Dovetail Peening by the Deflector Method

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Introduction

Shot peening is finding increased acceptance as a way to provide extra assurance against fatigue crack initiation and to extend the life of rotating turbomachinery. Often the life limiting area on a turbine or compressor disk is a hole or dovetail slot, which must be peened properly to obtain maximum benefit. A method for peening the interior surfaces of a hole has been described previously.(1) The established practice of peening with external nozzles relies on uncontrolled ricocheted shot to cover areas of high service stress, such as dovetail pressure faces, which are not directly in the shot stream. This practice is sensitive to peening conditions, especially when the length of the dovetail slot is considerably greater than its width.

Controlled deflector peening has been used effectively for holes in engine components where there is a large thickness-to-diameter ratio. More recently this technique has been applied to single and double tang dovetails in compressor and turbine disks (Fig. 1,2) to assure that residual compressive stresses of substantial magnitude and depth are developed in a uniform layer over the entire dovetail surface area. This is particularly important for the pressure faces where the crush stress produced by the outward radial load imposed by the mating blade dovetail is greatest.

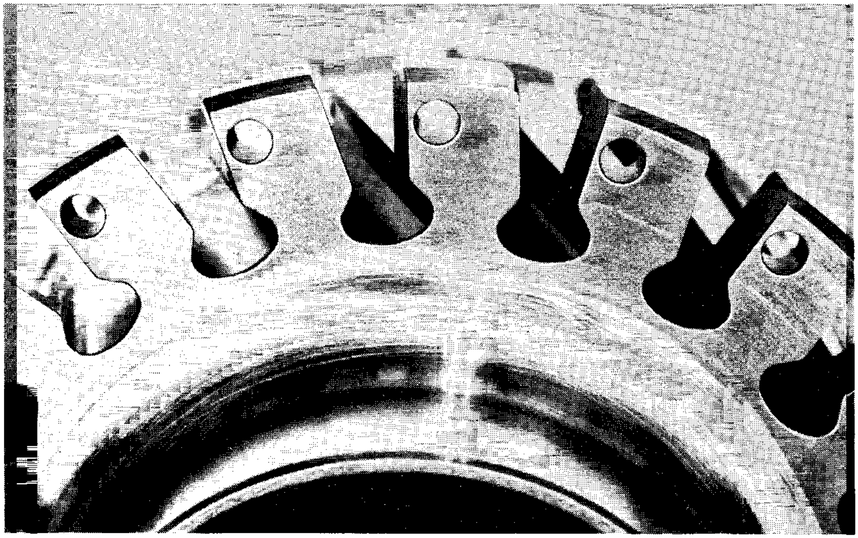


Fig. 1: Compressor Disk Single Tang Dovetails

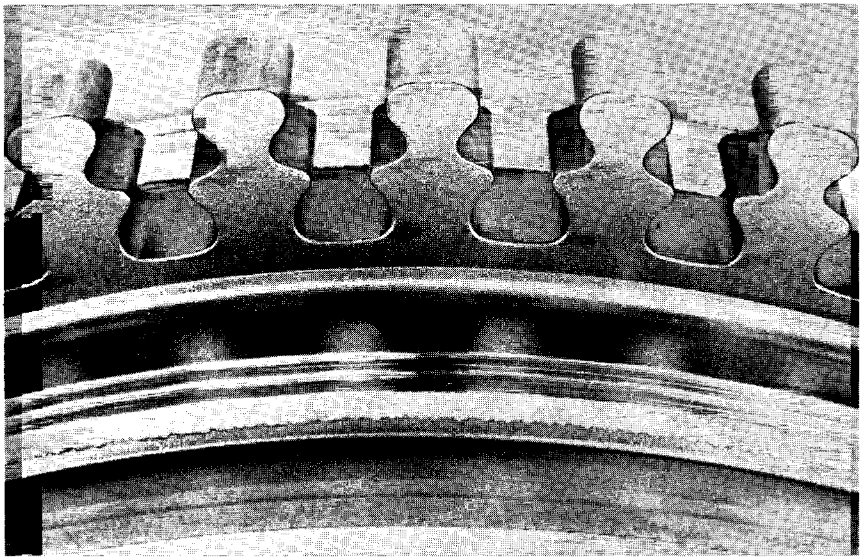
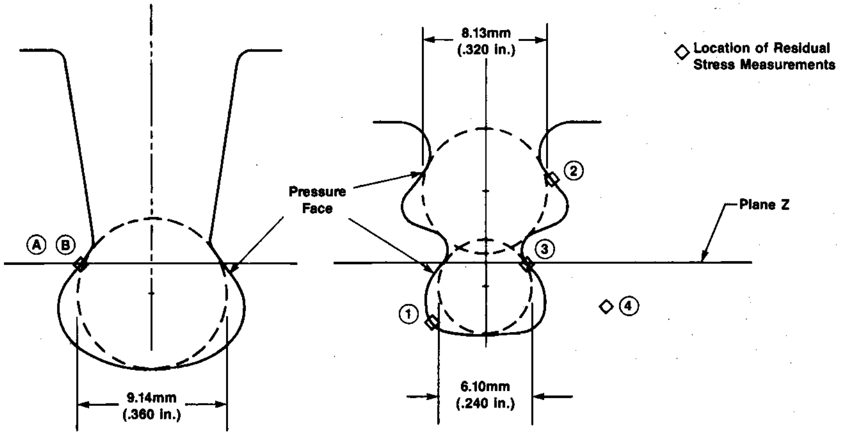


Fig. 2: Turbine Disk Double Tang Dovetails

Procedure

To establish criteria for peening the dovetail configuration in each disk, the first step was to locate a position in the dovetail tang equidistant between the design location of maximum loading on each pressure face (Plane Z) and the dovetail root. This was accomplished by scribing a circle on a layout of the dovetail cross-section (Fig. 3). A similar procedure was followed for the outer tang dovetail in the turbine disk, except that the circle scribed there nested on the inner tang protrusions. The center of each circle defined the location of the tip of the reciprocating deflector during the peening cycle.

For the compressor disk, a calibration fixture was constructed having a groove in the shape of a keyhole with a width "W" equal to that of the scribed circle diameter (Fig. 4). The radius of the keyhole is equal to W/2. A "N" Almen strip, which is to be peened in a band across its width equal to the keyhole width, was located in the calibration fixture at the base of the keyhole. A hardened steel pin was chosen to redirect the incoming shot 90° onto the Almen strip as well as the surface of the keyhole. Intensity calibration was then performed in the manner described for holes in reference (1). Calibration was based on a peening intensity of 6A using S110 cast steel shot. Peening time was 125% of the time required to achieve saturation intensity. Shot hardness conformed to MIL-S-851 (Rockwell C 42-52). In the case of the turbine disk, an existing keyhole calibration fixture used to study the effect of deflector peening on 6.45 mm (.254 inch) diameter bolt holes (1) was selected along with the fixture built for the compressor disk.



Single Tang Compressor Disk

Double Tang Turbine Disk

Fig. 3: Dovetail Configurations

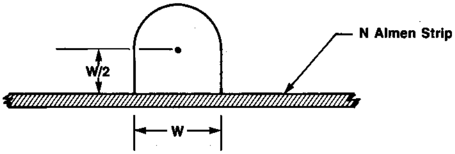


Fig. 4: Calibration Fixture Hole Geometry

Once peening parameters were established for each fixture, the number of required deflector oscillations for the turbine disk was proportioned depending on the relative circle diameter (circumference) of each dovetail tang. For example, the number of oscillations calculated for the outer tang with a 8.13 mm (.320 inch) diameter scribed circle was 8.13/9.14 or 89% of the number used to achieve peening intensity for the fixture, whose keyhole width was equal to 9.14 mm (.360 inch). Likewise, for a 6.10 mm (.240 inch) diameter scribed circle at the inner tang and using the hole calibration fixture, the corresponding number of deflector oscillations was reduced to 94%. All other parameters, including the diameter of the deflector pin, remained constant.

Disks of age hardened Inconel 718 alloy having an approximate hardness of Rockwell C43 were positioned in a holding fixture so that the deflector pin would oscillate along the axis of the dovetail as determined by the center of each scribed circle. Shot entered through a nozzle positioned against the dovetail face. Using the parameters established during calibration, each dovetail slot was peened via shot ricocheted off the deflector pin and directed 90° from its incident direction against exposed dovetail surfaces. Double tang dovetails in the turbine disks were peened with two deflectors, one for each tang, to assure development of a uniform compression zone. A liquid fluorescent tracer was used to verify surface coverage. All of the peening was performed at the Metal Improvement Company facility in Windsor, CT.

To substantiate the validity of this peening technique, residual stress-depth profiles were generated using the two inclined angle X-ray diffraction method. Diffraction measurements were made at the locations shown in Figure 3 in the axial direction of the dovetail slot. For the turbine disk, measurements were also taken on an adjacent flat surface where conventional peening was performed to a 6A Almen intensity by four nozzles positioned 90° apart and 45° to the surface of the workpiece. Where appropriate, correction factors for stress relaxation due to sectioning, layer removal by electropolishing and radiation penetration into the subsurface stress gradient were applied to the data. The residual stress work was performed at Lambda Research Incorporated, Cincinnati, OH.

Results and Discussion

For the compressor disk, X-ray diffraction measurements to determine residual stress were taken in the axial direction on the same pressure face 6.35 mm (1/4-inch) from each end (at locations A & B) of the 6.35 cm (2 1/2-inch) long dovetail slot. Measurements were also made at various depths at these locations after progressive metal removal by electropolishing to gain access to these subsurface areas. Stress data were plotted for both locations (Fig. 5).

Location A was closest to the nozzle. Both profiles show a compressive zone at least .124 mm (.0045 inch) deep and a maximum stress in the neighborhood of 828 MPa (120 ksi), .025-.050 mm (.001-.002 inch) below the surface. Stress values at the surface are 311 MPa (45 ksi) and (221 MPa) 32 ksi. The curves show that the depth of compression is quite uniform along the entire length of

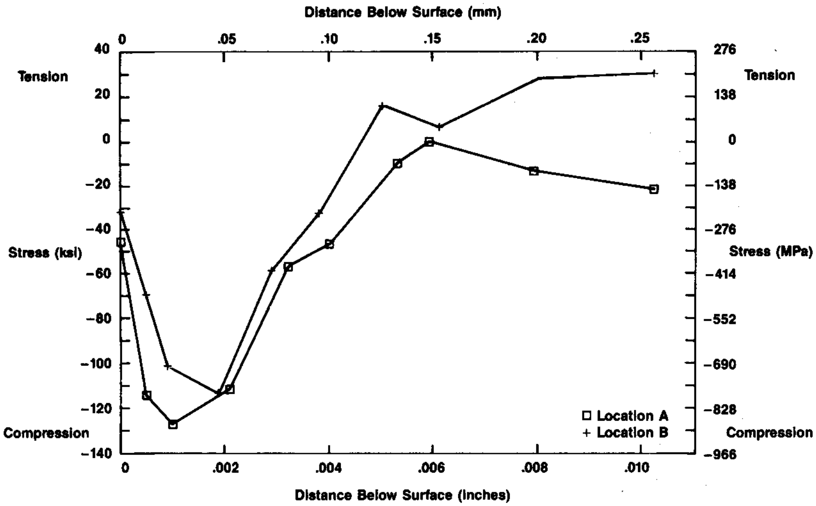


Fig. 5: Residual Stress Profile IN718 Single Tang Dovetail

the pressure face. Moreover, they demonstrate that deflector peening is capable of achieving a reproducible residual stress pattern along a dovetail slot length of at least 5 cm (2 inches), which corresponds to the distance between the points of stress measurement.

In a like manner, stress profiles were run at single points on the turbine disk double tang pressure faces and adjacent to the root in the area of maximum curvature (minimum radius). These were compared with a profile obtained by peening a flat surface to an intensity of 6A (Fig. 6).

Note that all compressive layers are at least .127 mm (.005 inch) deep. However, surface compression stress values of 304MPa (44ksi) at the minimum root radius (location 1) and 525MPa (76ksi) on an adjacent conventionally peened flat area (location 4) are less than for either of the pressure faces (815 and 849 MPa/118 and 123 ksi) but these profiles do extend somewhat deeper, especially in the region of higher compression. The tang pressure faces have much greater surface compression than observed on the compressor disk, a condition that is theoretically considered ideal from the viewpoint of retarding crack initiation. The compressor disk stress profiles near the free surface, on the other hand, exhibit the traditional stress inversion displayed by other turbine disk data.

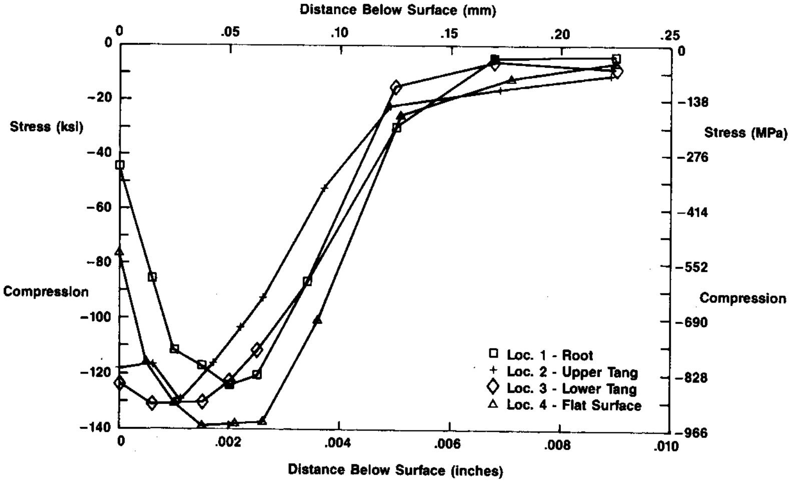


Fig. 6: Residual Stress Profile IN718 Double Tang Dovetail

In an effort to explain the absence of a stress inversion in both turbine disk pressure face residual stress profiles, the percent cold work was measured by x-ray diffraction line broadening at the same four locations. Percent plastic strain was calculated from an empirical relationship of true plastic strain obtained from tension and compression specimens.

The results, listed in Table I, show an apparent correlation between cold work and residual compressive stress, i.e., the data indicates that increasing cold work beyond some maximum value results in decreasing compressive stress at the surface. It would appear that during the peening process surface compression gradually increases to a threshold. This threshold is associated with an optimum amount of cold work which, for the turbine disk dovetail configuration and Inconel 718 material, was in the vicinity of 13 percent for the peening parameters selected. Additional cold work beyond the threshold causes a reduction in the compressive residual stress. The difference in the shape of the profile for the root radius, since it was peened with the deflector at the same time as the pressure faces, may be attributed to slight overpeening occurring from the second deflector. Unfortunately, this explanation cannot be applied to pressure face profiles for the compressor disk which was ostensibly peened under the same conditions. Undoubtedly, many variables contribute to the difference in results: shot impingement angle, shot size distribution, shot energy transfer to the part and coverage. Direct proportionment of deflector oscillations for the turbine disk using a calibration fixture having a groove width not equal to but in close proximity to the scribed dovetail circles is yet another variable to be considered.

Turbine Disk Location	Percent Cold Work	Surface Compression MPA	ksi
Inner Pressure Face*	13	849	123
Outer Pressure Face*	13	815	118
Flat Surface	17	524	76
Minimum Root Radius*	19	303	44

* Deflector Peened

Table 1: Effect of Plastic Deformation on Residual Stress

Many factors probably contributed to the manner in which plastic deformation took place as the surface topography of the material was altered. It should be mentioned that a substantial difference in surface stress has been also observed by the author in unpublished work with deflector peening of holes, and by a colleague in an unrelated study of conventional surface peening. Further work is needed to gain an understanding of the contribution made by the peening variables, separately and collectively, to the shape of the residual stress profile. There seems to be little doubt concerning the sensitivity of conditions required to achieve high surface compression in a single peening operation. It is possible that the ability to control profile shape at the near surface may be key to achieving even better fatigue performance, thereby maximizing the benefits obtainable from shot peening.

Closing Remarks

Residual compressive stress-depth data has demonstrated the effectiveness of a deflector to shot peen single and double tang dovetails in Inconel 718 compressor and turbine disks. Deflector peening is effective along a dovetail slot length of at least 5 cm (2 inches). Shape differences observed in the residual stress profile at the peened surface are believed to be related, in part, to the amount of cold work. It would appear that moderate amounts of cold work generate an almost flat stress profile in the near surface region, whereas greater amounts tend to create a stress inversion to lower compressive stress values. Apparently, there is a delicate balance between process variables for peening conditions resulting in the same Almen intensity. Certainly, more work is needed to understand the influence of these variables on the shape of the residual stress curve and to determine whether fatigue life improvement from shot peening can be further enhanced by accurately and quantitatively controlling the shape of the residual stress profile at and near the surface.

References

(1) M.B. Happ, "Shot Peening Bolt Holes in Aircraft Engine Hardware," Proceedings Second International Conference on Shot Peening (1984) 43.