THE EVOLUTION OF CENTRIFUGAL WHEEL SHOT PEENING IN THE AEROSPACE INDUSTRY AND RECENT APPLICATIONS

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ABSTRACT

Traditional methods of shot peening, with air nozzles, have been eclipsed by centrifugal wheel peening machines in many applications. New equipment designs and methods have been developed which offer high capacity, uniform coverage, and programmable control repeatability. Tests are described which prove centrifugal wheels achieve more precise shot velocity control than air nozzles while being many times more energy efficient. Special, aimable, centrifugal wheel peening systems have been developed for the aerospace industry to form wing skins to contour, improve the fatigue life of parts and prevent stress corrosion cracking.

This technology was first applied to production peening of wide body transports in 1969. Centrifugal wheel peening has since found wide application in the aerospace industry. Specific applications are presented.

KEYWORDS

Aerospace shot peening; particle velocity control; peen forming; saturation peening; centrifugal wheel peening; air nozzle peening.

INTRODUCTION

The automotive industry in the United States began to utilize shot peening on a production basis when it was discovered that the fatigue life of flat and coil springs could be dramatically improved. In time it became obvious that other parts also benefited. These discoveries were often accidental. As example; it was discovered that parts which had been shot blasted for cleaning or descaling exhibited improved fatigue properties.

Refinement of techniques to control the process and the invention of the centrifugal wheel method of throwing shot greatly increased the use of shot peening. High production requirements led to machines dedicated to peening one type of part. The high capacities of the centrifugal wheel and sophisticated part conveying systems combined to produce machine designs which could peen more than 1,000 pieces per hour.

The trend to high performance all-metal aircraft came at a time when automotive shot peening was well established.

Aircraft designers recognized the potential of shot peening to improve the integrity of metal parts. All structural parts of airplanes had to be designed to maximize safety because potential danger to human life is always present. In addition they had to be designed to be as light in weight as possible.

Shot peening prevents failures by inducing a permanent layer of compressive stress in the surface of the part, thereby reducing the magnitude of failure producing tensile stresses. At the same time it can effectively stop a stress riser from initiating failure cracks. These benefits are achieved without added weight and at relatively low cost.

When shot peening first began to be applied to aircraft parts, it was done with air nozzle systems. Air nozzle systems are relatively simple, small, and low in initial cost. The air nozzle can be manually or automatically manipulated.

Air nozzle systems were found to have some disadvantages in peening:

1. Inefficiency - They are very inefficient in terms of power required per kilogram of shot projected. Centrifugal wheels have proven to be 15 times more efficient than air nozzles. For example: a typical direct pressure air nozzle system using four 9.6 mm nozzles and operating at a pressure of $5.512 \times 10^5 N/m^2$ will project 6448 kg/hour of steel shot. This would require 103.6 kW to drive the air compressor. A centrifugal wheel system can project the same quantity of shot at the same velocity requiring only 6.7 kW.
2. Nozzle plugging - Keeping all foreign objects from the shot mix is difficult to achieve. Plugged nozzles restrict shot flow thereby reducing coverage.
3. Air pressure variations - Plant air pressure can be undependable at peak demand times. Reduced pressure will degrade Almen intensity and coverage.
4. Water - Excess water in the air can cause problems with the shot mix or with the parts being peened.
5. Uneven coverage - Air nozzles project small shot patterns and care must be exercised to achieve even coverage.
6. Noise - The high frequency noise, inherent to air nozzles, is difficult to reduce to desired levels.
7. Wear effects - Nozzle diameter increases with wear, requiring increasing air pressures and volumes to maintain constant shot velocity and flow rates.

Centrifugal wheel systems were widely used for automotive peening in the 1950's but they were not readily accepted by the aerospace industry. The reasons for this were the familiarity with air nozzle systems and a lack of understanding of centrifugal wheel systems. There appeared to be a fear of ruining aluminum or light gauge parts because of the large shot throwing capacity of centrifugal wheels. This fear was to be proven unfounded and this feature recognized as a major advantage for increasing production.

A centrifugal wheel throws a fan shaped pattern of shot. The width of this pattern is determined by the width of the throwing blades of the wheel. This fan shaped pattern can be advantageously applied in many applications. For example; multiple wheel patterns can be overlapped to achieve very close coverage and Almen control on a wide surface, without the necessity of moving or oscillating the throwing wheels. Because of the air nozzle's small conic impact pattern, they must oscillate in coordination with the part traverse speed.

A manufacturer of jet engine blades discovered that fatigue tests showed increased life on wheel peened parts versus air nozzle peened parts. Varying shot particle velocities from nozzles were postulated as a possible reason.

If shot particle velocities vary to any significant extent, it is possible that the normally thin compressive stress layer could be extremely thin or completely deficient in some areas. One of these areas could be the point where a failure crack would initiate.

The following test was conceived to study shot velocities by photographing shot particles from nozzles and wheels.

Procedure: Set up camera about 385 mm from shot stream. The lens is opened mechanically which starts the following automatic sequence, refer to Fig. 1:

1. Strobe #1 flashes for 3 micro seconds illuminating the shot at left end of "A." This strobe is monitored by a photocell which starts an electronic counter.
2. The flash delay for strobe #2 is initiated.
3. An electronic flash is triggered for approximately 1 milli second causing the streak "B" which is the guarantee that desired particle direction is known.
4. Flash delay initiated in Step 2. triggers strobe #2 which flashes for 3 micro seconds and illuminates the shot at right end of "A." This strobe also triggers a photocell which stops the electronic counter.

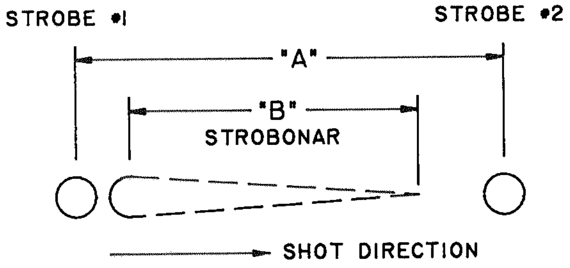

Fig. 1. Photographic method to study shot patterns.

Using this technique, photographs of shot from direct pressure nozzles showed a variation (up to 3 to 1) of particle velocities. Tests with shot from a centrifugal wheel indicated very close velocity control. This test was done with restricted shot flow for visual shot identification. To study this phenomena using full shot flows another test was prepared. The rotating disc test method for determining particle velocities was set up, as shown in Fig. 2. In this test, shot propelled at different velocities will make a wider pattern than shot propelled at a common velocity. Our test used a cardboard target plate which accurately recorded the number and location of all particle strikes. Velocity is determined as follows:

$$V = \frac{0.105\ SN}{\theta}$$

Where: V = Shot velocity in meters per second.
S = Distance between rotating discs (meters).
N = Revolutions per minute of rotating discs.
θ = Angular displacement in radians between hole in upper disc and the center point of the impact pattern on the lower disc.

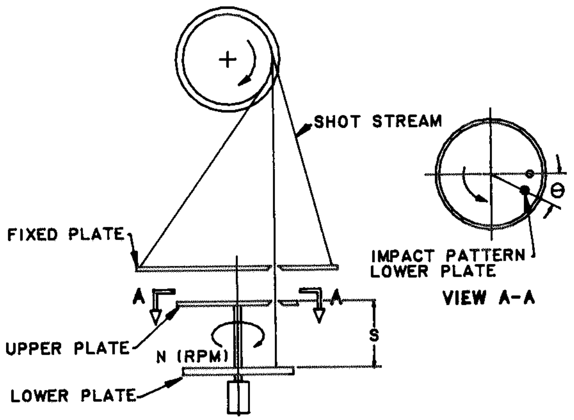

Fig. 2. Test set up for determination of particle velocity and dispersion by rotating disc method.

Figure 3. shows the test results of a 9.6 mm direct pressure nozzle and a 461 mm diameter centrifugal wheel with both operating at approximately the same average particle velocities and at normal shot flows. The centrifugal wheel results show a shorter strike pattern indicating more even particle velocities. Varying particle velocities could produce a dangerous uneven stress layer and would be undetected by the Almen strip system of intensity measurement or the visual appearance of complete coverage. Attaining better velocity control is therefore highly desirable.

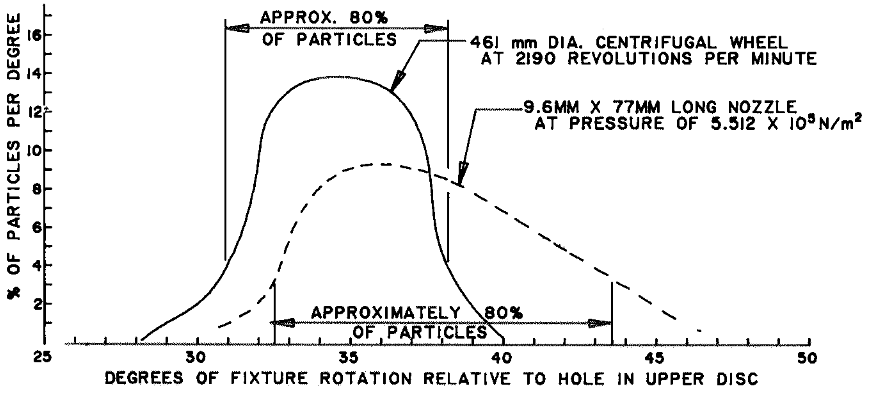

Fig. 3. Particle strike pattern of shot using rotating disc method.

The reason for erratic velocities of shot propelled from nozzles is not known. It may be caused by curved feed hoses, convergence of the nozzle entrance, uneven air flow patterns through the nozzle or other factors.

By the 1960's the development of wide body transports forced a reexamination of the capabilities of the centrifugal wheel. These large aircraft required peening to prevent stress corrosion cracking of their high strength alloys. A peen forming method was needed for thicker and larger wing skins.

The low volume shot flows of air nozzle systems were simply inadequate in the face of these requirements.

It was clear that fixed position, centrifugal wheel systems would not find wide shot peening applications in the aerospace industry. However their ability to throw large quantities of shot at very accurate velocities was needed. Therefore centrifugal wheels seemed the only logical way to meet these increased peening requirements.

What was needed was a small centrifugal wheel system which could be movably mounted totally inside a peening cabinet. It needed to be remotely aimable "like a nozzle" and have capability for variable shot velocity control. The design of such a system was begun in 1966.

The diameter of this centrifugal wheel is 333 mm and it is mounted directly on the shaft of a standard alternating current motor. The motor is encased in a steel shell to provide for protection and mounting. The wheel speed is controlled by variable frequency electronic drives and can operate at speeds from 600 to 4200 revolutions per minute. This provides very low to very high peening intensities. This drive is an extremely accurate speed control mechanism and is compatible with computer numerical control (CNC) or programmable controls. The speed signal originates in the drive, requiring no tachometer on the motor. This electronic drive, provides a level of Almen intensity control not previously attainable. Excellent control is achieved even with glass beads to low Almen "N" intensities.

For aiming versatility, a mounting system provides three axes of wheel movement. Additional horizontal and vertical movement systems can provide a total of five movements to the total system, see Fig. 4. All of these movements can be powered for remote control. Hydraulic, pneumatic, and electrically powered drives have been used. These movements may be controlled manually from the operator's panel or by pre-programmed systems. Most applications do not use all movements. In some applications more than one wheel is mounted on a supporting boom. In others, the wheel is simply mounted on the wall.

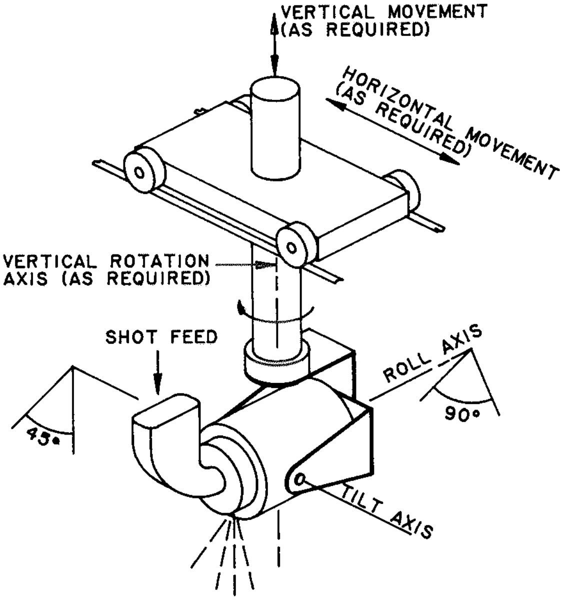

Fig. 4. The five positioning movements of the centrifugal wheel shot peening system.

The shot feed system provides full flow of shot to the wheel in all positions of movement. An infinitely adjustable, remotely controlled, shot flow gate is used with these wheels. An electronic feed back signal is generated to tell the operator exactly how much shot is flowing. The shot flow gate can be wired directly to computer numerical or micro processor based programmable control systems. Shot flow can be matched to wheel speed to achieve accurate and automatic coverage control. All control systems can be pre-programmed for various peening intensities. These controls can change the intensities at a predetermined point on the moving part. They can also accomplish shutdown for extreme faults and with the necessary peripheral equipment provide a permanent record of the program applied. Accurate monitoring of the quantity of shot flow in air nozzle systems is much more difficult to achieve.

SPECIFIC APPLICATIONS OF THE AIMABLE CENTRIFUGAL WHEEL TO AERONAUTICAL SHOT PEENING.

Jet Engine Blade Root Peening

Most blades produced in the United States are shot peened on an indexing table machine which used two centrifugal wheels mounted on special cabinet doors. The blade roots require that shot be applied from two directions. Each wheel is mounted to allow manual adjustment of its shot application angle. The blade root section is rotated in a chuck and exposed to the peening shot. These chucks rotate in pairs at the two peening stations. In this application the fan pattern of each wheel is used to peen parts at two adjacent work spindles, see Fig. 5. Two parts are completed at every table index. Smaller parts can be peened, two per spindle or four per index.

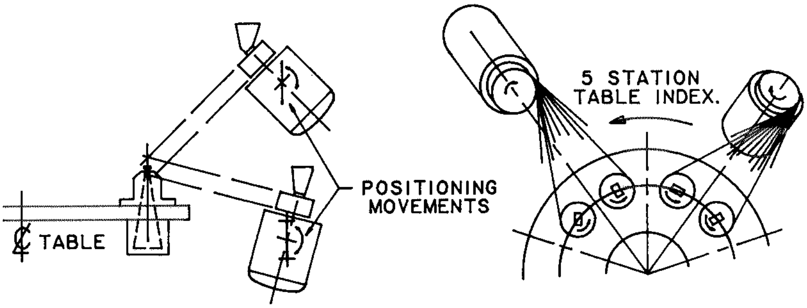

Fig. 5. Wheel positioning - jet engine blade peening.

Aircraft Landing Gear Peening

Landing gear are shot peened on a machine which uses two boom mounted centrifugal wheels. The workpiece is placed on a work car and moved under the wheel peening streams. The work car then automatically turns the workpiece 180° and traverses back through the peening streams, returning to the original load/unload position. This application replaces the four air nozzle set up where each nozzle is positioned 45° to the work, aimed at a common point, and placed in four quadrants. Because of the fan shape of the shot pattern from the wheel, no oscillation of the wheels is required during blast traverse. Two quadrants are peened in one traverse and two on the return traverse, see Fig. 6. The parts are then turned over to peen the other side.

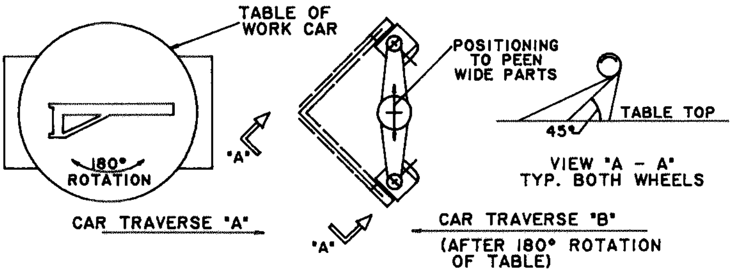

Fig. 6. Wheel positioning - landing gear peening.

Fuselage Bulkhead Peening

The machined fuselage bulkhead used for attachment of the empennage on a new transport aircraft is peened on a special machine using two centrifugal wheels. This machine carries the bulkhead horizontally on a work car with a rotating table. Both wheel shot streams apply shot, at 45° to the table top, from two quadrants on the first traverse. The other two quadrants are peened on the return traverse, see Fig. 7.

The work car accelerates as the shot target approaches the table center and decelerates as it approaches the table rim thereby applying very even coverage. The work car traverse speed is electronically controlled by a programmable system which also controls all machine parameters during peening.

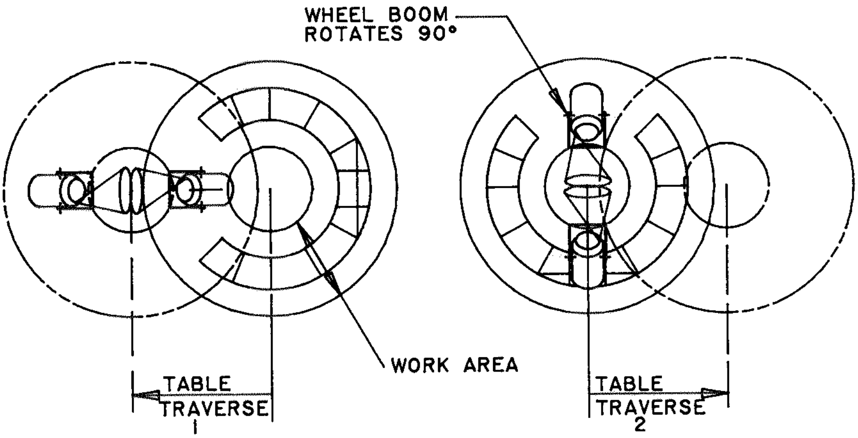

Fig. 7. Wheel positioning - fuselage bulkhead peening.

Flap Track Peening

Steel flap tracks and other parts for large transport aircraft are shot peened on a machine which uses three centrifugal wheels. The flap tracks have a long narrow cavity which must be shot peened. The external surfaces are peened in the manner of the landing gear application previously described. The deep cavity of the beams is peened by a third wheel mounted so that its shot stream enters the beam cavity. This shot is deflected by a ricochet bar to peen the cavity walls.

Peening of Aircraft Structural Shapes and Wing Skins

Most parts which make up the structural portion of the wings of a wide body transport are saturation peened and peen formed in a machine which utilizes five centrifugal wheels. These parts include the wing skins, wing rib and spar chords, and stringers up to 26 meters long. All parts are placed on a 1.83 meter wide by 26 meters long work car and moved through the peening cabinet at controlled speeds. Wing parts for a new British designed airliner are also being peened in this machine.

For structural shapes, a boom carrying four centrifugal wheels is rotated so that the shot patterns are applied to the work as shown in Fig. 8. Each wheel is rotated on its tilt axis so that the shot pattern is 45° to the work car top to cover sides and tops of parts. The boom is mounted on an overhead car which oscillates transversely to the work car movement. The workpieces must be turned over for a second pass to complete coverage. Electronic matching circuits can match and correct every boom car oscillation with the work car traverse for extremely fine coverage control.

The skins are saturation peened in this machine utilizing all five wheels. The four wheel boom is rotated 90°, see Fig. 9. Each wheel is rotated on its tilt axis to align all shot patterns transverse to the work car movement and 90° to the skin surfaces. For skin peening the wheel boom car remains stationary.

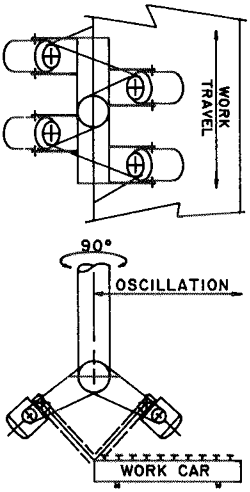

Fig. 8. Wheel positioning for peening of structurals.

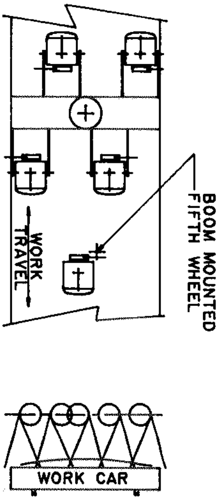

Fig. 9. Wheel positioning for peening of skins.

Some applications do not require movable wheel systems. Some non-movable centrifugal wheel systems are being used to shot peen wing and empennage skins and long structural members.

The applications above show that, compared to air nozzles, centrifugal wheels are much more energy efficient, have better shot velocity control, improved coverage control, and achieve much higher shot volume flow rates. They are thus much better suited to a wide range of applications. Their wide acceptance by the aerospace industry has reduced the cost of shot peening and improved control of the process.