An Overview of Peen Forming Technology

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ABSTRACT

Curving aircraft skins by the peen forming process has replaced traditional forming methods on many aircraft types. The process has facilitated major advances in aircraft manufacturing technology.

This paper describes application techniques, process variables, limitations, applicable machine designs, and aircraft design considerations to facilitate peen forming.

KEYWORDS

Peen forming, aerospace shot peening.

INTRODUCTION

Since 1968 use of the peen forming technique to curve wing skins has been increasing so that most medium to large aircraft produced in the world today utilize this process. Peen forming ranks as one of the major advances in aircraft manufacturing technology. It not only replaces more costly methods of forming, but more easily forms tapered and sculptured skins allowing wing designs to maximize strength to weight ratios. Additionally the technique does not sacrifice material integrity.

Peen forming cannot form all conceivable shapes. The wing skin design must be compatible to peen forming.

Peen forming is capable of producing only gentle curvatures with accurate control. It is advantageously applied to the skins of the wing torque box section (between main spars) because easily produced and controlled peening intensities can form this combination of relatively thick but gently curved parts.

Attempts to form severe curves by increasing peening intensity usually lead to loss of control due to the reverse curving phenomenon (Kondo 1981) and (Kopp 1981).

The minimum thickness of skins which can be accurately peen formed is limited to the minimum peening intensity level that can be accurately maintained using small shot. Centrifugal wheels are noted for their ability to control shot velocities more accurately than air nozzles. (Baughman, 1981) It is current practice for relatively thin empennage skins to be peen formed and saturation peened simultaneously using slightly higher shot velocity on the air passage side of the skin. With this technique it is important that the skin be struck first on the air passage side to start the curve forming correctly. Otherwise the curve may develop reversed regardless of the difference in shot velocities.

Although it is possible to produce peening intensities to very high levels, the maximum thickness of aluminum or titanium that can be peen formed safely is limited to those peening intensities which do not cause surface damage.

The ability of peen forming to curve a skin panel in controlled fashion appears to be principally a function of the ratio of the depth of compressive stress to the skin thickness.

Unlike normal shot peening, peen forming specifications typically permit shot size selection, intensity, and coverage levels as required to obtain the contour. Engineering drawings may give maximums permitted. The Almen strip system is seldom used in peen forming operations.

Shot size selection will depend on type of material, thickness, amount of curvature, and roughness requirements. A highly tapered skin may require several shot sizes although this complicates peening machine design. If the peening machine is equipped with programmable controls to dynamically change wheel speed (and thus intensity) then one shot size may suffice.

The application of peen forming to a new skin design must be experimentally determined. Once a technique is properly developed, wing skins will react in the same way to the process although usually requiring minor touch-up to compensate for normal material, machining, and peening variables.

Peen Forming Machine Types

Machines built for peen forming usually employ one of three methods to project shot:

Gravity Drop - This method has been successfully used on large wing skins. It is well suited to large shot (balls) 4.76 mm in diameter or larger and can easily produce intensities to form skins to 20.0 mm and thicker. Pre-stressing may be required for compound curving.

Large balls at low velocity and low coverage produce minimum aerodynamic roughness. Skins must lie flat to maintain a suitable impact angle from the gravity accelerated shot. Clearing spent shot from the target area can be a problem. Intensity variations are accomplished by varying drop height.

Air Nozzles - These systems are best used for small skins and very low production requirements. Besides their energy inefficiency and lack of good velocity control, nozzles cannot handle large shot or balls without enlarging the nozzle diameter (usually 3+ times ball diameter). Flow capacity with nozzles using large balls is very low.

Centrifugal Wheels - These systems are well suited to peen forming since they can flow large shot volumes, handle all shot and ball sizes up to 6.35 mm diameter, have very accurate and repeatable control of shot velocity, and adapt easily to programmable controls.

The narrow pattern of shot produced with a centrifugal wheel, when aligned to part movement, is particularly useful in minimizing spheric curving when peen forming simple contours. Conversely, their long shot pattern, when aligned 90° to part movement, advantageously peens large areas quickly. Centrifugal wheels on peen forming machines can be mounted externally (fixed position) and machines utilizing up to 12 wheels mounted in this fashion are in use. For maximum aiming versatility centrifugal wheels can be located inside the machine and mounted for controlled movements about multiple axes.

Part Conveying Methods - Aircraft skins are usually conveyed horizontally when the gravity accelerated shot system is used and placed at a 35° to 45° angle to the horizontal when air nozzle systems are used. Peen forming machines using centrifugal wheels usually support the skin from tooling tabs provided on one edge (later removed). The skin hangs vertically from an overhead monorail conveyor. This system allows peening both sides of the skin simultaneously or at separate times without removing the skin from the machine. It also facilities spent shot removal from the work zone.

Lifting hoists are provided on the overhead conveyor to handle the skin for loading and unloading. One machine design mounts the skin to a load bar which is then precisely manipulated by the lifting hoists under programmable control.

General Rules

In experimental peen forming on a new skin, it is important to record each application of shot intensity, location, and coverage so that a reasonable analysis of "why the skin responded the way it did" or "what to do next" can be made. When a large skin approaches completion, it is practically impossible to visualize the myriad stress patterns already built in, especially when work has been done on both sides of the skin. When a good knowledge of the stress patterns is lost the next shot application may cause a totally unpredictable movement from which recovery may not be easily possible. These records are also necessary for duplication of the program in production after successful contouring has been achieved.

When possible, peening intensities should be selected that will achieve the forming at low coverages (10 to 40% is a good range), see Figure 1. This leaves room to increase contour with increased coverage and usually provides a useful visual record of dimples on the skin surface. It is easier to work with the coverage variable than the intensity variable.

Peen forming techniques which do not require masking or pre-stress fixturing should be explored since both these techniques are labor intensive and time consuming.

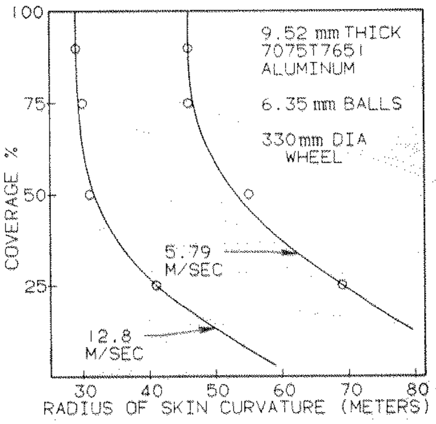

Fig. 1 Curvature vs. Coverage For 9.52 mm (.375 in.) Thick Skin

Forming Simple Contours

Skins with integral spanwise stiffeners can be peen formed in a straight forward manner using higher coverages or intensities or both on the areas requiring more contour. Normally intensities will be changed spanwise to compensate for the tapered skin thickness. Higher intensities may be required in thickened areas (doublers) designed to carry loads around cutouts, etc.

If the skin has no integral spanwise stiffeners, then techniques to avoid or correct for spanwise (spheric) curving must be considered. Some spanwise curving may be tolerated if the skin is flexible, tolerances for fit to the contour checking fixture are not tight, or the use of controlled weights is allowed on the contour check fixture.

Narrow peened strips running spanwise on common chord percent lines may reduce spanwise curving. Pre-stressing or clamping the skin in an overcurved condition on fixtures while peening also tends to avoid spanwise curving. If spheric curving develops, it may be corrected by overpeening the spanwise edges to higher intensities. The same areas on the skin back side will also have to be overpeened (but at lesser intensities). This correction works by evenly expanding the skin edges spanwise.

Saturation peening, when required, is often done in peen forming machines. On thin skins, one shot size may do both processes simultaneously. On heavier skins the operations are done separately using smaller shot (usually S-230) for saturation peening.

Forming Compound Contours

The area of an unrestrained plate subjected to even shot peening characteristically forms a spherical shape. This phenomenon is usefully employed to form the compound curvatures commonly associated with dihedral breaks (sometimes called aero breaks). These areas occur where the wing bends up or down, refer to Figure 2.

There are several methods used to form dihedral breaks. Usually the chordwise curvature is applied first. Care must be exercised in forming the spanwise contour so as not to change the chordwise curvature. A mathematical technique has been developed and is in use to predict the required peening intensities for producing the compound curvatures of dihedral breaks. The system draws from a data bank of part growth versus Almen intensity previously determined by testing (Harburn, 1982). The system is compatible to application by numerically controlled peening

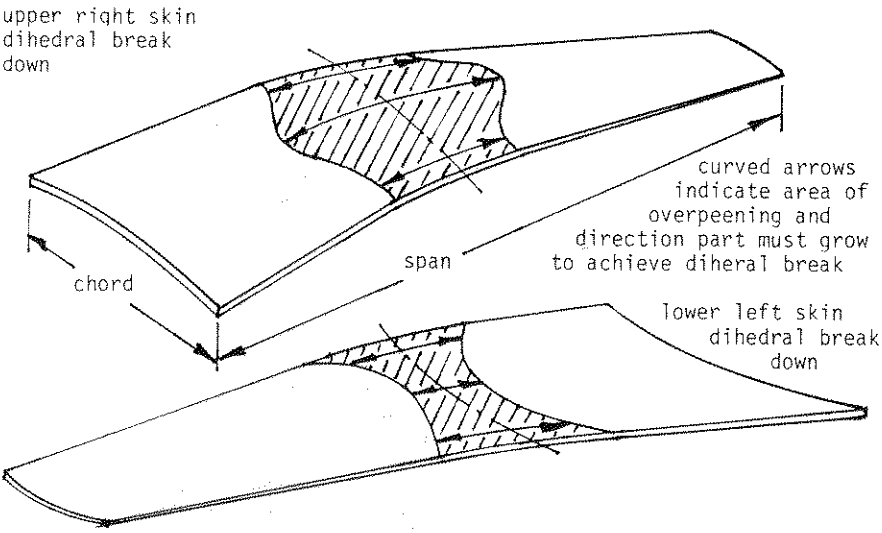

Fig. 2 - Typical Peening Application To
Form Dihedral Breaks (Compound Contours)

machines. Peening is done on both sides of the skin simultaneously. When wing design permits a sufficiently long distance in which to accomplish the break, then pre-stressing fixtures may not be required.

Peening programs necessary to form dihedral breaks are also determined experimentally and, once determined, can then be applied with peening machines using programmable controls (Baughman, 1972). Dihedral breaks usually require higher intensities achieved with larger shot than that used for chordwise curving. The areas to be peened depend on the geometry of the dihedral break. Masking may be required.

Pre-stressing fixtures, when required, should be constructed to resist the erosion from peening if long life is expected.

Minor contour corrections can be made in the peening machine or outside the machine using portable air nozzle equipment. This process usually involves locating the "touch points" where the skin rides hard on the contour templates. Raising these areas by selective peening will lower the skin to a better total fit. Correction may require peening on both sides.
The common use of weights on the contour checking fixture, when allowed, is also helpful.

Design Considerations to Facilitate Peen Forming

The advantages of peen forming over other methods of forming are so significant that design considerations to facilitate its use should be considered in the initial stages of the aircraft design.

Integral Spanwise Stiffeners are used on some aircraft but most very large aircraft and many others utilize skins free of stiffeners. Integral spanwise stiffeners may not be a problem for peen forming as long as they are located on common wing chord percentage lines so that they will remain a straight line (un-bowed spanwise) when fitted to the wing structure.

Spanwise stiffeners can be helpful as a deterrent to the tendency of peening to form spherical contours when only simple chordwise curving is required. This was the case with the wing design on which peen forming was first used (Lockheed Constellation).

Integral Chordwise Stiffeners Should be avoided since they require deformation in compression. This cannot be accomplished by peening except possibly where skins are relatively thick and the stiffeners are small.

Compound Contoured Areas or dihedral breaks are difficult to form, and the designers' goal should be to allow production of these peen formed contours without the use of costly pre-stressing fixtures.

To peen form a dihedral break, the skin must receive increased peening intensity and/or coverage near its center to achieve the required spanwise elongation while fairing to light peening at its edge or vice-versa, depending on the break geometry. Spanwise elongation is required to form dihedral breaks and since the spanwise elongation possible in short distances with peening is limited, it follows that dihedral breaks of large spanwise bend radii can be formed more easily. The designer should allow the dihedral break to be accomplished in the longest spanwise dimension possible. He should increase this dimension as the skin width, thickness, contour, or angle of break increases. Severe skin thickness changes should be avoided in dihedral break areas.

Alclad skins, used to prevent corrosion on unpainted wings, may complicate peen forming. The clad surface is softer than the parent metal and will deform more easily under shot impacts. If this surface cannot be sanded and painted, its roughness may be unacceptable. Larger shot sizes at lower velocities, and the use of hard clad materials have been used to obviate this problem.

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