peening streams, only a few production techniques are economically applicable.

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 blisks or blisk drums requires new approaches 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) and the important area of the fillet of the blades without different coverage rates in the exposed and covered blade areas. For achieving the required intensities with this method, relatively aggressive machine settings are necessary and the possible angle of impact 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 little 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. Because of different impact angles and the direct or indirect impacts of the peening media onto the component surface, an individual blade can be peened with different intensities and levels of coverage.

The solution might be simultaneous peening of the suction- and pressure-side of the blade which would eliminate these disadvantages.
To achieve this, new ways of shot peening have to be undertaken. Special nozzle shapes, precisely adjustable machine parameters 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 Figures 2 and 3. Owing to the design of the nozzle outlet, the shot peening stream hits the surface almost perpendicularly whereby the surface roughness remains constant in the range of Ra 0.4 microns. Because of the complex twisted 3D shapes of the actual blade design, only (and at least) a 5-axis movement is capable of following the blade shape., The blades are peened from the blade root to the tip by individual parallel nozzle paths without any deformation of the component. Because the shot stream hits the surface of the whole blade almost perpendicularly, moderate peening parameters have to be used. In order to ensure a uniform flow of media, the shot peening media dosage and the pressure control units have to be calibrated really accurately. Due to these machine settings, the medium speed is low meaning the round medium shape abrasion of peening tools is nearly negligible. Because the distances between the blades of small 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) is required for the filigree shot peening processes. Although the peening pressure is not greater than 2 bars, compressive stresses are obtained as shown in Figure 4 without deforming the filigree blade. With this process, it is possible to peen very small fillet radii individually without special equipment. Another advantage of this new shot peening method is that the shot media hits the surface in a controlled way and not chaotically (very low ricochets). Other components such as blade geometries can also be shot peened with the same tools after the nozzle paths are reprogrammed accordingly.

It must be noted that a conventional teach-in programme 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 makes an optimal nozzle path evolution according to the freeform blade shape possible.

For verification, the machine parameters of the known and established Almen-strip-method are used. Owing to the defined nozzle movement parallel to the surface, the development of intensity curves and the intensity verification can be done on a simple Almen-strip-holder. No complex and expensive multi-sample holders have to be designed, manufactured and treated because the component - Almen strip–peening nozzle orientation - is permanently the same. A patent has already been applied for the nozzle design and the shown peening treatment on blisk and blisk-rotors (EP 2 093 021 A1).

Author: Wolfgang Hennig
For Information:
Rolls-Royce Deutschland Ltd & Co KG
Hohemarkstr. 60-70, 61440 Oberursel, Germany
Tel. +49.6171.90.6875
Fax +49.6171.90.56.6875
E-mail: **wolfgang.hennig@rolls-royce.com**
www.rolls-royce.com