FULL ASSURANCE SHOT PEENING OF

AIRCRAFT GAS TURBINE ENGINE COMPONENTS

PG Bailey
DR Lombardo
HG Popp
RA Thompson

ABSTRACT

This paper is a progress report on the approaches and perspectives described in a paper entitled *New Challenges for Shot Peening of Aircraft Gas Turbine Engine Components* which was presented at Surfair X in Cannes in 1992 and subsequently published in Metal Finishing and The Shot Peener. The approach has been refined and is now focused in four areas - rigorous process control, non-destructive evaluation (NDE) for intensity and coverage, improved media control and reliable use of the Almen strip. Data collected for the process, NDE and media will be preserved in an archive by part serial number. Together, these four areas comprise what GE Aircraft Engines will be implementing as Full Assurance Peening. The main tasks are to reliably control the process, prove intensity and coverage on the part, measure shape and size of the media and not be misled by imprecise Almen strip data. This paper describes this effort and its implementation as a new Critical Parts peening specification for application on rotating parts.

SUMMARY OF PREVIOUS PAPER

The *New Challenges* paper described three stages of process control sophistication. It termed them: Typical Practice Stage I, State-of-the-Art Stage II, and Enhanced State-of-the-Art Stage III. The latter stage included:

* Machine malfunction sensors

* Almen strip reliability controls

* Reduced run to run intensity variations

* On-machine shot separators

* Part and nozzle fixtures

* Almen fixture criteria

* Operator qualification

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Projects under development in several areas were noted:

* Process fundamentals
* Process modeling
* Workstation
* Shot velocity measurement

In addition, non-destructive testing to prove attainment of the required residual compressive stress was cited as a need.

RATIONALE FOR FULL ASSURANCE PEENING

Narrow process windows for robust peening of advanced rotor alloys and increasing pressure to take formal credit for the part life of shot peened engine components require a new level of control. Taking credit goes beyond fatigue testing of test specimens or part components. It involves answering several questions for each part. Were the machine nozzle motions and shot velocity correct ? Were the specified intensity and coverage achieved ? Was the part put in the machine right side up and was the correct peening nozzle used ? Is wear on hoses and nozzles within limits ? Is the size and shape quality of the peening media acceptable ? The pedigree of the almen strips is very important, especially since new suppliers are entering the market. Just as important, is the need for documentation of the machine parameters and proof of the results. We believe that machine sensors that detect all predictable malfunctions, NDE capable of showing intensity and minimum coverage on parts and documentation of shot quality will provide that proof. The attributes of numerical control (NC) of part and nozzle motions will also be prerequisites of the new system.

RECENT DEVELOPMENTS

Process development has concentrated in several areas:

* Defining robust peening process windows
* Process control strategy
    - Malfunction sensors
    - Operator competency
    - System issues
* Almen strip measurements

* NDE

* Shot quality measurements

ROBUST PROCESS WINDOWS

A strategy has been developed and implemented at GE Aircraft Engines which defines fatigue-safe shot peening parameters for specific alloys. It is based on the process fundamentals and process modeling referenced in the previous paper. It also relates to fracture mechanics and the stresses at in-service conditions. The resultant process window is made up of interrelated limits on intensity, coverage and shot size. Limits on rework shot peening are also considered.

The concept of robust process windows encompasses several competing needs:

* Sufficient compressive depth to counter machining stresses and to inhibit crack initiation

* Limits on parameters that contribute to overpeening and to corner damage

Evaluation of process effects must relate to the mode of potential part failure:

* Temperature and stress levels

* Failure mode - fatigue, stress corrosion or fretting etc.

* Possible interactive effects with pre- or post-peen processing

A robust process window may include limits on the following:

* Maximum intensity levels related to shot size

* Maximum coverage percentages

* Minimum impingement angles

* Controls on rework peening limiting intensity and coverage

PROCESS CONTROL STRATEGY

Control of the peening process must not only control the peening machinery but also the operators of that machinery and the measurements of the process. Lastly, the administrative systems must ensure that everything planned does happen.

MALFUNCTION SENSORS

GE Aircraft Engines' current shot peening specification for critical parts requires peening machines to be equipped with sensors that detect out of limits process parameters such as air pressure and shot flow and motions of the part, peening nozzle and turntable. If any parameters or motions vary beyond prescribed limits, the machine shuts down. The currently detectable malfunctions are being expanded to cover other possible difficulties such as kinked or excessively worn hose and deflector tip loss for nozzles so equipped. Nozzle spray patterns and media quality are also being addressed. Sensors being developed include shot velocity, nozzle air pressure, air mass flow and nozzle tip continuity.

OPERATOR COMPETENCY

Mistakes by a properly trained operator are not likely, especially with numerical control systems. However, selecting the wrong program, installing a deflector tip nozzle in the wrong orientation, or a part upside down are possible. Inadvertent shot entrapment under almen strips is another possibility. Improved fault avoidance training and sensitization to critical steps will enhance training plans. Part recognition devices and part / nozzle orientation recognition devices may be utilized.

SYSTEM ISSUES

Faults that occur because of system errors outside of the peening environment such as mislabeled parts or inadequate peening instructions or system errors such as inadequte machine or fixture maintenance can be just as damaging as machine malfunctions. Systemic approaches to prevent these faults will be employed.

ALMEN STRIP MEASUREMENTS

The Almen strip system that is used as a measurement tool represents a number of issues, none of them trivial. There are reproducibility questions related to the strip manufacture which are becoming significant because new strip suppliers are trying to become qualified. Recent tests show that meeting MIL specification requirements does not necessarily equate to adequate intensity response. In one comparison test of old and new suppliers, arc height averages varied 0.004A(in) between suppliers and standard deviations ranged from 0.00016 to 0.00037A(in). Almen gage repeatibility is less of an issue with new gage designs. Necessary almen strip handling and usage was described in the *New Challenges* paper referenced above.

Another issue not commonly recognized is the relationship of Almen strip tolerances to intensity range callouts on drawing notes. Shot stream impingement angles and placement of Almen strips on part simulation fixtures can arbitrarily affect that relationship. Because intensity is proportional to the sine of the impingement angle, the proportion of the drawing specified range that is available for Almen strip intensity tolerance varies widely. Assume a 4-8A (0.004-0.008A in.) specified range. If all peening is at 45 degrees and all Almen strips are on horizontal or vertical surfaces, corner intensities that are really 40% higher are ignored and all strips will read approximately 6A. This leaves an "apparent" tolerance of +/-2A. If a strip at 85 degrees to the shot stream is added and the air pressure is adjusted to center the intensities within 4-8A, the 45 degree strip will read 5A and the 85 degree strip will read 7A. Thus the individual strip tolerance changes to +/-1A. In a third case of 75 degree maximum and 35 degrees minimum, the tolerance in a 4-8A spread changes to +/- 0.5A. See table below:

Drawing permitted Impingement Angles	Resulting Part Intensity Values	Remaining Tolerance Available - each strip
all 45	6A	+/-2A
45 to 85	5A to 7A	+/-1A
35 to 75	4.5A to 7.5A	+/-0.5A

The solution to this inconsistency is to not allow the apparent tolerance to be used but require run to run tolerances for each Almen strip location to be +/-.5A from the approved value recorded at process setup.

NON DESTRUCTIVE EVALUATION

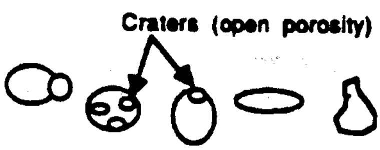
Modeling of the peening process has shown that the depth of the compressive layer may be determined by analyzing the topography of peening dimples. Stylus and vision systems have been evaluated. With very sophisticated methods it is possible even to differentiate between levels of coverage above 100 percent.

The system that is most likely to be adopted is a relatively simple one that utilizes a 100X video probe to observe and record dimple topography of selected part features. These areas may then be visually compared with a standard and archived by part serial number. The video images could also be evaluated electronically by more sophisticated means.

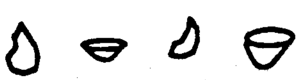
MEDIA CONTROL

Control of media quality is currently dependent on operator judgement and diligence. It involves running "fracture counts" to determine the amount of broken or misshapen particles and periodic "sieve tests" to determine shot size distributions. The figure below shows common defective shapes for the two major types of shot. Cast shot as purchased is predominately spherical but typically contains elongated particles, doublers and hollows. It also has a significantly wide size distribution. Preconditioning or initial use followed by screening will remove most of the first two defectives. In use, fractured particles are produced. Conditioned cut wire shot as purchased is quite uniform in size and is faceted from the conditioning. If the wire is not uniformly cut, elongated particles result and if not completely conditioned, non spherical and even as-cut particles have been observed. In a solitary occurrence, what is believed to be wire with a centerline defect, produced shot with surface cusps. In use, conditioned cut wire shot does not fracture but wears to smaller sizes. Its minimum size is controlled by the 'take out" screen of the integral separator. Well screened shot of both types approach the same size distribution.

1. Acceptable Shapes of Cast Shot

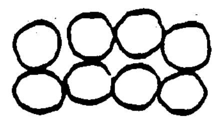


2. Unacceptable Shapes; Deformed Cast Shot

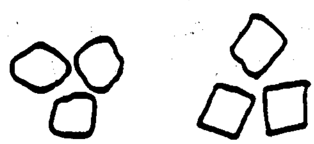


3. Unacceptable Shapes; Broken Cast Shot

Cast Steel Shot



1. Acceptable Shapes of Conditioned Cut Wire Shot



2. Unacceptable Shapes; Partially and Unconditioned Cut Wire Shot

Conditioned Cut Wire Shot

SHOT IMAGE ANALYSIS

Rather than rely on "fracture counts" and "sieve tests" which produce numbers but only crudely characterize shot quality, image analysis of shot will perform both of these functions to a more measurable and reproducible degree. More significantly, the system will:

* Produce size and roundness measurements (average and standard deviation)

* Be archivable as proof of shot quality

NC MACHINE CONTROL

Current GE Aircraft Engine peening specifications encourage but do not require NC motion controls. NC or microprocessor systems that at least duplicate the precision and feedback features of NC peening machines will be required in Full Assurance Peening.

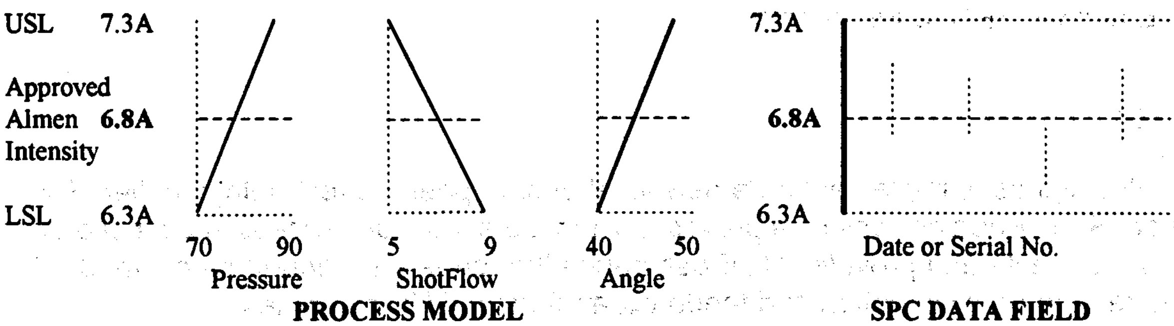
SPC

Currently required air pressure, shot flow, intensity and fracture count data will be expanded and process capability limits will be added.

SPC AND PROCESS MODEL COMBINATION

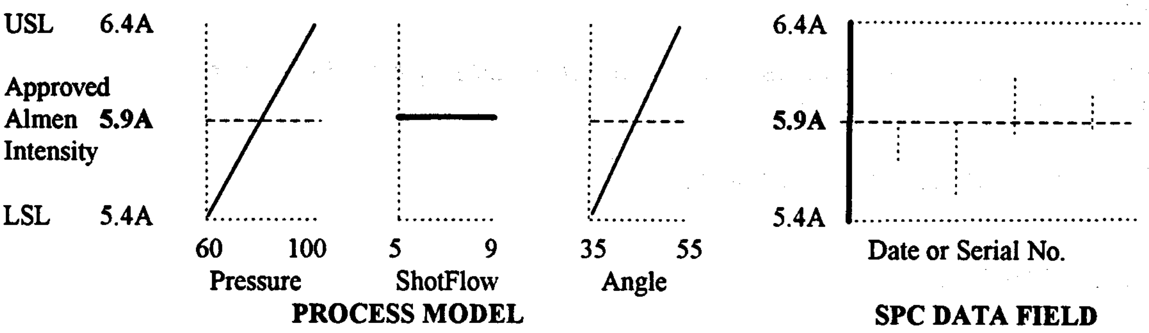
Developing a simple intensity model for each peening machine setup which can be shown graphically should make everyone involved more sensitive to the necessity of machine control. Combining it with the SPC chart will put it right in front of the operator. The following is an example for a direct pressure peening machine.

DIRECT PRESSURE PROCESS MODEL / SPC



A second example for a gravity suction machine is shown . Note that the process model shows quite different intensity responses compared with direct pressure.

GRAVITY SUCTION PROCESS MODEL / SPC



IMPLEMENTATION

Full Assurance Shot Peening will be implemented by creating a new Critical Parts Peening specification that will have the following additional requirements:

* Drawing note inclusion of certain prescribed process parameters for production and rework peening
* Demonstrated machine shutdown capability when specified malfunctions are detected
* System and Operator control criteria
* Media control for size and shape by image analysis
* NDE of parts for intensity and coverage
* Archival of peening parameters, media measurements and part NDE by part serial number
* Effective SPC requirements

SUMMARY

GE Aircraft Engines is implementing a new level of shot peening technology called Full Assurance Shot Peening which improves on the detection of process malfunctions, assures shot quality and provides NDE assurance that parts are peened as claimed. It also requires the precise motion and feedback attributes of NC machines.