Shot Peening Bolt Holes in Aircraft Engine Hardware

Marvin B. Happ
General Electric Company
Lynn, Massachusetts, USA

ABSTRACT

This paper deals with a method for shot peening deep holes in which a calibration procedure to achieve the required Almen intensity is described. The validity of the calibration procedure is established through a comparison of residual stress profiles, obtained by X-ray diffraction.

KEYWORDS

Shot Peening, Residual Stress

INTRODUCTION

Highly stressed aircraft engine components, such as super-alloy turbine disks, are shot peened to inhibit fatigue crack initiation at minute surface or near surface flaws. The parameters selected for peening the external surfaces of these parts are defined by well-known methods. Peening intensity is established using one or more Almen test strips mounted on either a scrap piece or a model of the part to be peened. A saturation curve is developed and conditions for peening the part are set forth accordingly.

Conventional peening methods cannot be applied to small diameter bolt holes in turbine disks designed with a thick web section, because of the inability to direct shot normal or near normal to the surface to produce the desired magnitude and depth of compressive stress. Since these holes are areas of stress concentration, the introduction of a residual compressive stress can have a dual benefit: retard crack initiation caused by low cycle fatigue, and inhibit the further propagation of a crack if it does form. A typical disk is shown in Figure 1. In this part, the web thickness is .817 inch (20.8mm) and the

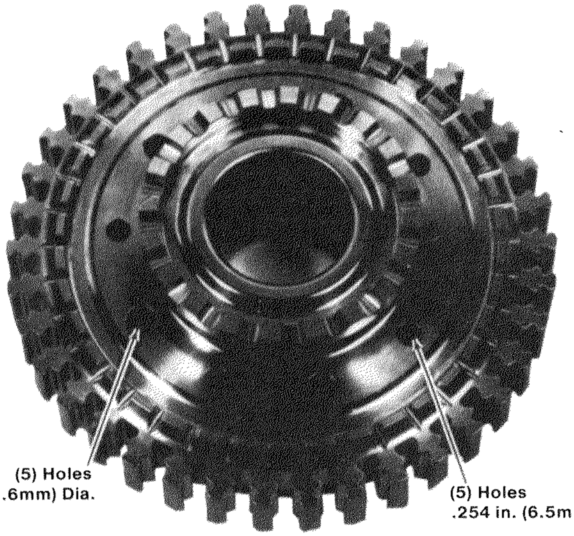

FIGURE 1 - TYPICAL ENGINE TURBINE DISK

diameters of bolt holes through the web region are .254 inch (6.5mm) and .300 inch (7.6mm). The thickness-to-hole diameter ratio is 3.2 and 2.7 respectively. A ratio of 2.0 is considered to be the theoretical limit for regular peening to be effective in a hole, assuming that the hole is peened from externally located nozzles positioned at a 45° shot impingement angle to each end of the hole.

This paper discusses a method for inducing a compressive layer in hole surfaces to reduce the probability of crack initiation. The method, referred to as deflector peening, was developed and patented by Metal Improvement Company, Inc.[1]

DISCUSSION

In the deflector peening process steel shot, propelled under air pressure through a nozzle centrally located in the hole to be peened, enters the hole and travels at high velocity until it collides with the carbide tip of a reciprocating deflector pin. The shot ricochets off the deflector pin and is redirected 90°, perpendicular to the internal surface of the hole. Figure 2 is a schematic of the process. Note that the deflector pin must be sized so that a sufficient opening exists for the spent shot to exit downward. The deflector's reciprocating action assures that there is uniform surface coverage, and reversal of the part during the process guarantees that each end of the hole is peened.

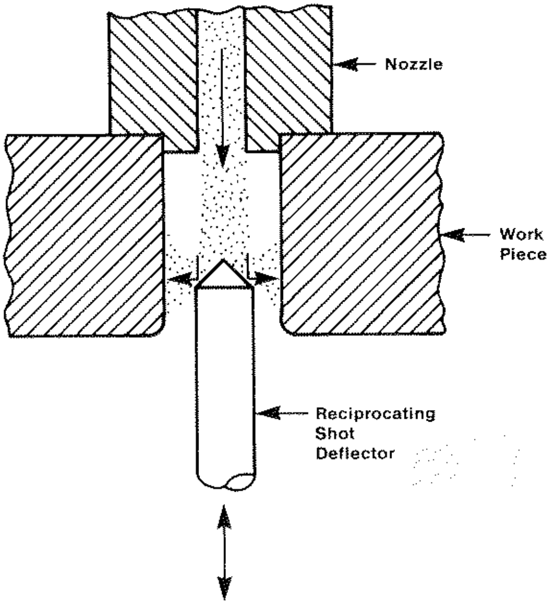

FIGURE 2 - DEFLECTOR PEENING

The calibration procedure used to obtain the proper peening intensity inside holes is illustrated in Figure 3. First, the desired arc height is obtained on an Almen A strip in a conventional manner for the peening conditions specified. This is done in accordance with the procedures specified in MIL-S-13165, using the holding fixture described therein. Thus far the procedure is identical to that used to establish peening parameters for flat surfaces. Next, a thinner N strip which has been masked, is mounted in the same fixture, but with a length (w) exposed which is equal to the diameter of one of the holes to be peened. The N strip is then peened under the same conditions and time as the A strip, and its arc height determined. Another N strip is mounted in a calibration fixture in which a single shaped hole has been made, whose width is equal to the diameter of the hole in the part. The shaped hole is semicircular, with flat sides. The distance between its center and the N strip is equal to the radius of the hole to be peened. This is a departure from Metal Improvement Company's original process in which three holes were used. The fixture is then placed on a deflector peening machine and peening parameters established which will give the same arc height as that measured on the masked N strip that was peened in the standard support block.

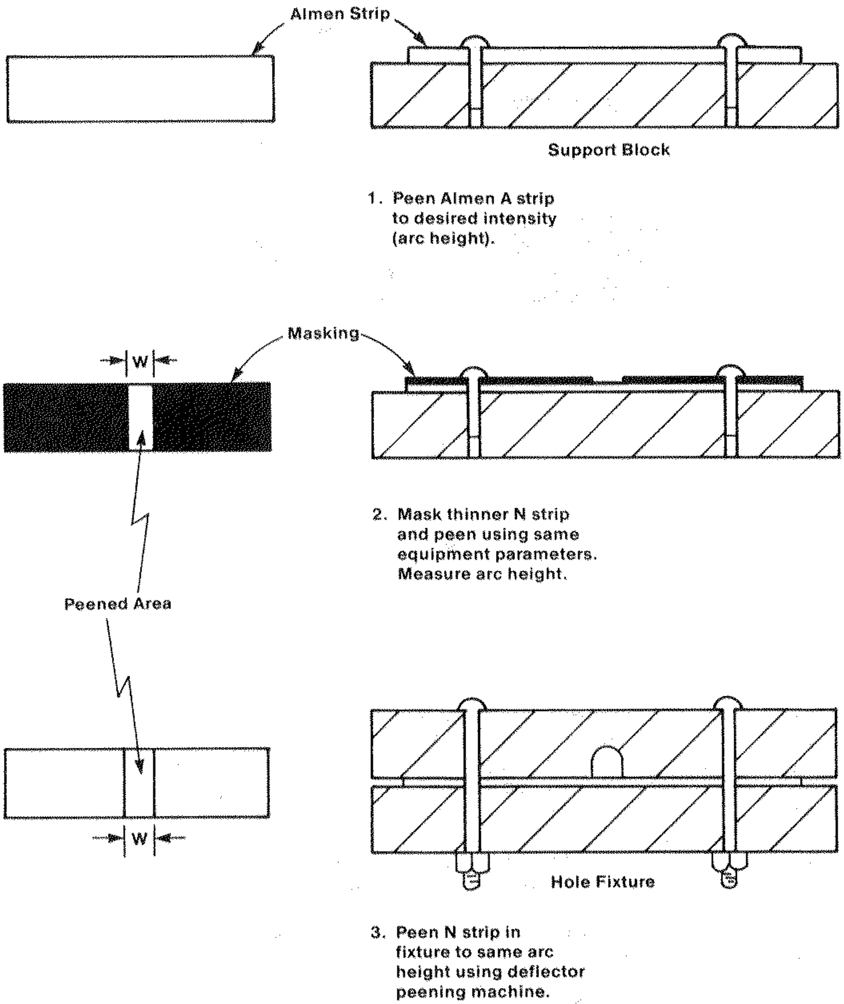

FIGURE 3 - CALIBRATION PROCEDURE

It is important, for economic reasons, that the oscillation distance of the deflector pin not exceed the length of the hole in the part. Since the speed of oscillation is fixed by the peening equipment, peening time is determined by the number of oscillations. Hence, the number of oscillations for peening a particular size hole is identical to that determined from the calibration procedure, even though the deflector travel distance may be somewhat different. Also, since the two size bolt holes in the disk shown in Figure 1 are almost the same diameter (within 20%), a calibration setup for only one hole is necessary. A proportionate number of oscillations of the deflector pin can be used for the second size hole with good approximation.

To establish the validity of the calibration procedure described above, a test part with a hardness of Rockwell C47 and a .2% yield strength of 196 ksi (1352MPa) in tension was peened using S110 cast steel shot. The shot had an average hardness of Rockwell C57, converted from Knoop hardness measurements. The Knoop readings were taken on particles of shot placed in a metallographic mount, using a 500 gram load. The same lot of shot was used to peen the external surfaces as well as the .254 inch (6.5mm) diameter holes. The part was peened under standard conditions in an 8-nozzle Peenamatic Model 613 cabinet, while the holes were peened individually using a special deflector peening machine designed by Metal Improvement Company. 1.25 times the time to achieve intensity saturation was selected to peen the part. Peening time for the part was two minutes and the intensity achieved was 7A. For the masked N strip with a narrow band peened under the same conditions, Figure 3, the intensity reading was 7N. A saturation curve was then developed for an N strip using the hole calibration fixture which was mounted on the deflector peening machine equipped with a .125 inch (3.2mm) diameter deflector pin. In an attempt to obtain a peened condition for the hole as near as possible to that for a flat surface, air pressure to the deflector peening equipment was adjusted so that the intensity reading obtained on the N strip was exactly equal to that measured on the masked N strip. Twenty oscillations of the deflector pin were required to achieve saturation. Twenty-five oscillations, 25% greater than the number to produce saturation, were used to peen the holes in the part.

The effectiveness of the hole peening process was determined by comparing the subsurface residual stress profiles for a flat surface and a .254 inch (6.5mm) diameter hole using X-ray diffraction. The hole to be measured was sectioned along its axis, and X-ray measurements taken on the hole surface at mid-thickness in the circumferential direction. From electrical strain gage measurements, stress relaxation due to cutting the metal was calculated and

X-ray values corrected accordingly. Measurements were also taken on the flat surface area adjacent to the hole, which was peened to the same intensity. Material in the hole section and on the flat surface was removed by electropolishing in incremental steps of approximately .001 inch (.025mm). After each step, the residual stress measurements were repeated on the newly exposed surface. Each of these measurements was corrected for the effects of X-radiation on the sub-surface stress gradient and for stress relaxation occurring from metal removal by electropolishing. The X-ray diffraction work was performed at Lambda Research Incorporated, Cincinnati, Ohio.(2) The results of the corrected values of residual stress are displayed as a function of subsurface depth in Figure 4. The profiles for a peened flat surface and a hole are observed to be quite similar. Surface values of compressive stress are within 10 ksi (69MPa), with the hole surface being at a higher value of 132 ksi (910MPa). Although the maximum level of compressive stress appears to be 20 ksi (138MPa) higher around the hole, at 183 ksi (1262MPa), the overall depth of the compressive layer is greater for the flat portion of the part. The zone of compression for both extends to 5-6 mils (.13-.15mm), with the transition from compression to tension for the hole occurring about .5 mil (.013mm) nearer to the surface.

One possible cause for the slight difference in the two residual stress curves is the influence of geometry of the hole versus the flat surface. In addition, X-ray measurements of lattice strain were taken in the circumferential direction for the hole - no attempt was made to determine axial values. Another and perhaps more plausible explanation is the difference in the way the shot impacted the surface of the part. For the flat areas, multiple nozzles were positioned at an angle of 45°, whereas the ricocheted shot was directed perpendicular to the hole circumference by the deflector pin. The latter method of shot impingement may induce slightly greater surface compression and achieve a higher maximum value of residual compressive stress, caused by higher impact energy of the shot, and greater work hardening of the immediate surface. The two curves, however, do bear a close enough relationship to conclude that the intensity calibration method for deflector peening is compatible with the universally accepted Almen test strip intensity calibration procedure.

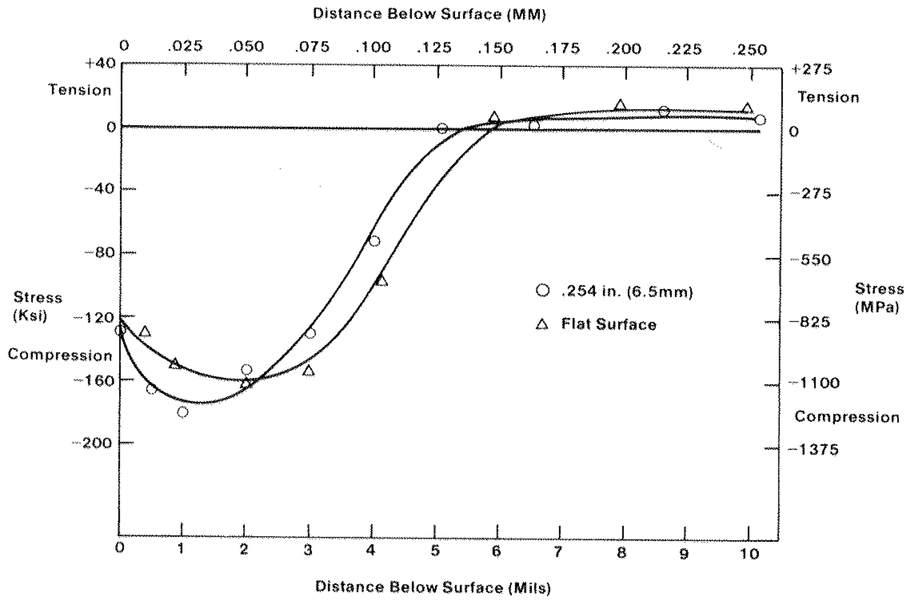

FIGURE 4 - RESIDUAL STRESS PROFILE

SUMMARY

A method to shot peen deep, small diameter holes in high strength, high temperature parts for aircraft engines has been described, followed by a detailed discussion of a calibration procedure used to obtain values in the mid A range of Almen intensity. X-ray diffraction was employed to examine the residual stresses around a hole and in an adjacent flat surface peened to the same intensity. Sub-surface residual compressive stresses were compared and found to be in good correlation.

References:
(1) U. S. Patent #3,695,091
(2) Report, Lambda Research, Inc., 1981