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Application of Gravity Accelerated Shot Peening At GE Aircraft Engines

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Introduction:
The shot peening process has been used throughout the automotive and aerospace industries for several decades to impart compressive residual stress into metal components to improve fatigue properties and inhibit stress corrosion cracking. The theory behind applying the peening process is fairly simple and straight forward. Hard spherical particles, typically steel balls or glass beads, are accelerated toward a workpiece. The impact of the hard particles against the softer workpiece causes the workpiece to plastically deform. This deformation produces an internal compressive residual stress which is beneficial to the workpiece peened.

The typical peening machine utilizes compressed air to accelerate the peening media toward the workpiece. There are three basic types of pneumatic peening machines; pressure pots, gravity suction, and suction. The difference between these is the method of shot delivery to the blast stream. In the gravity suction and suction shot delivery systems, the shot and the compressed air are fed to the blast nozzle separately, where they are mixed and accelerated. Pressure pot systems add the shot to the compressed air line upstream of the blast nozzle. The shot/compressed air mixture travels to the blast nozzle where it reaches it's final velocity and exits to impact the workpiece. No matter which shot delivery system is utilized, the operation of the pneumatic equipment is the same; momentum is transferred from the compressed air to the media accelerating the media toward the workpiece.

In all of the pneumatic peening systems, the blast nozzle positioning is done in several different ways. The most sophisticated and repeatable method is to use NC robots to manipulate either single or multiple nozzles around the workpiece. A less sophisticated but fairly repeatable method is to use nozzle holding fixtures and simple oscillation to move the nozzle fixture over the workpiece. Finally, the least repeatable but most widely used method is to manually position the nozzles around the workpiece. The typical media diameter for the pneumatic peening process is between 0.003" to 0.040". This range of media sizes is used since they are massive enough to plastically deform the part and small enough to provide peening coverage in the shortest period of time.

Although the peening process is straight forward for pneumatic equipment, there are a number of significant process parameters which must be monitored and controlled. Listed below are these significant parameters.

Media Size
Air Pressure
Shot Flow Rate
Nozzle Diameter
Air Jet Size
Nozzle Position
Nozzle Angle
Peen Time

The majority of peening machines used in the automotive and aerospace industries are pneumatic equipment. These machines are very versatile and peen a wide range of applications from small gears to large gas turbine rotor disks. However, even though pneumatic peening is widely utilized and some very sophisticated NC peening equipment exists, process control is still difficult and requires a lot of attention. There are many key process parameters in pneumatic peening which must be closely monitored and controlled to assure a consistent peening process.

Gravity Accelerated Peening Description :

The GASP process overall is a much simpler process then the pneumatic peening process. The equipment is simpler and the process of accelerating the peening media is much more consistent and repeatable. Therefore, there are less key process parameters to control and monitor. Listed below are the GASP key process parameters:

Media Size
Drop Height
Peen Time
Part Location/Orientation

The GASP process is a viable process which uses simpler equipment and is very constant, reliable and easy to control.

In the GASP process, large peening media, larger the 0.040" diameter, is dropped from a predetermined height above the workpiece. The GASP process requires larger media for a very simple reason. The maximum velocity which is attainable with the GASP process is relatively low, for example it is only 270 in/sec for a 96" drop height. Since the maximum velocity is rather low, the mass of the particle dropped must be fairly large to allow the process kinetic energy to be high enough to achieve the desired peening intensity. As a side benefit, peening with larger media produces a better post peen surface finish. This point is illustrated by figure 1. For a given intensity, the impact dimple diameter is constant. Therefore, due to the radius of curvature of the ball, the larger GASP media produces a shallower dimple than pneumatic peening media. In addition the speed of the dropped media is very predictable since the particle accelerates due to gravitational acceleration which is always constant. The drop height in GASP is analogous to the air pressure setting in pneumatic peening.

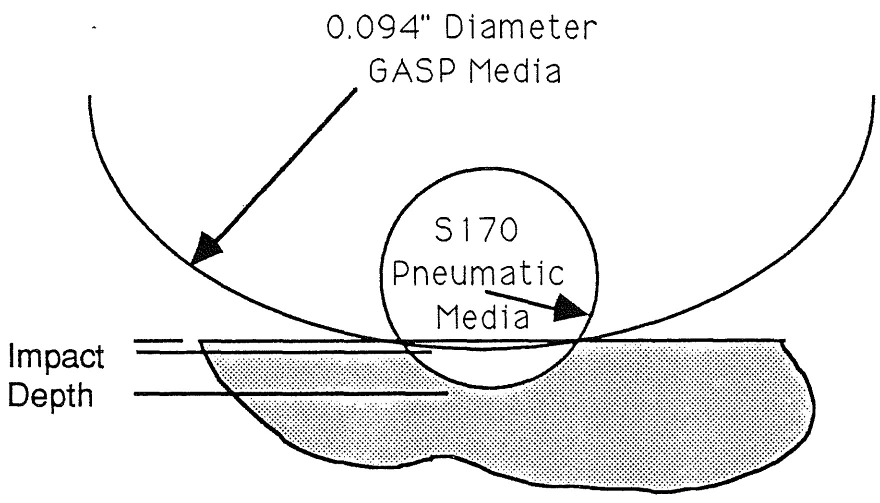

Figure 1: Media Comparison GASP vs. Pneumatic

The GASP process was invented and first used in the early 1980's. A joint team of Pratt & Whitney and Progressive Technologies developed and patented the process and the equipment. Shown in figure 2 below is a schematic of a GASP machine. As is shown in the schematic, the GASP equipment is fairly simple. The machine consists of three basic components, the media return conveyor, the hopper, and the part tilt and rotation axes.

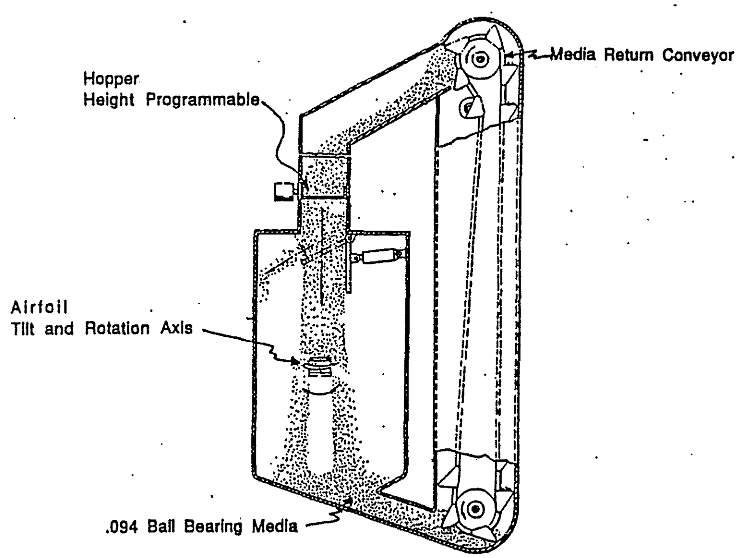

Figure 2: GASP Equipment Schematic

The heart of the system is the media transfer system. GASP machines typically contain a fairly large amount of media, 2,000 - 4,000 lbs. This equipment also has a large shot stream area and requires the media charge to be cycled at least 2 times per minute. Because of the requirement to circulate this large amount of media, a very robust, reliable media return conveyor is required to move the peening media hopper.

The drop hopper has the ability to be positioned at various heights. The accuracy and repeatability of the hopper height is a critical process parameter since the height of the hopper determines the ball velocity and peening intensity. At the bottom of the drop hopper is a door which opens and closes to begin and end the flow of media.

The final component of the GASP machine is the part manipulator. Unlike pneumatic peening equipment where the nozzles are manipulated over the workpiece, in the GASP process, the workpiece is manipulated under the shot stream. There are typically two degrees of freedom used to manipulate the parts.

Advantages of GASP:

The GASP process has several advantages over the competing pneumatic peening process. The first advantage is that the peening equipment is much simpler and much more reliable. Based on GEAE's experience, the maintenance and downtime costs for the GASP equipment is 50% lower than pneumatic equipment. There are less components in a GASP machine therefore there is less chance for system failure.

Another advantage of the GASP process is that the peening intensity is applied more uniformly. The drop height plays the largest role in determining the intensity, and with this controlled, the intensity over a large component can be applied very consistently. Since the GASP process uses larger media than pneumatic peening, the post peening surface finishes are much better for the reasons previously described.

In addition, an important advantage of the GASP process is that it is a process which is easier to control. If one controls and monitors the media drop height and part orientation, the process will repeat and be consistent. There are less key process parameters and all of the needed process controls are built into the equipment and are computer controlled by the machine.

Overall the GASP process offers many advantages over the pneumatic peening process, however, there are also several limitations. The most significant of these is that the peening cycle times in the GASP process are longer. The reason for these longer cycle times is due to the large media size used in GASP machines. With larger media, there are less particles per pound and therefore less part impacts. The GASP equipment builders try to make up some of the difference by using very high shot flow rates, 5,000 to 10,000 lb/minute and by peening multiple blades at one time.

Another limitation of the GASP process is the type of geometry where it can be applied. Candidate applications for GASP are those which have large relatively flat surfaces with unobstructed access and those which require very good post peen surface finishes are candidates for GASP. The GASP process is used mainly in the aerospace business. The current aerospace applications of the GASP processes are for gas turbine compressor and fan blade airfoils. These components are large and relatively flat and require low post peen surface finishes (16 Ra). Another gas turbine application is the denisification of oxidation resistant coatings on turbine airfoils. Again these components require low post peen surface finishes and have large unobstructed areas to peen.

The GASP process can play a large role in the peening plans for many industries. It has a proven track record and if the applications are chosen and researched correctly, this process will be more cost effective and reliable than conventional pneumatic peening equipment.

A summary of the GASP process advantages and limitations can be seen in figure 3 below.

GASP	
Advantages	Limitations
Uniform Intensity	Peening Cycle Times Longer
Improved Process Control	Initial Media Cost Higher
Improve Post Peen Surface Finish	Application Limited
Lower Equipment Maintenance	

Figure 3: GASP Advantages and Limitations

GEAE's Application of GASP:

GEAE began investigating the possibility of applying the GASP process to large commercial engine fan blades back in 1988. After some unexplained product variation, an investigation was undertaken to determine the cause. One of the observations from this investigation was localized hardware distortion. The cause of this distortion was traced back to the peening operation. At that time, hardware was pneumatically peened to a wide intensity range 10-25N. Review of the peening operation showed that due to the complex non-symmetric hardware geometry, the intensity varied along the part surface and was not uniform from one side to the other.

In addition to the variation within one part, there was a large part to part variation. The variation was largely due to the fact that the nozzle positioning and process set-up were all done manually by the operator. As a result of the investigation it was determined that a new peening process which could improve the intensity variation within one part as well as part to part was needed. This requirement led to the specification and building of GEAE's GASP facility.

Since the GASP equipment design already existed, it was scaled up to meet GEAE's need to peen to large (34" long by 19" wide) fan blades, two at a time. Attention was than focused on selecting the media to be used in this machine. The GEAE application required that the airfoil surface finish after peening be below a 22 Ra. With the pneumatic peening process, a post peen surface finish of 60 Ra was achieved and vibratory tumbling was required to lower the airfoil surface finish . One of the goals of introducing GASP was to offset any cycle time increase with the elimination of the vibratory tumble operation. For this reason, it was decided that we would select large GASP media (.094' diameter) to improve the post peen surface surface finish.

After the media size was selected, its material and heat treatment needed to be specified. To determine this, media vendors and other GASP users were surveyed. The majority of the GASP users specified hardened carbon steel ball bearings in the size range of 0.040" to 0.094". This media was through hardened and it fractured after use. To eliminate the tendency for the media to fracture into half spheres which could nick and degrade the life of a component, GEAE specified that the GASP media for our equipment be case hardened low carbon steel. The average case hardness depth was required to be .025" to a hardness of 50-55 Rockwell C. The theory behind case hardened media was to provide the required hardness but leave the ball center ductile to resist fracture.

GEAE's GASP Results:

In late 1989, GEAE received and began to install it's GASP facility. The initial application for this facility was to peen the fan blade airfoils. Within two weeks of the initial machine startup, a production GASP peening process was developed and production parts started to be peened. The GASP process had a much more uniform intensity distribution than the previous pneumatic peening process. With the previous process the intensity range over the part was between 16 to 23 N at certain locations. This uneven intensity distribution caused part distortion. The initial GASP process produced an intensity range of 16-18N. The GASP peened parts were dimensionally inspected and it was shown that with the tighter uniform intensity, did not distort.

Another advantage which was realized with the GASP process was that the part to part intensity variation was much smaller than the previous pneumatic process. Shown in the figure below are statistical process control (SPC) charts for the old process average intensity and the first 48 GASP peened parts. This figure dramatically shows that the GASP process is much more repeatable and consistent. This is due to the machine controlled vs operator controlled process.

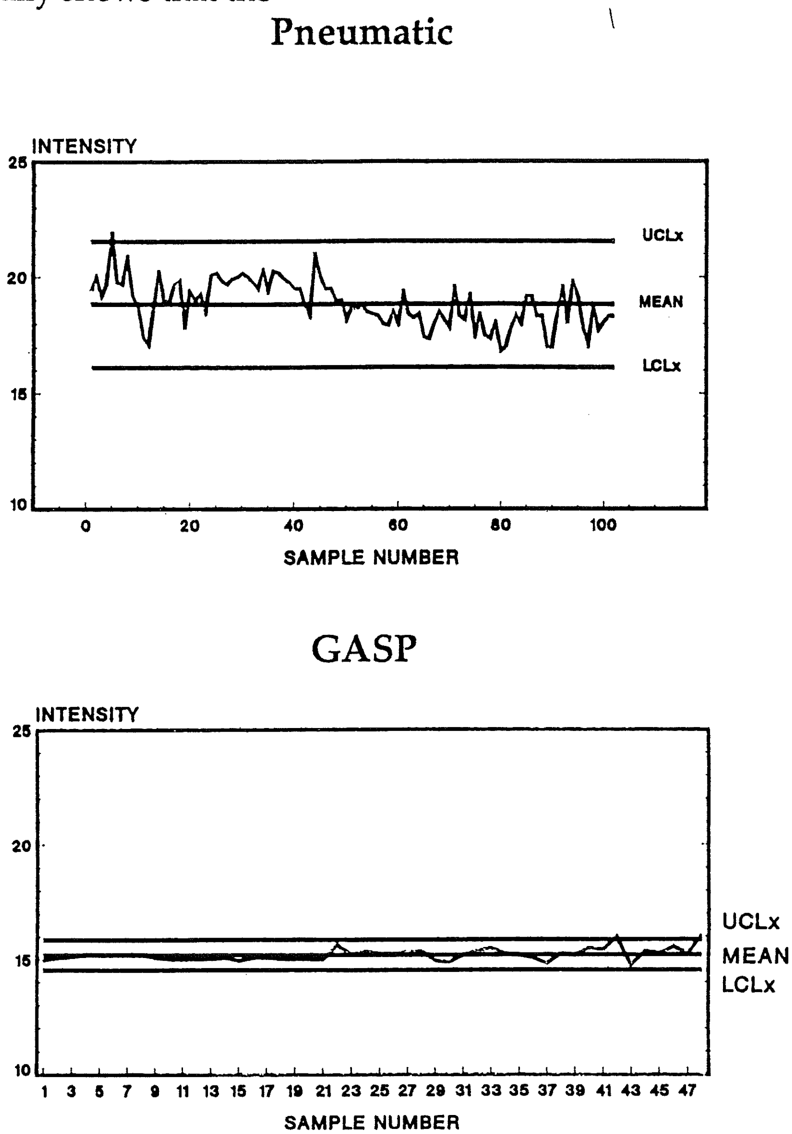

Figure 4: SPC Control Charts for Average Intensity Pneumatic vs. GASP

Evaluation of the part surface finish before and after peening revealed some interesting data. On average the pre peen surface finish was about a 22 µ" Ra. After pneumatic peening the surface finish was raised to about a 60 µ" Ra. This required that the blade be vibratory tumbled to return the surface finish to the drawing requirement of 22 µ" Ra. In contrast, the GASP peened parts had the same pre peen surface finish, but the surface finish after peening actually lowered to a 17 µ" Ra average. This allowed the elimination of the vibratory tumble operation and reduced blade manufacturing costs. Figure 5 below graphically represents the surface finish data for the pneumatic and GASP processes.

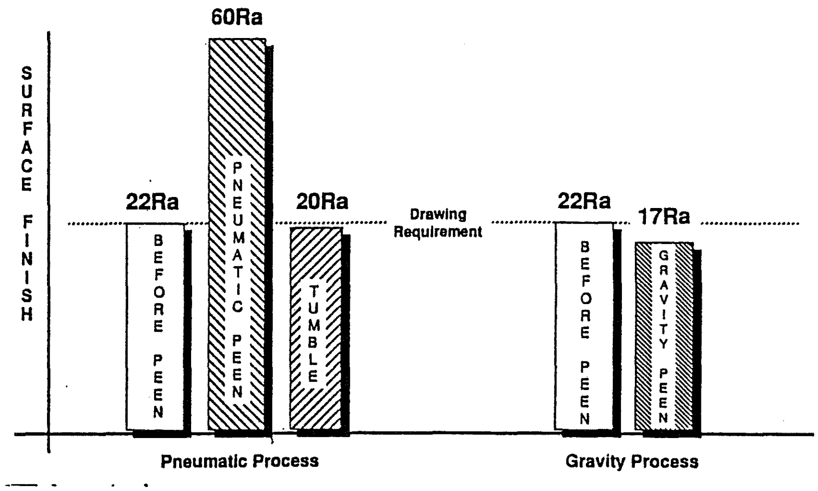

Figure 5: Surface Finish Comparison Pneumatic vs. GASP

The only remaining concern after the GASP process was introduced was that the relatively long peening cycle time. The pneumatic process required 24 minutes to peen, as compared to the initial GASP process which required 37 minutes. In an effort to reduce the process cycle times, a program was implemented to evaluate the GASP process, optimize it and reduce the cycle time to 25 minutes.

The initial process evaluation revealed that the part was completely covered by peening impacts well before the Almen strip saturation point was reached. To overcome this and to reduce the peening cycle time, it was decided that a 15% "saturation rule" would be used rather than the standard 10%. The saturation rule states that saturation is achieved when the intensity value does not increase by more than 15% when the peening time is doubled. To verify that this process change would not adversely effect the fatigue properties of the fan blade, fatigue testing was performed at two different intensities 12N and 25N as well as 10%, 15%, and 20% saturation points. The results of this testing are shown in figure 6. These results indicate that the fatigue properties for all three saturation points were all well above the material baseline and that a change to a different saturation rule to lower the peening time would not adversely effect the fatigue properties. As a result of this data, the GASP peening process was altered to the 15% saturation rule and the cycle time was reduce to 25 minutes.

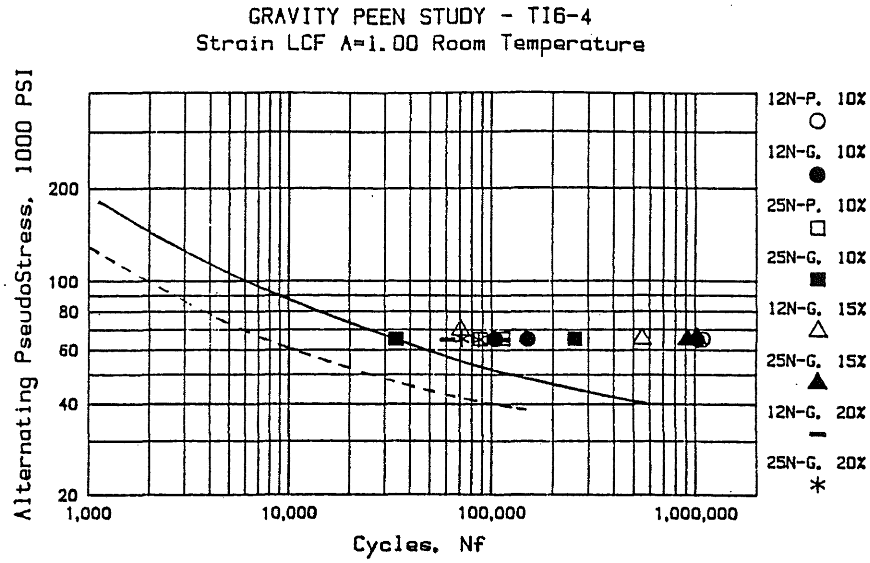

Figure 6: Fatigue Results of GASP at Various Saturation Rules

Conclusions:

The GASP process is a simple peening process for certain applications. It produces a very uniform intensity distribution across a component while maintaining or improving the post peening surface finish. Because of the nature of this process, it is very easy to control with low process variability and excellent capability.

GEAE realized the benefits of the GASP process and applied it to certian hardware. Parts peened with the GASP process were dimensionally stable due to the even peening intensity, and a post peening vibratory tumbling operation was eliminated. The use of GASP at GEAE has improved a product's producability while lowering manufacturing costs.