Application of Vibropeening on Aero-Engine Component

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Abstract

The ball pressure polishing or Vibropeening method is one of famous polishing methods mainly used for treatment of car wheels or various types of furniture and cutlery. Together with the surfaces improvement without material removal as an optical embellishment this method enables hardening of component surfaces due to introduction of residual stresses by the “knock” effect of the media vibration. The hardening effect has not been studied in detail so far. Vibropeening could be used on aero-engine components as an alternative technology to shot peening and vibropolishing, which allows reduction of cost especially on complex geometry parts such as blisk. This paper describes the treatment of test components for understanding of key process variables and the method applied for process evaluation. Special attention was paid on investigating the correlation of process parameters and surface properties of compressor blades.

Variation of process variables in vibropeening achieved a significant increase of residual stress level - comparable with shot peening - on compressor blades.

Keywords: mechanical surface treatment, vibropeening, shot peening, vibropolishing, residual stress, fatigue strength, blade integrated disk (blisk)

1. Introduction

Aviation industry sets standards to performance effective design, lightweight construction and cost efficient manufacturing. During the last 15 years the design of high pressure compressor (HPC) drums changed from conventional bladed bolded drums to multistage electron beam welded blade integrated disk (blisk) rotors. This design change enabled a significant weight reduction combined with a increase of engine performance. Modern HPC rotors (see Fig. 1) have to resist heavy loads caused by a combination of cyclic mechanical and thermal loads as a result of high rotational speeds, instable aerodynamic forces, and high compression ratios. [1] These loads are effective against the blades which thicknesses are progressively decreasing caused by aerodynamic design and lightweight construction. The demand for high compression ratios, small compressor sizes and material saving design causes the need of reducing component dimensions as well as raising the number of blades per stage.

Decreasing accessibility combined with increasing demands for aerodynamic and product life cycle performance brings current mechanical surface treatment technologies to their limits.

Today's typical requirements for HPC aerofoils are a low surface roughness of $Ra \leq 0.25 \mu m$ and elliptical leading edges for performance reasons as well as appropriate high cycle fatigue (HCF) life. To achieve these partly competitive requirements more then one surface modification process are needed today. One applied solution is shot peening of the aerofoils followed by vibropolishing. Shot peening is used to introduce the desired compressive residual stresses but typically
increases the surface roughness. Vibropolishing improves the roughness, but might impact the shot peening effect and influence the leading edge geometry by material removal.

Fig 1: Rolls-Royce Trent XWB 3 stage high pressure compressor blisk-drum [2]

This paper describes the current used processes shot peening and vibrofinishing as well as the development of the alternative process vibropeening. Vibropeening enables a simultaneous creation of the desired surface and subsurface condition in one process step.

Results discussed cover surface roughness, residual stress profiles, high cycle fatigue life, part geometry as well as process cost.

2. Surface Modification Processes

Common technologies for increasing residual compressive stresses in compressor blades are shot peening, deep rolling, ultrasonic peening or laser shock peening. Each technology is experienced in single blade or blisk treatment but none of these technologies except for shot peening is currently used as a standard manufacturing method in multistage blisk rotors. [3, 4]

The main challenge looking at alternative technologies in mechanical surface treatment is the lack of space between the blisk stages and their blades as well as the required HCF strength of the component as described above. [6]

2.1. Shot Peening

Conventional shot peening is commonly used to introduce compressive residual stresses in a wide variety of applications using steel, ceramic or glass peening media. Key process variables are the impact of the media particle on the surface influenced by the media itself (mass, hardness, size, shape and velocity) and the surface coverage, i.e. the number of hits on the surface. [3, 5]

For peening of blisks or blisk drum aerofoils it needs to be considered that accessibility is a concern and the typical impact angles around 90° are hardly achievable for all areas of the aerofoils especially for small high pressure compressor blisk assemblies. Furthermore distortion of thin aerofoils has to be minimized and elliptical leading edge geometry must be sustained.

To achieve that a calliper nozzle for shot peening has been developed and patented to enable simultaneous peening of the suction and pressure side of an aerofoil. An increase in surface roughness which results in the need of further processing aiming for a decrease in roughness is the major disadvantage of shot peening.

Fig 2: scheme of a calliper flat jet nozzle for shot peening of aerofoils [2]

2.2. Vibrofinishing

Vibrofinishing or vibropolishing is a widely used media finishing technology, in which components are immersed in a bowl containing a polishing mixture made out of polishing chips (ceramic or plastic), abrasive paste, compound and water. The round or tub vibrators are common machine concepts used for the treatment (Fig.3). Due to vibration of the bowl the vibrations are transferred to a polishing media and cause the media flow round the work piece. Two types of media movement are realized in the bowl – circulate around in a vertical plane while moving forward around a vertical axis in a horizontal plane.

The relative movement of media particles leads to interaction between chips and component surface resulting grinding, deburring, polishing and strain
hardening effects. In comparison to other surface polishing technologies as burnishing or chemical polishing the vibrofinishing is simpler (fewer variables for controlling, simple design), cheaper (all features treated during one processing) and environmentally friendly. The treatment of components with complicated geometry demand investigations of geometry evaluation of each features due to possible differences in media flow and influence of gravitational force.

Vibrofinishing is used for mass finishing of aerospace engine components like aerofoil parts from fan blades to the high pressure compressor aerofoils as well as single blisk and multistage blisk assemblies. [4, 6]

Caused by the measured unevenness of induced residual compressive stresses and roughness reduction above the dumping heights a horizontal vibropeening solution became necessary (Fig. 4). The horizontal vibropeening with a driven rotational shaft enables a more uniform treatment of the areas diving through the vibropeening media.

3. RESULTS

Experimental results reported are related to a multistage blisk assembly out of a nickel based alloy.

3.1. Roughness

Roughness was measured with a tactile measurement system from Mahr.

The roughness requirement targeted in this application is $Ra \leq 0.25 \mu m$. As shown in Fig 5 the input roughness after passing the process chain before the mechanical surface treatment is an average of $Ra = 0.32 \mu m$. Shot peening increases the roughness to $Ra \approx 0.43 \mu m$ which leads to the need of the additional roughness reducing process step vibropolishing which decreases the roughness below the requirement.

Vibropeening decreases the roughness comparable to vibrofinishing below the requirement. This is caused by a combination of the above mentioned peening and burnishing effect. Another investigation shows with increasing dumping heights a treatment time reduction accompanies to reach the required roughness.
3.2. Residual Stress Profiles

All of the above mentioned technologies are inducing residual compressive stresses (RCS), the standardized profiles are shown in Fig. 6.

Shot peening shows high surface RCS, a RS maximum in 25 μm depth and an influence depth of about 80 μm.

The 1st vibropeening attempt with soft media shows high surface RCS with a continuous decrease to an influence depth of about 150 μm. This is mainly generated by the unfavorable pairing between component and media hardness which leads to a shifting of the generated RCS by plastically deformation and hertzian pressure. [6, 8]

The 2nd vibropeening attempt shows surface RCS almost equal to shot peening with a bellied distribution in a depth of 25 μm equal to shot peening. The influence depth is higher than shot peening and lays about 150 μm.

3.3. High Cycle Fatigue

The results of the high cycle fatigue tests of the treated blisk blades are shown in Fig. 7. For each condition a set of 6 respectively 7 blades was tested for the 1st flap mode at room temperature. The bar on the right shows the average of each tested set.

The untreated blades show an average value of 2,47 mHz with a standard deviation of 0,10 mHz. The 1st attempt of vibropeening treatment with the soft material increases the HCF strength of the blades of around 35 % to 3,33 mHz with a standard deviation of 0,16 mHz. The results for the 2nd attempt are still outstanding. The results of the shot peening blades show an increase of 61 % to an average value of 3,97 mHz with a standard deviation of 0,18 mHz.
3.4. Component geometry

The material removal rate was defined after measurements using conventional coordination measurement systems (CMM) and optical measurements (GOM) before and after treatment.

All of the mentioned treatments affected the component geometry within the tolerances of the component.

4. DISCUSSIONS

Results reported show that vibropeening treatment reduce the roughness significantly below the requirement of Ra ≤ 0.25 μm against while shot peening increases the roughness.

Vibropeening treatment increases the residual compressive stresses of the untreated condition. A significant difference between the 1st attempt with a soft vibropeening media (media hardness slightly below work piece hardness) and the 2nd attempt with a hard vibropeening media (media hardness significant higher than work piece hardness) is visible. The 2nd attempt shows an almost equal residual stress state compared with shot peening.

The linked high cycle fatigue results show an increase of the fatigue strength for the 1st attempt of vibropeening of about 35%. The shot peening treatment leads to an increase of 61%.

Assessing all results in total it can be assumed that the 2nd attempt of vibropeening with the shown increase of the residual compressive stresses as well as the decrease of the roughness will lead in an additional increase of the high cycle fatigue strength compared to the 1st attempt.

The geometrical change as well as the material removal through the vibropeening process is negligible. Furthermore a dimensional change (wear) of the vibropeening media was not measurable.

Comparing cost assumptions for the vibropeening treatment offers a significant cost reduction potential. This is due to the fact that during vibropeening all immersed aerofoils are treated simultaneously. In contrast to that during shot peening aerofoils are treated individually.

In summary the vibropeening process offers potential to replace shot peening and vibropolishing to process blisk assembly aerofoils. Cost wise vibropeening looks attractive to replace shot peening and vibrofinishing.

5. ACKNOWLEDGEMENT

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