Spring 2014
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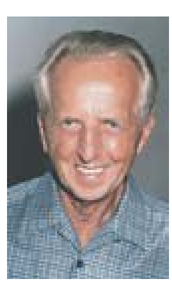
The Shot Peener

Sharing Information and Expanding Global Markets for Shot Peening and Blast Cleaning Industries

INNOVATIVE Machine Solutions for COMPLEX Aerostructures

PLUS: THE PEENING TIME PARADOX • 3D PRINTING AND THE METAL FINISHING INDUSTRY • CONTROL SYSTEMS IN PEENING MACHINES • AND MORE

PHOTO: A MIXED PART LOAD IS PROCESSED IN ONE CYCLE



COVER PHOTO: LOADING AND STAGING AREA OF TWO-SIDED SHOT PEENING MACHINE BY PROGRESSIVE SURFACE

THE SHOT PEENER
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Milestones and Moving Ahead

Milestones: Electronics Inc.'s 40th Anniversary
January 2014 marked the 40th anniversary of Electronics Inc. (EI). I started EI in 1974 with the intent of supplying process controllers to Wheelabrator Air Pollution Control Division for their dust collectors. Upon the successful delivery of the process controllers, Wheelabrator Blast Cleaning Division asked me to furnish a media flow monitoring system and controllers for a Boeing 747 Jumbo Jet project. The project had 16 abrasive wheels on a large monorail peen-forming machine. Looking for more opportunities, I then developed a media flow valve for air-type peening machines that I named the MagnaValve®. It was so well received that it became the impetus for a complete product line for the shot peening and abrasive blast cleaning markets.

JACK CHAMPAIGNE

I couldn't find suitable advertising opportunities for the MagnaValve® so I started *The Shot Peener* in 1986. To help underwrite the cost of the publication, EI began marketing Almen strips, introducing the concept of graded strips to meet the needs of various industries including automotive and aerospace. That's a very brief history of how and why our two main product lines, the MagnaValve® and Almen strips, and *The Shot Peener* were launched.

Electronics Inc. would then go on to launch many more firsts: The first shot peening education workshop in 1991, the first *Shot Peener of the Year* award in 1992, the first online library devoted to shot peening and blast cleaning in 1995, the first FAA-approved source for shot peening training in 2001, the first polished and numbered Almen strips in 2011, and other product innovations through the years.

Moving Ahead
Electronics Inc. has moved four times to accommodate its growth. In 2002, the company moved into its present facility—a 24,000 square feet building on the St. Joseph River in Mishawaka, Indiana. EI is in the process of expanding the company's manufacturing capabilities and is adding workflow and technology innovations. Watch for new product developments, services and ways of supporting our customers later this year.

In This Issue
Why EI keeps pushing the boundaries is evident in this issue of *The Shot Peener*. Companies like Progressive Surface are developing machines to keep ahead of the rapidly changing demands of the aerospace industry—suppliers must keep pace with their customers' innovations. I have to admit, however, that I wonder if some of the technologies in the 3D printing article will eventually limit the need for shot peening, but I am encouraged when I learn that companies like Peening Technologies are already taking advantage of 3D printing. And I'm always encouraged when I read material by David Kirk and John Cammett. They are two of the finest minds in the shot peening industry and both have a talent for making complex topics understandable.

My marketing team often hears me say, "This is fun." And I really mean it, I'm very fortunate to be a part of an industry that I enjoy so much.

THE SHOT PEENER

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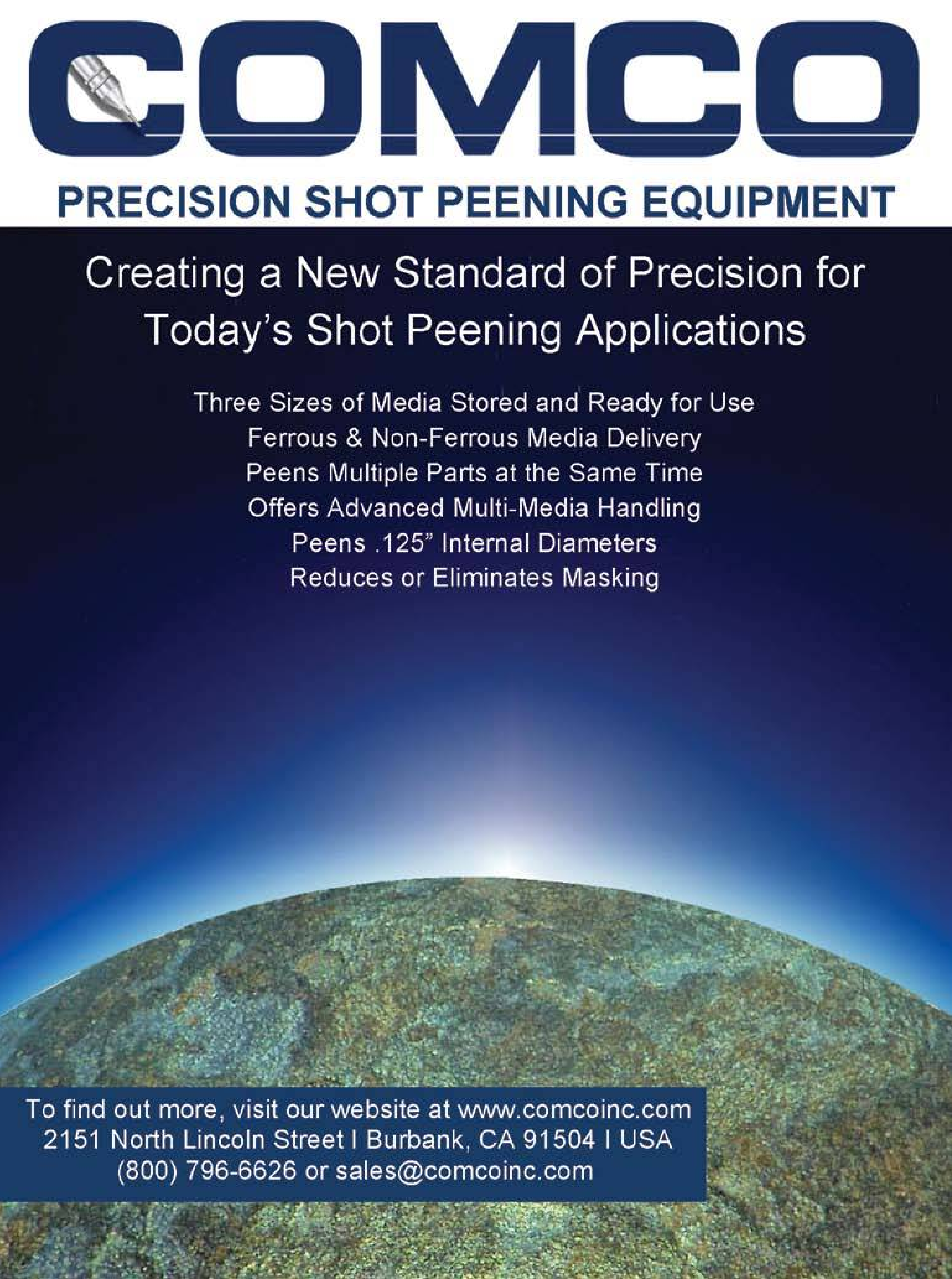
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by Ken I'Anson | Sales Engineer | Progressive Surface

Two-Sided, Vertical Shot Peening

NEW COMMERCIAL AIRCRAFT DESIGNS are providing additional challenges for component manufacturers and processors. With the rising price of fuel, airline operators have been pushing aircraft manufacturers to provide, and guarantee, lower operating and per-seat costs. Total aircraft weight is a major factor when the goal is to increase efficiency and lower cost.

At Progressive Surface, we've seen firsthand the traditional aluminum airframe structures morph into larger but lighter components. In some cases, the materials have changed as well to meet strength-to-weight goals. Specifically, we've witnessed wing rib structures increase in size to suit the larger wings but machined thinner to minimize weight.

During shot peening, these complex structures can distort and expand lengthwise. The part distortion must be eliminated and the part growth must be controllable and absolutely repeatable. Unfortunately, there isn't a "one-size-fits-all" solution. Some parts are symmetrical side-to-side along the length and some parts are asymmetrical with one side that is flat without structural features and the opposite side is a complex array of intersecting structural and strengthening features. As is the case of the asymmetrical parts, there is a major imbalance with much more surface area on the structurally complex side of the part than on the flat side.

If this doesn't cause enough problems, add in the condition of varying part thicknesses commonly found on the latest generation of aerostructure components. How can we effectively shot peen these parts and maintain critical part dimensions?

An asymmetrical part with varying thicknesses in the vertical two-sided robotic shot peening machine

Shortcomings of Traditional Part Processing

For years, large aerostructures have been shot peened with centrifugal wheel systems that use multiple fixed-wheel positions to achieve part coverage. Some of these systems incorporate up to 24 wheel units to satisfy the part size and geometry. (Read *The Shot Peener*, "Rising to the Challenge, page 8, Fall 2009.) Due to the fixed positions of the wheels, the blast pattern "hot spots" become very difficult to manage on aluminum structures. Dimensional control is difficult.

Another approach is to shot peen components oriented on a platen or roll conveyor as they pass through the shot streams of moving nozzles. One side is peened and then the part is turned over and the other side is peened. Some can peen both the upper and lower surfaces in a single pass.

The two-sided method has limitations when trying to process asymmetrical parts, which as discussed, are not equal side to side. Commonly, the flat side faces downward to allow conveyance on rollers. The flat surface gets much higher (sometimes 4:1) part coverage than the complex side during processing. The top and bottom method of shot peening doesn't work well with complex, symmetrical components either as they aren't flat and don't convey well at all unless fixtured.

A Flexible, Modern Solution for Complex Aerostructures

Progressive Surface has designed and commissioned a vertical, two-sided robotic peener for GKN Aerospace of St. Louis. These dual-gantry, CNC-controlled robots can shot peen

Single-sided pass-through machine

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Our affordable CNC machines allows every shot peener to eliminate manual nozzle setups. CNC offers exceptional part processing speeds, accuracy of peening and consistent quality of parts.

both sides of aerostructures simultaneously with equal or varying programmed peening coverage. Four peening nozzles are positioned on each of two robots located on either side of the vertical monorail conveyor. The peening nozzles are strategically positioned at compound angles to access all part surfaces. The two robotic manipulators can operate completely independently or coordinated with each other to provide different results. Commissioning has shown the following operation modes:

- Peen both side simultaneous, coordinated and equal. The parts can be peened to 100% or 200% in a single pass or build up to this coverage with multiple, high-speed passes, depending on part growth and distortion.
- Peen the complex side of asymmetrical parts only on the first pass (or multiple passes) then complete the part with all eight nozzles operating in a coordinated controlled mode to complete both sides of the part requirements. This method provides excellent part shape and size control.

Some large ribs have very thin sections between the structures that require masking to prevent shot peening. The new shot peener is CNC controlled and the nozzle clusters will trace the structural features of the part to ensure full coverage. In a follow-up program, it will then peen the complete part and either hit the masking or minimally hit the masking to complete the part, thereby saving time.

Lastly, when complex, asymmetrical parts are processed, the structural features of the complex side of the part can be traced with double the normal media flow. The four nozzles with high media flow are rapidly moved over the features, creating fast part feature coverage. Once the complex areas are peened, all eight nozzles are turned on to the normal media flow and the part is completed in the next peening pass.

The two-sided CNC-controlled shot peener has the PRIMS Pro Operator Interface for process control, monitoring, PM and report generating

Progressive Surface has encouraged GKN Aerospace to maximize the system's efficiency by running mixed and multiple parts numbers per batch or load (filling the part fixture). The parts must all have the same shot peening coverage and intensity requirements as well as being of the same material or alloy.

A CNC-programmed Gantry Robot was chosen for this application due to its robust design and ease of programming. The part geometry of wing ribs is very linear and simple, therefore a six-axis, industrial robot was not needed.

Control, flexibility and repeatability are the core design pillars for this shot peening system.

A Brief Overview of the Machine

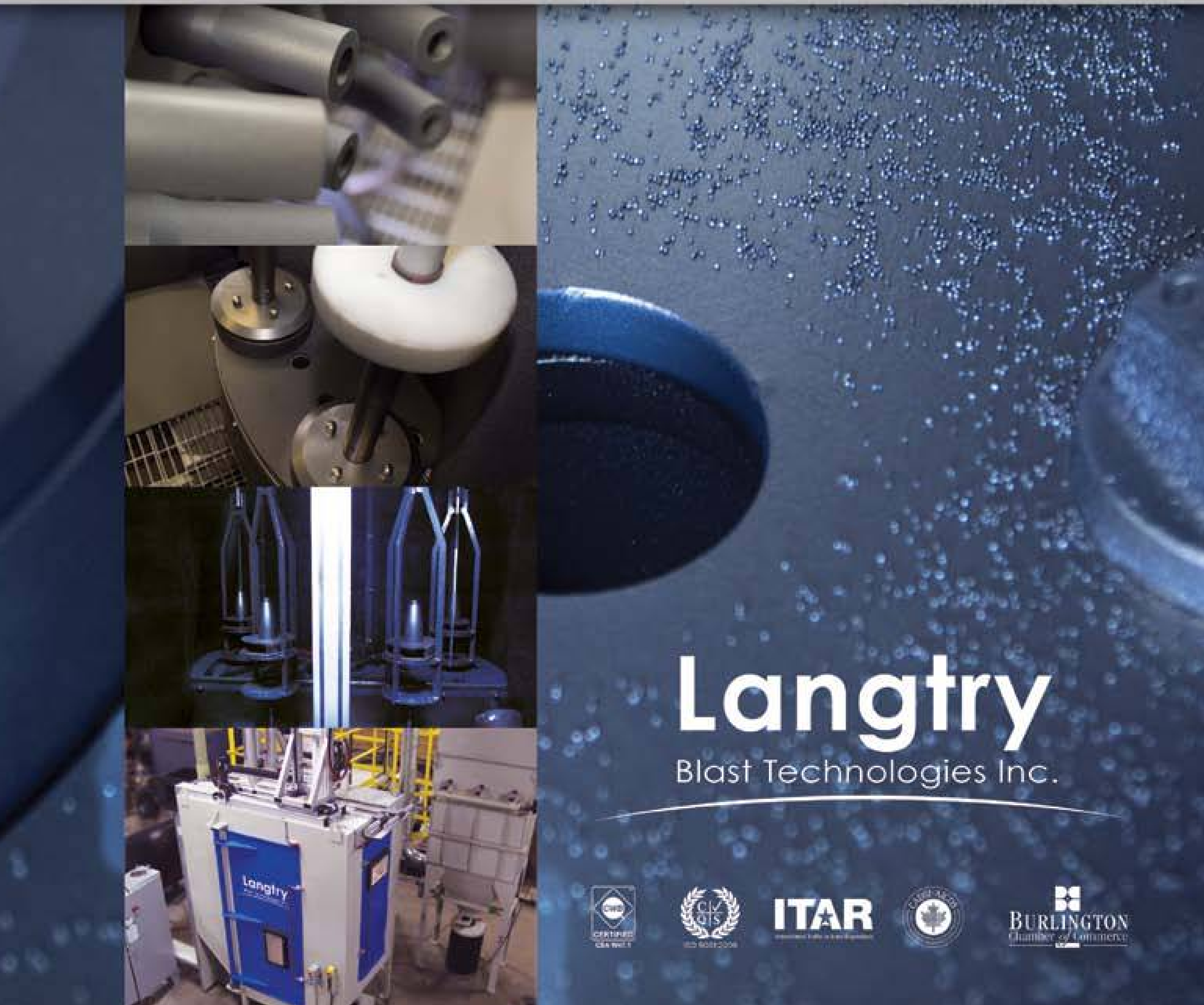
- Two overhead Gantry Robots with a total of eight peening nozzles
- Coordinated CNC overhead monorail with large manganese steel "picture frame" fixtures
- Efficient, pneumatic reclaim system with 100% of the reclaimed media classified
- CNC interpolated axis, closed loop media and compressed air control
- PRIMS Pro Operator Interface with process control, monitoring, PM and report generating
- Dual track switching of the monorail allows loading and unloading during the peening process
- Two pneumatic part manipulators to assist the operators when loading and unloading parts
- Power Requirements–130 FLA, Compressed Air–1,300 CFM at 80 psi (37 CM/m at 5.5 bar)

In closing, the quest to reduce aircraft weight is here to stay. Reducing the aircraft total weight is a major factor for increased fuel efficiency and lower operating costs in our competitive world. We're expecting the use of composites as well as new alloys to reduce weight. The traditional machined and fabricated airframe structures are now machined as large, single monolithic pieces, with cross sections thinned to further reduce weight. Aircraft engine designers are also advancing the strength-to-weight ratios, using new materials and techniques to reduce engine weight and operational costs.

As shot peen processors, we need to keep pushing the envelope and develop methods of peening the new structures in order to meet the weight and cost reduction goals of our industry.

At Progressive Surface, we'll continue to provide thorough, upfront discovery, process-specific designs and our promise of lifetime support.


POWER ON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by John Cammett | Consultant, Nadcap Auditor, EI Shot Peening Training Lead Instructor

Understanding the Peening Time Paradox

The Key to Uncoupling Intensity and Coverage

WHAT I REFER to as a time paradox is only a seeming paradox. Time is used in the standard protocol for determining peening intensity, yet intensity itself is independent of time during peening provided that machine settings or other key parameters are not altered during the process. This may seem paradoxical though in reality it is not. Coverage certainly is time dependent because an increase in exposure time during peening results in more impact dents on the surface of the part. One of the continuing challenges encountered in my twenty-plus years of teaching shot peening in training and workshop sessions has been to get students to grasp the difference between intensity and coverage concepts and their separate relationship to time. If you truly understand the conceptual independence of intensity and coverage in peening, then you need not read the remainder of this article. On the other hand, if you believe there is a fundamental relationship between the two, or even worse, attempt to relate them in practice, then I invite you to read on. You are belabored by a misconception. As the saying goes, we really must talk about this.

An Analogy

Let us begin discussion in a semi-technical vein and defer matters more technical to later. A useful analogy is that of a garden hose delivering a stream of water under pressure. If the water is delivered into the hose by the utility provider at constant pressure and the hose nozzle meters at a constant flow rate, then the force of the water is analogous to peening intensity. It matters not how long the time, whether for a second, a minute or an hour, the force of the flow remains the same and so does the intensity provided by the media stream in peening. Both the force of water flow and peening intensity are independent of time. There is, however, a time dependence of the water flow and this is the amount of moisture delivered to the ground or plants that are being watered—more time, more wetting. This is analogous to coverage in peening—more time, more coverage. Indeed, a certain degree of wetting from the hose on a given area can be achieved by passing the hose back and forth over the area at any constant rate. All that matters is that the wetting occurs over the necessary total time. And so it is with peening. The desired coverage will be achieved in the necessary total time irrespective of the speed of passes over the given area of the part.

An Example

To illustrate the uncoupling of intensity and coverage, consider that a job shop company involved in shot peening for a variety of customers employs two people on a part-time basis. One individual is responsible for doing intensity determinations and establishing machine settings to achieve intensities according to customer requirements. The first person does this in the mornings for the peening jobs that the second individual performs in the afternoons. The two individuals are on separate work schedules and communicate only by computer records in the company system. The lack of additional communication is not problematic since the first employee provides the machine settings appropriate to the intensity levels that the second employee must use in peening parts. Usually, the second employee must verify that the given machine settings will produce the desired intensity for each part by performing an intensity verification. Then the second employee must also determine the peening cycle time for each part according to customer coverage requirements. Let us suppose now that the parts to be peened include materials of different hardness, soft, medium and hard, but that the intensity required by customers for each is the same and the coverage requirement is also the same. Clearly, the typical sizes of dents in the each of the different parts will be different given that the media is the same and the impact energy is the same. The soft part will have larger impact dents than the medium hard part and much larger dents than the hard

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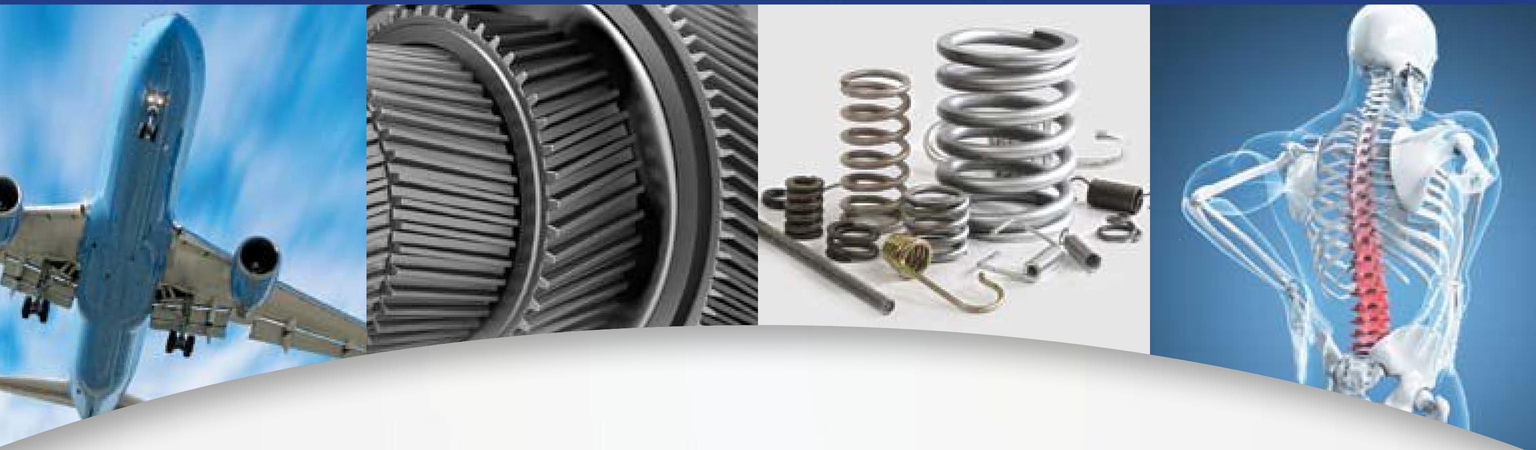

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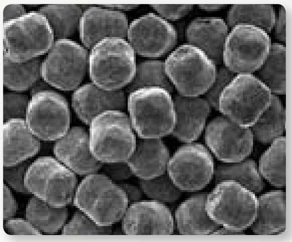
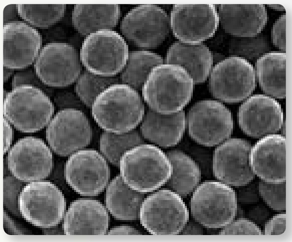
As Cut



Normal Conditioning



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part. Because of the differences in dent size, the soft part will achieve the desired coverage much sooner in time than either the medium hard and hard parts under the imposed condition of equal intensity and media flow rates for each. Despite this contrived but plausible scenario, two very important points may be posed. The peening cycle times for the parts will be quite different and thereby, there is no correspondence of cycle times to the Almen strip peening exposures or even the saturation times for each intensity determination. Note that, because the intensities sought were the same, the Almen strip exposure times and saturation times would have been the same for each. Indeed, since the same intensity was being sought, irrespective of part hardness, it may have been necessary to do only one intensity determination and not three.

Intensity: Some Technical Considerations

Now, let us consider the concept of intensity in peening on a somewhat more technical level and in a bit more detail than that presented above. Conceptually, intensity in shot peening is simply a measure of how hard we hit a work piece with media propelled via air or wheel. This involves the transfer of kinetic energy of the media into deformation of the surface layers of the work piece. Not all of the media kinetic energy is transferred. Some is lost as the kinetic energy of rebounding media. Some is lost as elastic energy of deformation of the media particles and some is lost as elastic energy of recovery of the work piece deformed layers. The remainder of the media kinetic energy is retained as plastic deformation of the work piece surface layers. Hopefully, we propelled the media with sufficient total energy to cause some plastic deformation; otherwise, we will not have achieved anything useful from the bombardment. It is the amount or degree of plastic deformation that matters as far as producing the desired effects of peening. As a practical matter, we do not concern ourselves with the partitioning of media kinetic energy thus, but simply want to have a measure of the effect of peening (the relative amount of plastic deformation produced). The measure that we call intensity is an analog quantity expressed as a specific property of a saturation curve. Please read on for further explanation.

Recognizing the principles involved, John Almen in his early work on shot peening patented a scheme for determining peening intensity using standard test strips (Almen strips) made from SAE 1070 spring steel with the standard dimensions of 3" x 0.75" x Thickness and heat treated to a specified hardness range (44-50 HRc). A key feature of Almen strips is that they are thin enough to bend when subjected to peening on one side because of plastic deformation produced at surface and in near-surface layers. Three thicknesses of Almen strips are used today to give appropriate amounts of bending depending upon the intensity range being used for peening. Almen also patented a gage (Almen gage) for measuring the degree of curvature produced in Almen strips after being impacted by media. The successor to Almen's patented gage, in use today, determines arc-heights. An arc-height is the chordal elevation of the unpeened surface of the test strip above a reference plane defined by the positioning of the strip on the gage. Almen also introduced the concept of saturation, recognizing that the bending of strips increases with peening exposure time until no further increase occurs after sufficiently long exposure. It may have been fortuitous that Almen chose 1070 spring steel as the Almen strip material because another material, such as aluminum or other austenitic alloy, would not have exhibited saturation behavior as observed with the SAE 1070 steel. More information on Almen strips (including saturation behavior and intensity determination) and Almen gage characteristics are available in SAE specification J442.

A typical Almen saturation curve is shown in Figure 1 from SAE J443. The curve is a plot of Amen strip arc-height on the Y-axis versus peening exposure time on the X-axis. To generate a saturation curve, a minimum of four Almen strips must be used and each is peened for a different exposure using the same machine settings. Note that the time scale need not actually be time itself, but may be any uniform time-based unit such as machine cycles or inverse velocity of part or nozzle motion. Each of the four or more Almen arc-heights produced is exactly that, an arc-height and not an intensity. Intensity is derived from the saturation curve by invoking what is termed the ten-percent rule. The saturation curve is a best-fit curve representing the Almen strip data and not a point-to-point fit to the data points themselves. The intensity is defined as the first point on the best-fit curve (not generally at a data point itself) whereby the arc-height increases by only 10% when the exposure time is doubled. Deriving the intensity value can be done satisfactorily by manual calculation, but it is most effectively done by use of computerized algorithms validated per SAE J2597. The time at which intensity is thus declared is called the saturation time.

Some very important points involved in the process of intensity determination include:

- The time scale of a saturation curve can be in terms of any time-based unit provided that the units are uniform.

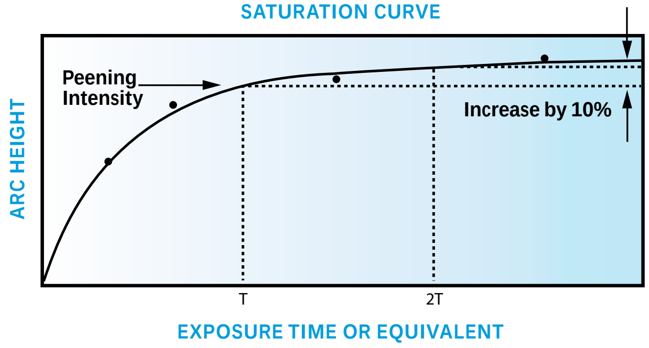

Figure 1. Almen Saturation Curve

- The Almen strip has only one function and that is intensity determination. Almen strips are not intended, nor were ever intended (except erroneously), to be used in any way to establish peening time for parts.
- The intensity value obtained by analysis of a saturation curve represents the entire curve. It is absolutely important to note that the derived intensity is independent of time. Further, It is vitally important to understand that the saturation curve is a plot of arc-height versus time and is NOT a plot of intensity versus time.
- The exposure times for Almen strips are only that and these bear no relationship to times for peening of parts, which are usually made of different material than Almen strips and respond to peening differently.
- The saturation time obtained during intensity determination is neither an independent nor a fundamental quantity and has no further use after intensity determination, except possibly as an exposure time for intensity confirmation when required.
- The time of peening, or the velocity of part/nozzle travel, is not dictated nor is it even influenced by anything done in intensity determination. Of course the same machine settings must be employed to ensure peening continuously at the desired intensity, but the peening time for a part is related independently only to peening coverage considerations.

Coverage: Some Technical Considerations

Until now, I haven't provided much technical discussion of coverage although it has been mentioned in passing. Coverage is defined as the relative amount of obliteration of or replacement of the original unpeened surface features by dents produced by media impacts. Most germane to this article is that coverage is time dependent as may be seen in the typical coverage curve shown in Figure 2. This is a plot of coverage percentage from 0 to 100% versus time of peening on the y-axis versus time (or time-related quantity such as passes) on the x-axis. The subject of coverage in peening is quite important and deserving of considerably more discussion than it is receiving here, but this is not necessary to current purposes. Here it is given limited mention because, in the current context, it is important to observe only that coverage is time dependent and that, under constant intensity and media flow rate, the progression of coverage from 0 to 100% with time occurs continuously but at a progressively declining rate. In other words, a coverage curve is a decelerating curve whereby the rate of coverage declines continuously with increasing time. Because of the subjectivity of coverage determination, normally done by optically aided visual technique and combined with the relatively slowness of rate approaching 100%, coverage is considered complete when at least 98% has been attained. This is assuming that each unimpacted area is comparable in size to a typical impact dent and that the unimpacted areas are randomly distributed. There are some individuals who believe that even small unimpacted areas can be deleterious to fatigue strength in peened parts, but this is not so. The reason is that the subsurface extent of plastic deformation associated with a peening impact dent is much greater than the size of the dent as seen on the surface. But I digress. The important aspect of coverage relative to this article is that it is time dependent and, of course, that the peening cycle time for a part depends upon attainment of a desired or required coverage amount.

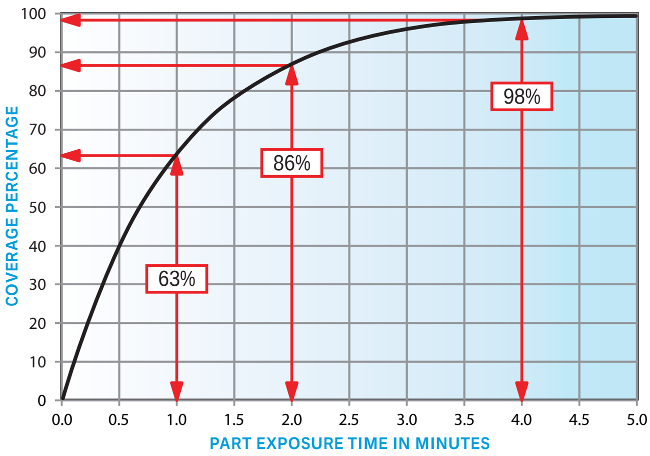

Figure 2. Coverage Curve

Summary

I have presented some basic concepts on intensity and coverage in peening. Central to discussion presented is the argument that the two concepts are separate, independently determined, and are not related by time. Further, it has been demonstrated by argument that intensity is not time dependent whereas coverage is. A most significant corollary to this is that what is done during the performance of intensity determination and what results from it, has no bearing on subsequent peening of a part in terms of coverage or resulting cycle time.

by Kathy Levy | InfoProse | www.infoprose.com

3D Printing and the Metal Finishing Industry

3D printing creates a three-dimensional solid object of virtually any shape, using a laser beam to melt the raw material and laying horizontal cross sections to build the part based on information supplied by a digital model. 3D printing for industrial applications is commonly called *additive* manufacturing because of its additive process. Traditional machining techniques mostly rely on the removal of materials by methods such as cutting and drilling (*subtractive* manufacturing). 3D-printed parts tend to be lighter than traditionally forged parts because they don't require welding, and the process generates less scrap material. A 3D printer is a limited type of industrial robot that is capable of carrying out an additive process under computer control.

NOW THAT GE AVIATION and Pratt & Whitney are using 3D printing to make metal jet engine components, it's time to think about the impact 3D printing could have on the shot peening and blast cleaning industries.

If you're surprised to read that 3D printing has progressed this far into mainstream manufacturing—albeit aerospace is a leader in manufacturing innovation—here are few examples of how the futuristic technology is progressing.

Aerospace Components

In the spring of 2013, The University of Connecticut (UConn) and Pratt & Whitney announced the opening of the new Pratt & Whitney Additive Manufacturing Innovation Center at the university. A press release from UConn cited that it is the first additive manufacturing facility in the Northeast United States to work with metals rather than plastics. The press release quoted Paul Adams, Pratt & Whitney's chief operating officer, as saying, "Additive manufacturing is complementary to traditional methods by enabling new innovation in design, speed and affordability, and is necessary to build the next generation of jet engines. We are currently using additive manufacturing to build complex components with extreme precision for the flight-proven PurePower® commercial jet engine."

When MIT Technology Review publicized additive manufacturing as one of the "10 Technology Breakthroughs of 2013," the magazine featured GE Aviation in the related article. GE made their top 10 list because "…the decision to mass produce a critical metal alloy part to be used in thousands of jet engines is a significant milestone for the technology."[1] The critical parts in the spotlight are 3D printed jet engine nozzles—GE Aviation is committed to supplying more than 85,000 3D-printed fuel nozzles for its new LEAP jet engines by late 2015 or early 2016. To help GE realize the potential of additive manufacturing, GE Aviation purchased Morris Technologies and Rapid Quality Manufacturing in 2012. Both companies specialize in additive manufacturing.

3D-printed components aren't earthbound: NASA and Aerojet Rocketdyne of West Palm Beach, Florida recently announced that they have finished testing a rocket engine injector made through 3D printing. "NASA recognizes that on Earth and potentially in space, additive manufacturing can be game changing for new mission opportunities, significantly reducing production time and cost by 'printing' tools, engine parts or even entire spacecraft," stated Michael Gazarik, NASA's associate administrator for space technology in Washington, D.C., in a press release. "3D manufacturing offers opportunities to optimize the fit, form and delivery systems of materials that will enable our space missions while directly benefiting American businesses here on Earth," said Mr. Gazarik.

Medical Implants

"3D printing is becoming more commonly used in the medical industry, specifically in product development as a way to create fast prototypes for design feasibility testing," said Scott Hatfield, Manufacturing Engineer with Medtronic. Mr. Hatfield added, "It is also used in the creation of prototype and custom manufacturing fixturing and gaging." Medtronic divisions—Medtronic-Diabetes for example—are already using 3D printing for rapid prototyping. Medtronic's new Customer Innovation Centre in Galway, Ireland has 3D printing facilities to prototype new ideas along with extensive training and education facilities.

3D printing is also developing rapidly in medical implant manufacturing. At Peking University Third Hospital


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in Beijing, Liu Zhongjun and his team of surgeons started clinical trials with 3D-printed titanium orthopedic implants last year. A typical usage is repairing a fractured pelvis with a titanium implant that fits perfectly with the anatomical structure of the pelvis. "3D printing technology has two very nice features: 1) It can print specific structures 2) It is capable of producing porous metal," Liu stated in article on his team's accomplishments. He explained that pre-clinical studies have indicated that bone can grow into the metal pores, and enhance the strength of the implant. "In the past we used clinical titanium mesh, but with the growth of bone, titanium mesh could easily stick to the bone and cause collapse. 3D printed implants fit the bone completely. And as a result, not only the pressure on the bone is reduced, but it also allows the bone to grow into the implants."[2]

Restoration of Worn Metal Parts

GE scientists have developed a 3D-printing technology they call "Cold Spray" that can rebuild worn parts without machining or welding. The additive technology is closer to 3D painting than 3D printing. According to a press release on www.worldindustrialreporter.com, metal powders are sprayed onto a worn part at high speeds to rebuild the worn elements of the parts. Spray technologies will be especially conducive to the repair of large components and have the potential to transform repair processes for industrial and aircraft components including rotors, blades, shafts, propellers and gearboxes. (You can watch a YouTube video on Cold Spray at tinyurl.com/coldspray.)

New Metal Alloys

Additive manufacturing will give product designers the ability to create new shapes and components because they won't be hampered by the limitations of today's casting and machining technology. They will need metal alloys to meet their design parameters. According to Martin LaMonica in his article on additive manufacturing for MIT Technology Review, "GE engineers are starting to explore how to use additive manufacturing with a wider range of metal alloys, including some materials specifically designed for 3D printing. GE Aviation, for one, is looking to use titanium, aluminum, and nickel-chromium alloys. A single part could be made of multiple alloys, letting designers tailor its material characteristics in a way that's not possible with casting. A blade for an engine or turbine, for example, could be made with different materials so that one end is optimized for strength and the other for heat resistance."

What Our Industry Experts Are Saying

Industry leaders share their opinions on 3D printing and its significance to the shot peening and blast cleaning fields.

Scott Hatfield, *Manufacturing Engineer for Medtronic*
If 3D printing makes shot peening obsolete on a medical implant, then that implant didn't need shot peening in the first place. Medical implants are shot peened to create a layer of residual compressive stress to increase fatigue strength. If this layer of residual compressive stress is needed to get the desired performance out of an implant, simply changing the method of manufacturing to 3D printing will not create a surface that is in a state of compression. It will still retain tensile stresses at the surface and will require the same secondary operations as they do now to facilitate the creation of residual compressive stresses to counter the inherent tensile stresses in the material.

Walter Beach, *Vice-President of Peening Technologies*
Peening Technologies is shot peening aerospace engine components manufactured with 3D printing. As far as blast cleaning, parts may still need post work to remove slag/residual material.

Kumar Balan, *Director, Global Sales for Empire Abrasive Equipment*
The threat to shot peening is minimal. At this stage, 3D printing is a complement to traditional manufacturing processes and together they increase efficiencies. If additive technology achieves the high production rates possible with current processes, it will be yet another type of manufacturing for the shot peening world. In other words, the tensile stresses produced by this manufacturing process will still have to be countered by compressive stresses provided through shot peening.

One could make an argument that being an "additive" process and not a "subtractive" process like current manufacturing, the tensile stresses created by 3D printing may not be a threat. I'm eager to see how our aerospace design engineers respond to that and will be very surprised if they eliminate a proven stress-countering process, especially given the time involved to update our stringent specifications and audits. It takes several years to approve the use of different and better peening media than established ones! In my mind, the larger threat to shot peening is alternative materials such as composites and exotic alloys of aluminum and titanium. That said, aerospace engineers that I've spoken with don't perceive these materials as replacing conventional materials.

Blast cleaning removes scale, rust and burrs and it etches, deflashes, and more. Although some 3D-printed parts may not require a step like deburring, blast cleaning is here to stay as long as the parts are metallic, especially because of heat treating. Metallic components go through heat treatment processes after forging, casting and other conventional manufacturing processes. A 3D-printed component will also have to be heat treated. Heat treatment produces scale, and components stored long enough oxidize to develop rust. These contaminants will have to be blast cleaned regardless of the upstream production process.

Blast cleaning is widely used in high-production automotive facilities. I don't see 3D printers advancing to the extent of being capable of producing large quantities; for example, 10-14 tons of brake drums or similar components an hour, much less at an operating cost that's competitive to a metal foundry. Given the amount of infrastructure and

capacity being added to foundries and forge plants around the world today, and their constant search to reduce operating costs by adopting newer technologies, the limitations of 3D printing must be evident to experts in those industries. In addition, the large industry sector in raw sheet steel, structural steel and other weldment will still rely on blast cleaning to clean their stock before downstream fabrication processes. As a complementary process, however, I do see 3D printing shrinking the development time of tooling and patterns in foundries and forge plants.

Jörg Kaltmaier, *Project Planner with voxeljet AG*
Cast parts made from voxeljet models are like any cast parts. They need to be cleaned, blasted and machined. (voxeljet is a leading manufacturer of industrial 3D printing systems and operates what it believes to be one of Europe's largest service centers for the "on-demand production" of molds and models for metal casting.)

Are We Finished?
Not by a long shot…at least in the foreseeable future. While it's difficult to predict how emerging technologies will eventually impact us, for the most part, components that benefited from shot peening and/or blast cleaning after conventional subtractive manufacturing require metal finishing treatments after today's additive manufacturing. In addition, the new technology faces challenges before it will be widely accepted:

- High cost: The price of materials and equipment are out of reach for most manufacturers
- Slow speeds: The pace of 3D printing will need to increase a hundredfold to compete with conventional manufacturing in many applications[3]
- Lack of raw materials: Even though companies like GE are experimenting with new alloys specifically developed for additive manufacturing, only a few metals and plastics are currently suitable for the process
- Poor consistency: Parts are not always identical from machine to machine, or from day to day on the same machine[3]

Even more encouraging are the innovators in our industry that are already looking for ways to take advantage of additive manufacturing. "Peening Technologies is working with a 3D printer services supplier to develop polymer masks. The technology is very expensive now, but it will definitely have a place in creating very sophisticated and resilient polymer masks for aerospace components," said Walter Beach. "I can see purchasing a 3D printer in the future."

1. http://www.technologyreview.com/featuredstory/513716/additive-manufacturing
2. http://3dprinterplans.info/beijing-hospital-uses-3d-printed-titanium-orthopedic-implants-for-patients
3. Freedman, David H., "Layer by Layer," MIT Technology Review, December 19, 2011.

by Kumar Balan | Global Sales | Empire Abrasive Equipment

Control Systems in Shot Peening – A Discussion

ELECTRICAL AND ELECTRONIC CONTROL SYSTEMS in shot peening equipment have greatly evolved in the last decade. Any peening machine manufactured now has, at the bare minimum, a Programmable Logic Controller (PLC) to monitor and control the programmable features of the process with an Human Machine Interface (HMI) so the machine operator can command the machine to perform desired tasks.

Shot peening machines of the past relied on relay logic controls, pushbuttons and other forms of controls/interfaces. A large part of this evolution was driven by users in aerospace who, with their familiarity of CNC controls from other equipment such as machining centers, raised the benchmark for shot peening equipment. Also, their desire to promote repeatability, accuracy and reliability along with process reporting requirements made it a compulsion for electrical controls in shot peening equipment to be upgraded to current levels. Conformance to specifications and audit criteria also assisted in this evolution.

These are steps in the right direction, but peening equipment may now be more complicated than it needs to be. Veteran experts in our industry often say, "Blast cleaning and shot peening as processes are not as complicated as the science of rocket propulsion!" There is a lot of truth to this statement, especially when compared to other machine tools such as multiple-axis machining centers and routers where precision is critical.

With this in mind, we should ask, "Are we over-complicating our peening machines?" Control sophistication comes at a cost, and it could easily be the single most expensive cost component in machines.

Process Controls in Shot Peening

In order to discuss electrical/electronic controls, we must understand the role played by process controls in shot peening. The prime variables that control the outcome of a peening cycle can be categorized into the following:

1. Impact Energy - represented by velocity of the blast media and its type/size/hardness
2. Exposure Time - this determines the percentage of coverage on the component being peened

Let us analyze the factors that determine impact energy:

- In a centrifugal wheel machine, the velocity is determined by wheel diameter and its speed of rotation. Gradual wear of wheel parts also has a marginal effect on the impact energy. Media velocity and impact energy are directly proportional to wheel speed. Variable frequency drives for blast wheels, some with closed loop feedback, ensure maintenance of constant wheel rotational speed.
- In an airblast machine, the velocity is determined by the air pressure/nozzle orifice size in direct proportion. Also, like with a centrifugal wheel, nozzle wear has an effect on the generated impact energy. Closed-loop feedback or air pressure monitoring will correct fluctuations in air pressure delivered to the blast nozzle.
- In both cases, type and quality of media affects the end result. Cast steel shot, the most commonly used peening media, is susceptible to the inherent imperfections of a cast product. MIL-specified cast steel shot is typically used for shot peening applications and the cast media is pre-screened and imperfections are separated out to provide ideal media conditions for peening.
- Size consistency of blast media is also very critical in peening applications. A mixture of blast media sizes will lead to difficulty in achieving saturation—the measure of process stability. Some of us have experienced the occurrence of the 'double knee' when plotting the saturation curve, signifying deterioration in the quality of abrasive in the machine, typically due to contamination of two or more sizes of media. Size consistency is kept in check by using a vibratory classifier. Some aerospace applications also require the use of a spiral separator to remove broken media from the mix (shape classification).

In comparison, the factors that determine exposure time are relatively simple. Peening coverage is always checked directly on the component being peened. Exposure time can be changed by changing the speed of the conveyor in an inline machine, or the speed of the rotary table in a table-type machine. Part exposure time is independent of the time taken to achieve time "T" on our saturation curve.

Simple Control Architecture

How is this discussion relevant to the use of a PLC in our shot peening machine? The PLC has digital and analog inputs and outputs that monitor the health of all the elements that have an effect on the impact energy. For example, an inbuilt digital timer in the PLC will trigger an alarm to shutdown the process if the air pressure doesn't reach the pre-set/desired

Continued on page 26

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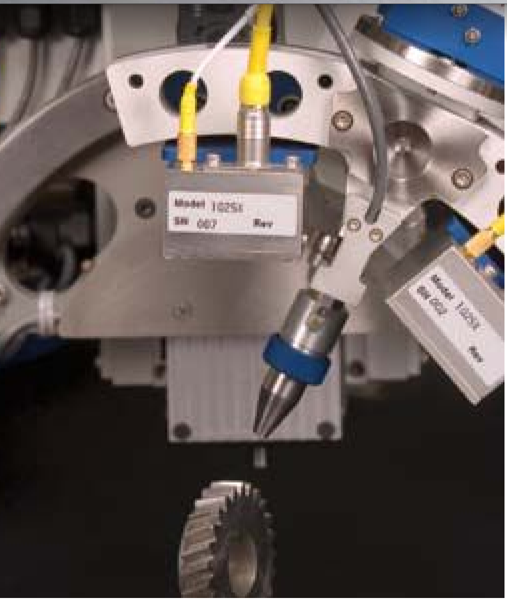

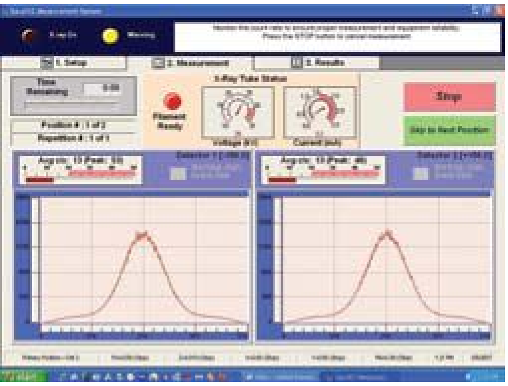

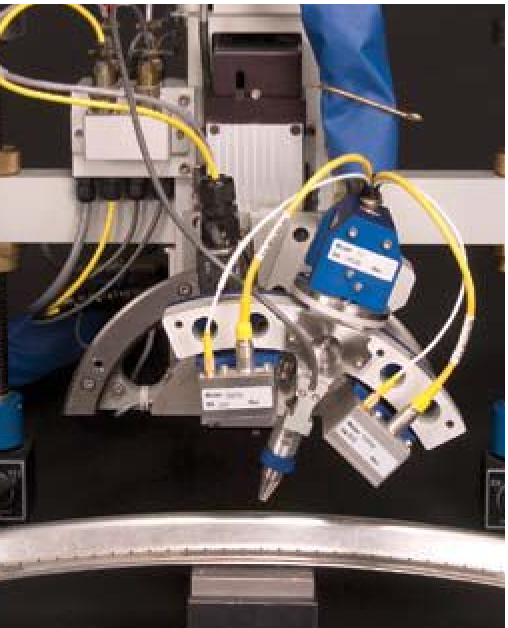

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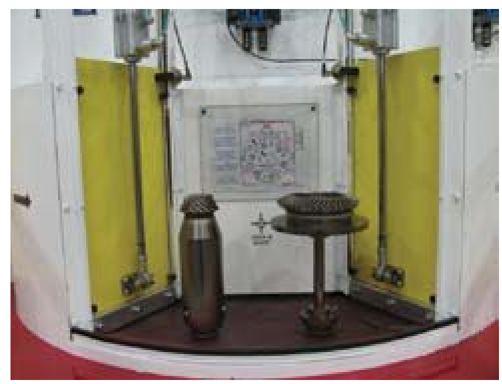

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value within a specified time, or if it exceeds the pre-set value. Similarly, a feedback loop will attempt to correct the wheel speed in a centrifugal wheel-type machine through digital outputs from the motor and variable frequency drive. The diagram below is of a simple control system.

The system PLC also stores recipe/technique information and provides the data for downstream processing through an Ethernet (or similar) connection. The motors and associated variable frequency drives in the architecture could drive a centrifugal blast wheel or different axes of a multi-axis nozzle manipulator. The output is graphically represented in an HMI (touchscreen or otherwise) which also provides the ability to create recipes, store and retrieve when required.

The Role of Specifications

Specifications and their interpretation also had a role to play in the evolution of controls. For our purposes, let's refer to two of the commonly used specifications:

AMS 2430 (Rev. S, revised 2012-7) - (R) Shot Peening, Automatic (*only relevant discussion points are cited from the specification*)

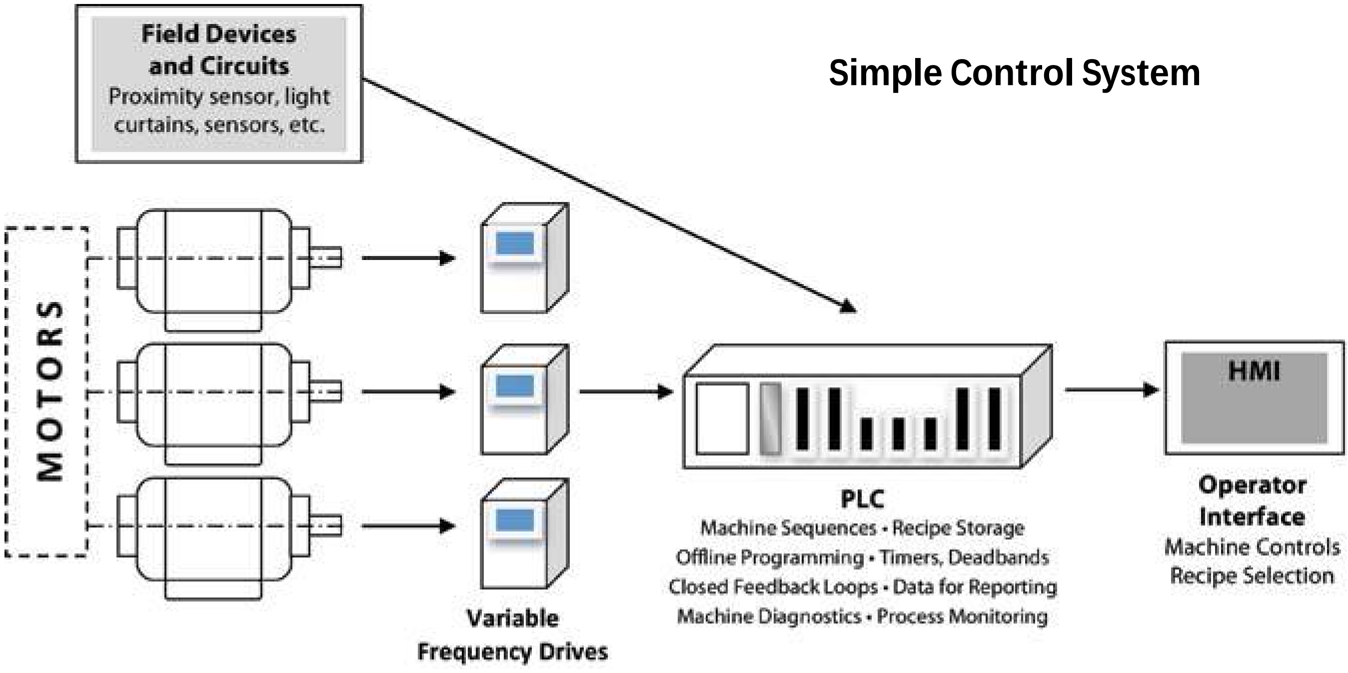
- The purpose (1.1) is identified as "specification covers the requirements for automatic shot peening of surfaces of parts by impingement of media, including metallic, glass or ceramic shot."
- 3.2.1.1 states, "the peening machine shall run automatically and may be computer controlled."
- Under 8. Notes, the specification defines Automatic (8.2.1) as "A class of peening machine that precludes use of manual movement or either the shot stream or the work part but relies upon mechanical means to provide these features".
- 8.4.5.3: Peening Equipment states as follows, "Robotic machines provide line of sight media impingement for a wide variety of geometries reducing multiple setups. Computer controlled and monitored machines offer the industry's best practice for process control. Computer controlled shot peening equipment should be considered for use in man flight [*sic*] vehicle components, components where shot peening is used as part of the design strength of the component, and components that are considered critical to system success."

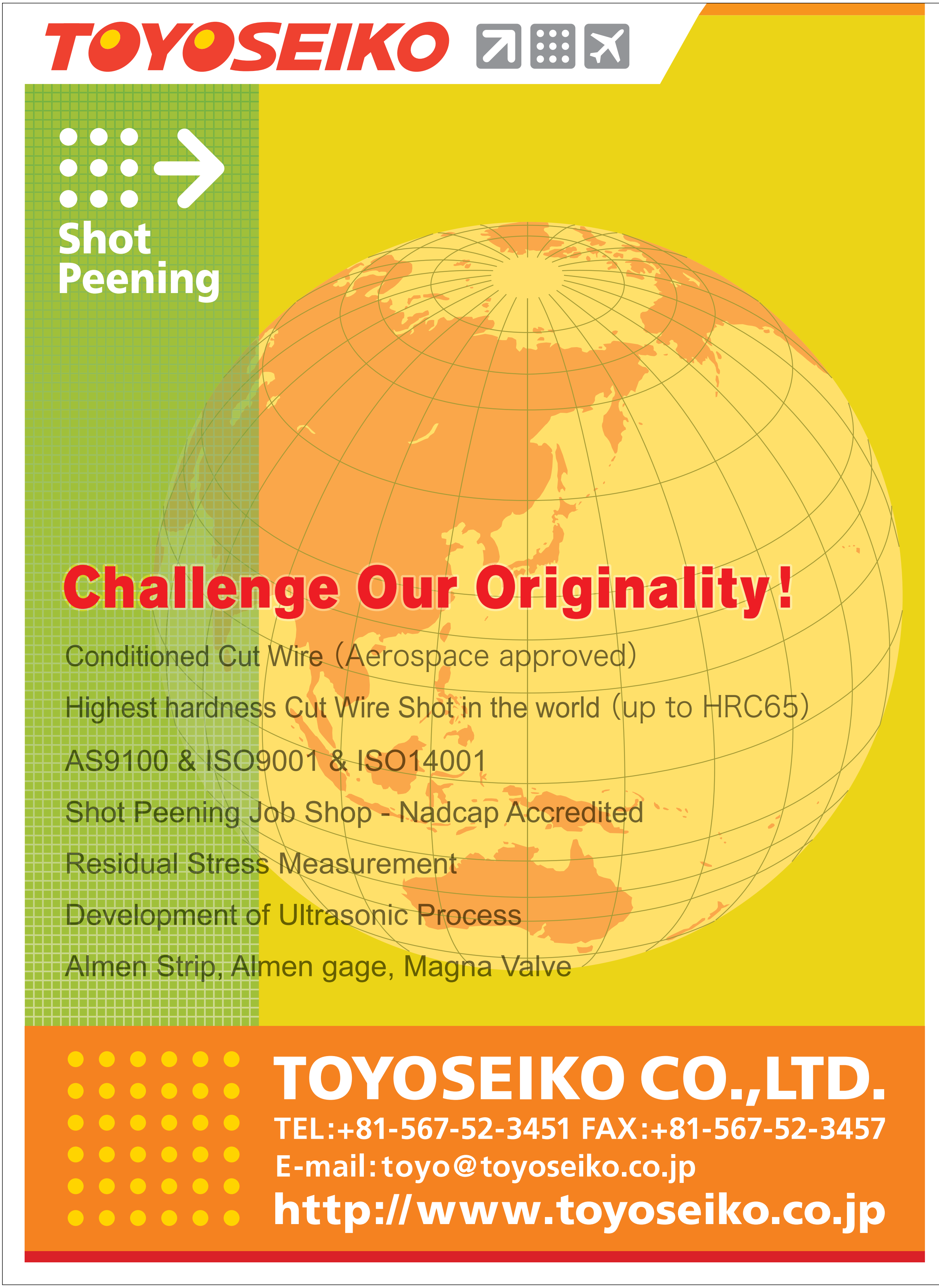
AMS 2430 also elaborates on maintenance of media quality in the machine, measurement of results and other aspects for a thorough peening process set-up.

The terms "computer controlled and monitored" could be open to interpretation not only in terms of this specification, but also in general use of the terminology. However, our industry has taken the safe approach and automated its controls to use PLCs and PCs. Interestingly, the specification defines the process without forcing the user to employ a particular type of control system in the machine. In the simple architecture shown below, the enhancement to "computer controlled and monitored" will result in the use of an industrial PC to store a greater number of recipes/techniques and also provide the interface to transfer process information through an electronic data highway to the customer's central controls system for further processing. Some industrial PCs are also available with a soft PLC integrated into the PC as a software PLC. This results in less hardware with a possible cost savings.

AMS 2432 (Rev. C, revised Sept 2007) - Shot Peening, Computer Monitored (*only relevant discussion points are cited from the specification*)

- The purpose (1.1) is identified as "specification establishes the requirements for computer-monitored peening of parts surfaces".

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- 3.2.4 states that "Peening machines shall be equipped with computers for continuously monitoring and recording the parameters shown in Table 1 within the tolerance indicated." Table 1, paragraphs 3.2.4.1 to 3.2.4.12 lists all critical parameters such as media flow, air pressure, wheel speed, nozzle speed, and table speed. with their respective allowable process tolerance (shutdown limits).

AMS 2432 elaborates on process monitoring and the user could draw similar inferences about the use of computers/ industrial PCs when referring to this and AMS 2430. However, AMS 2432 provides background information on a much debated topic in our industry—motion control.

Motion Control in Shot Peening Equipment

To quote from AMS 2430S 3.2.1.1: "…The machine shall provide a means of propelling, at a controlled rate, media with air pressure against a part…The nozzles and the part shall be held and moved mechanically. The part shall not be subject to any random movement during the process. The machine shall be capable of consistently reproducing the required shot peening intensities."

The goal of a peening process specification is repeatability and accuracy in a reliable machine. With regards to motion control related to shot peening, this means maintaining a constant stand-off distance from the component being peened, and repeating it when the same part is processed at a later date. This also means maintaining the same angle of impingement to all surfaces of the component, usually between 45 to 80 degrees, preferably towards the higher end of the range. AMS 2432C, 3.2.4.11 and 3.2.4.12 tabulate process tolerances for nozzle/wheel position and table/part indexing at 0.062" (1.57 mm)/5 degrees. My machine programmer colleagues in this industry will agree that these tolerances are a far cry from tolerances of 0.00004" to 0.004" that could be possible and even a requirement with other machine tools. In order to achieve such tolerances, the use of CNC machines is inevitable.

A survey of various peening applications over the years makes it abundantly clear that such tolerances in a shot peening machine have never been called for. The peening process is very forgiving in terms of tolerances. Accuracy of ± 0.005" and repeatability of ± 0.002" are well within compliance with all specifications drafted to date for peening processes. Such values can be easily achieved using servomotors and motion controllers without the need for CNCs and a knowledge of their programming codes.

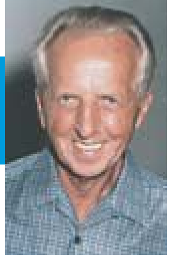
This discussion is not to advocate the use of one system over the other, in this case the use of motion controllers over CNCs, but to evaluate the need and simplify our equipment for a relatively simple process (shot peening).

A shot peening machine with simpler controls will allow the operator and maintenance personnel to focus on the most important aspect—the peening process itself. The use of robots in shot peening machines has added a new dimension to our discussion where complete proven and packaged solutions have eliminated discussions of motion control and G codes. Although not applicable for all applications, robots are also commonly used with nozzle manipulators to increase the versatility of the shot peening machine to handle parts of varying geometry.

Summary

- The success of your peening operations depends on more than just controls. When your machine specification lists a "CNC Peening Machine," it is beneficial to evaluate your peening process and determine whether CNC is really a requirement. Motion controllers are usually less expensive than CNCs and don't require a special programming language. There is no argument about the aerospace customer's familiarity with CNC equipment, but it has to be made clear that shot peening cannot be placed in the same category as a CNC milling center when discussing the process.
- The next generation of shot peening machines need to emphasize user-familiarity with the process and make the controls intuitive with less needless sophistication. This can be achieved only if the user takes ownership of the equipment and develops the process with established and documented procedures.
- The peening process has been established with proper measures for process stability such as the plotting of saturation curves. It's important that shot peening be treated as a special process and not an extension of an existing blast cleaning process.
- Machines are secondary; your peening process design comes first.

A robotic peening cell with an ABB 6-axis robot to control nozzle movement and a DC or Servo drive to control part movement.



ACADEMIC STUDY

by Prof. Dr. David Kirk | Coventry University, U.K.

Estimate Compressed Layer Depth by Using Almen Peening Intensity

INTRODUCTION

Shot peening induces a surface layer that contains compressive residual stress. It is this compressed surface layer that is largely responsible for improved fatigue performance of components. The depth of the layer is therefore of pivotal importance to users. X-ray stress analysis, involving multiple layer removals, is the most accurate method of determining the depth of the compressed layer. Indirect methods, such as micro hardness profiles, also involve multiple layer removals. Both methods are tedious and expensive and are carried out after peening.

Almen peening intensity is necessarily available for every peening operation. This article describes how Almen peening intensity can be used as an acceptable guide to the depth of the compressed surface layer.

Most shot-peened components go directly into service. Occasionally, components are fine-finished after peening. This is done either to change the smoothness of the surface or to induce minor dimensional changes. Fine-finishing processes include polishing, lapping, honing and sanding. AMS 2432B provides some guidance as to the amount of material that can be removed without severely affecting the property enhancement provided by shot peening.

This article describes the principles that lie behind the limitation of surface removal by fine-finishing. Essentially only a small fraction of the compressed surface layer should be removed. The thickness of the compressed surface layer is rarely measured, whereas the peening intensity is, of necessity, always available. AMS 2432B attempts to use peening intensity values as a guide to the amount of material that can be removed. To some extent the article is complementary to some sections of AMS 2342B.

DEPTH OF COMPRESSED LAYER

The depth of the compressed surface layer, **D**, is of primary importance with respect to fine finishing – it controls the amount of material that can safely be removed. A typical residual stress profile is shown as fig.1. **D** varies with both peening intensity and hardness of the component material. 10% of the depth, **D**, would seem to be a reasonable maximum amount that could be removed without any significant adverse effects on service performance.

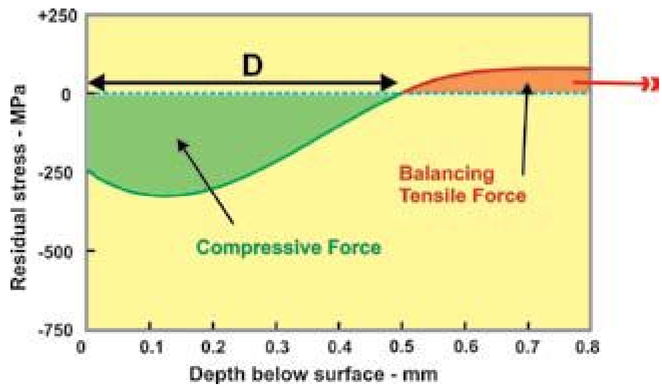


*Fig.1. Typical shot peening residual stress profile having a compressed layer depth, **D**.*

RELATIONSHIP BETWEEN DEPTH OF COMPRESSIVE STRESS AND ALMEN 'A' PEENING INTENSITY

It is reasonably obvious that the depth of the compressed surface layer will increase with increase of peening intensity. Also obvious is that the depth will be greater for soft materials than it will be for hard materials – for a constant peening intensity. Table 1, which uses some of the values in Table 2 of AMS 2342B, quantifies the effect of material strength.

In Table 1, a fixed Almen 'A' intensity, 0.20 mm, has been applied to a range of materials. For the values given, the average measured depth of 0.182 mm for **D** is certainly close

Table 1. Depths of Compressive Stress, D, for peening intensity of 0.20mm using 'A' strips

STRIP TYPE	A
Intensity - mm	**0.20**
Material	**D - mm**
Aluminum	0.25
Titanium	0.18
Steel < 1379 MPa	0.20
Steel 1379 MPa	0.13
Nickel Alloys	0.15
Average	**0.183**

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to the applied peening intensity of 0.20mm Almen 'A'. This gives us the very useful relationship that:

The depth of compressive stress is, on average, approximately equal to the Almen 'A' peening intensity.

The values given in Table 1 refer to a specific peening intensity – 0.20 mm A. It is, however, reasonable to suppose that the depth, **D**, will be linearly proportional to peening intensity over the range of allowed range of peening intensities. This effect is illustrated by fig.2 – for which the 0.20 mm 'A' values have been extrapolated.

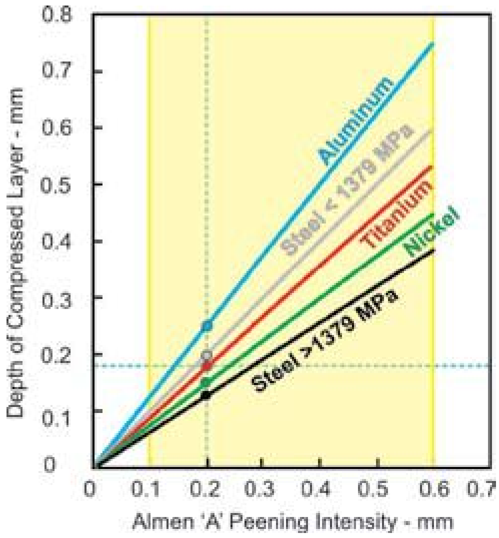

Fig.2. Projected variation of compressed layer depth with Almen 'A' peening intensity.

A second important observation is that:

The range of compressed layer depths (in Table 1) is in a ratio of less than 2 to 1.

To many shot peeners it might appear surprising that the range of depths is so small – given the large range of corresponding material strengths. It has, however, been shown (TSP 2004) that the diameter of a peening indent is inversely proportional to the fourth power of the material's Brinell hardness. A range of 2 to 1 of indent diameters would therefore need the hardness to vary by a factor of 16 (2^4 = 16). Compressed layer depths are directly proportional to indent diameters and Brinell hardness ratios are very similar to tensile strength ratios. For the materials given in the table the range of tensile strengths is about 17 to 1 – which is very close to 16 to 1. Extending that argument, a range of 3 to 1 of compressed layer depths would require the tensile strengths to vary by a factor of 81 to 1 (81 being 3^4) which covers the full range of tensile strengths for available shot-peened materials.

Fig.3 illustrates the relationship between indent diameter and compressed layer depth. For a soft material, **A**, the indent diameter, $\mathbf{d_A}$, and the compressed layer depth, $\mathbf{D_A}$, are both less than those for a hard material, **B**, - $\mathbf{d_B}$ and $\mathbf{D_B}$.

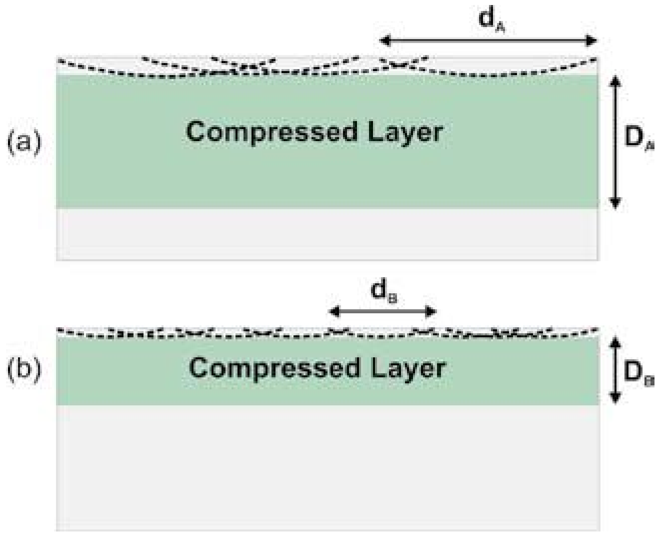

*Fig.3. Doubling indent diameter doubles compressed layer depth, **D**.*

Fig.2 indicates that for the compressed layer depth, D, that:

(1) D is approximately equal to the Almen 'A' peening intensity for materials of average tensile strength,

(2) For very soft materials, such as aluminum, D can be as much as 50% more than the Almen 'A' peening intensity and

(3) For very hard materials, such as high-strength steels, D can be as little as half of the Almen 'A' peening intensity.

Going from peening intensity plus 50% down to half of peening intensity is a range of 3 to 1. That, as mentioned earlier, corresponds to a range of 81 to 1 in tensile strengths of component materials.

RELATIONSHIP BETWEEN DEPTH OF COMPRESSIVE STRESS AND TYPE OF ALMEN PEENING INTENSITY

Almen 'N' and Almen 'C' strips are also used to measure peening intensity–though not as often as are Almen 'A' strips. Table 2 (page 34) uses all of the values published in Table 2 of the AMS 2432B Specification. Almen 'N', 'A' and 'C', intensities of 0.20 mm have been applied to a range of materials and corresponding depths of compressive stress are presented.

The ratios of 3.14 (for A/N) and 2.95 (for C/A) are close to the 'conversion factors' specified in J442. Those are that "C strip reading x 3.5 = A strip reading and A strip reading x 3.0 = N strip reading". Hence, as guiding principles, it can be postulated that:

(1) D is approximately equal to one-third of the Almen 'N' peening intensity for materials of average tensile strength and


Ceramic Shots
Types Hardness - average
CB & CZ > 700 HV
CY > 1000 HV
Typical Sizes
0.0025″ - 0.005″ 0.005″ - 0.01″
0.01″ - 0.018″ 0.024″ - 0.033″
Size (Fine Shot)
0.004″ 0.003″ 0.002″
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(2) D is approximately equal to three times the Almen 'C' peening intensity for materials of average tensile strength.

It has already been shown that: (a) for very soft materials, such as aluminum, **D** can be as much as 50% more than the Almen 'A' peening intensity and (b) for very hard materials, such as high-strength steels, **D** can be as little as half of the Almen 'A' peening intensity. Extending this to 'N' and 'C' strips allows the construction of the graphs shown as figs.4 to 6.

An approximate compressed layer depth can be read off from the appropriate figure using a measured value of Almen peening intensity. For example: in fig.4 a measured Almen peening intensity of 0.5 mm 'N' indicates that the compressed layer depth will be between 0.08 mm and 0.25 mm – depending on component hardness. If the component is known to be of average hardness the depth would be indicated as being 0.15 mm.

PERMITTED LAYER REMOVAL BY FINE FINISHING

A 10% removal of the compressed layer depth would appear to be a reasonable maximum. There are, however, some specifications that provide definite limits – notably AMS 2432B. This allows for the fact that the actual depth of the compressed layer is not usually measured. Instead it relies on the readily available Almen peening intensity values – as stated earlier. A further restriction requires that "… evidence of peening impressions shall remain after material removal."

Specified Amount of Layer Removal

AMS 2432B states: "For parts with a specified minimum tensile strength of 220 ksi (1517 MPa) and over, no more than the equivalent of 5% of the specified minimum "A" intensity …shall be removed from the surface". Hence it would follow that if the specified range was 0.20-0.30mm Almen 'A' then 5% of 0.20 mm would be the maximum that could be removed from components for which the tensile strength was at least 220 ksi (1517 MPa). 5% of 0.20 mm is 0.01 mm. Using fig.5 indicates that the compressed layer depth for very hard materials is about 0.10mm. Removal of 0.01 mm from a layer depth of 0.10 mm corresponds to removing 10% of the layer's thickness.

AMS 2432B also states: "For other parts, no more than the equivalent of 10% of the specified minimum "A" intensity … shall be removed from the surfaces". If the specified range was 0.20 - 0.30mm Almen 'A', then 10% of 0.20 mm would be the maximum that could be removed from components for which the tensile strength was less than 220 ksi (1517 MPa). 10% of 0.20 mm is 0.02 mm. Using fig.5, a compressed layer depth of 0.20 mm appears for materials of average tensile strength. Hence for components of average tensile strength 0.02 mm could be removed, which corresponds, again, to 10% of the compressed layer thickness.

AMS 2432B accommodates the fact that intensity may have been specified using either 'N' or 'C' scales. It does this

Table 2. Depths of Compressive Stress (AMS 2432B values)

STRIP TYPE	N	A	C
Intensity-mm	0.20	0.20	0.20
Material	Depth of Compressive Stress - mm		
Aluminum	0.08	0.25	0.69
Titanium	0.05	0.18	0.46
Steel < 1379 MPa	0.06	0.20	0.64
Steel > 1379 MPa	0.05	0.13	0.38
Nickel alloys	0.05	0.15	0.51
Averages	**0.058**	**0.182**	**0.536**

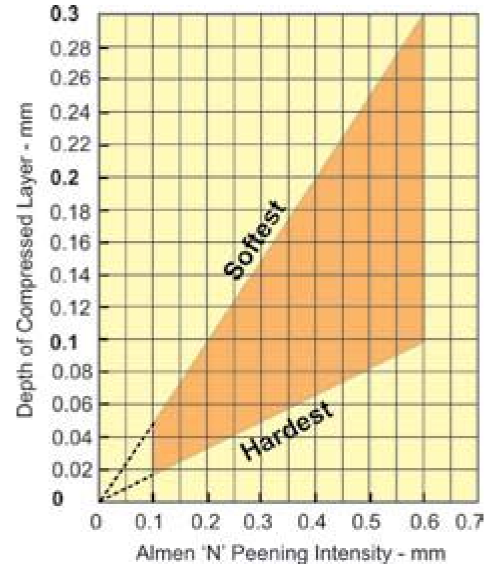

Fig.4. Guideline Diagram for Conversion of Almen 'N' intensity to Depth of Compressed Layer.

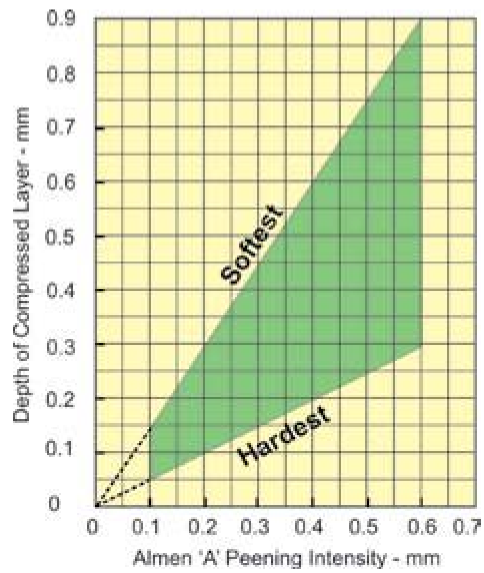

Fig.5. Guideline Diagram for Conversion of Almen 'A' intensity to Depth of Compressed Layer.


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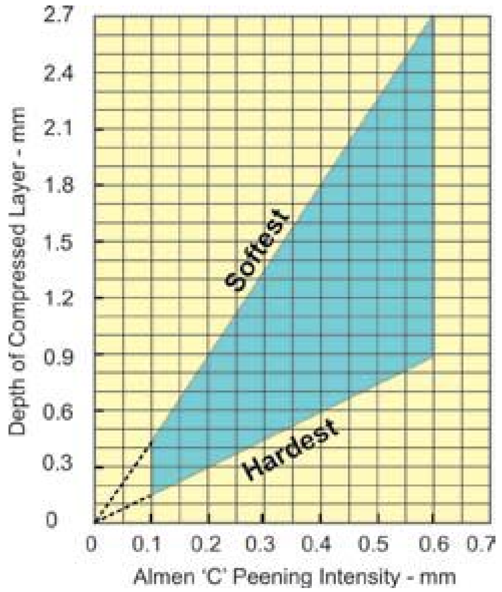

Fig.6. Guideline Diagram for Conversion of Almen 'C' intensity to Depth of Compressed Layer.

by using the phrase "… or equivalent "N" or "C" intensity (See 8.6)…" This applies for parts with a minimum tensile strength of 220 ksi (1517 MPa). Section 8.6, Intensity Comparisons, contains the familiar (a) "…Type "A" test specimen deflection may be multiplied by three to obtain the approximate deflection of any Almen test strip Type "N" specimen when shot peened with at the same intensity" and (b) Type C Almen test specimen deflection may be multiplied by 3.5 to obtain the approximate deflection of a Type A Almen test strip when shot peened with at the same intensity". Two examples are:

(1) A specified range of 0.35-0.50 mm Almen 'N' intensity for parts with a minimum tensile strength of 220 ksi (1517 MPa) means that first we must divide the minimum 0.35 mm by 3.5 (giving 0.10 mm) and then divide that by 20 (to give the 5% allowance). This yields 0.005 mm as the maximum that can be removed by fine finishing. Using fig.4 indicates that for an Almen intensity of 0.35 mm 'N' the compressed layer depth would be about 0.058 mm. Removing 0.005 mm from a depth of 0.058 mm is about 9%.

(2) A specified range of 0.30-0.45 mm Almen 'C' intensity means that we multiply the minimum 0.30 mm by three (to give 0.90 mm) and then divide by 20 (to get 5%) giving 0.045mm. Using fig.6 indicates that the compressed layer depth (for hardest material) would be about 0.45mm. Removing 0.045 mm from 0.45 mm is 10%.

Somewhat ambiguously, for "other parts" i.e. of lower tensile strength, AMS2432B refers to its section 8.3.4.2 for guidance on equivalence. That section is, in fact, simply the Table 2 mentioned earlier in this article. For practical reasons it is better to follow the 'equivalence' defined in the previous paragraph. The following two examples refer to "other materials" i.e. less than 220 ksi (1517 MPa).

(3) A specified range of 0.35-0.50 mm Almen 'N' intensity means that again we divide the minimum 0.35 mm by 3.5 to give 0.10 mm. This can now be divided by 10 (to give the 10% removal allowance. Hence we are allowed to remove 0.01 mm. Using fig.4 at 0.35 MM Almen 'N' the compressed depth is about 0.10 mm – for components of average tensile strength. That again corresponds to 10%.

(4) A specified range of 0.30-0.45 mm Almen 'C' intensity means that we multiply the minimum 0.30 mm by three (to give 0.90 mm) and then divide by 10 (to get 10%) giving 0.090mm. Using fig.6 indicates that the compressed layer depth (for material of average hardness) would be about 0.90 mm at 0.30 mm Almen 'C' intensity. Removing 0.090 mm from 0.45 mm is, yet again, 10%.

Evidence of Peening Impressions

AMS 2342B also requires that if fine finishing has been applied then "…evidence of peening impressions shall remain after material removal." It has been shown, in the previous section, that up to about 10% of the compressed layer thickness can be removed by fine finishing. Such an amount can only be removed if evidence of peening remains. This can only be achieved if the peened surface roughness exceeds 10% of the compressed layer depth, **D**.

Fig.7 is a schematic representation of a peened surface with a roughness just exceeding 10% of **D**. This shows a region of potential "evidence" of prior shot peening.

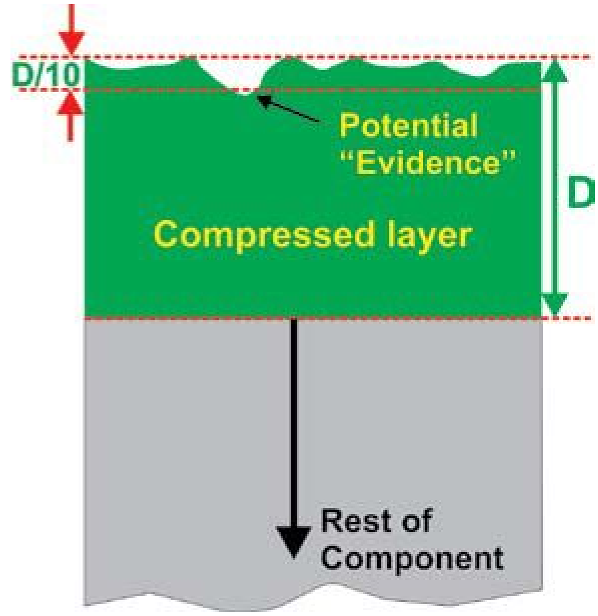

Fig.7. Surface roughness just exceeding 10% of the compressed layer depth, ***D****.*

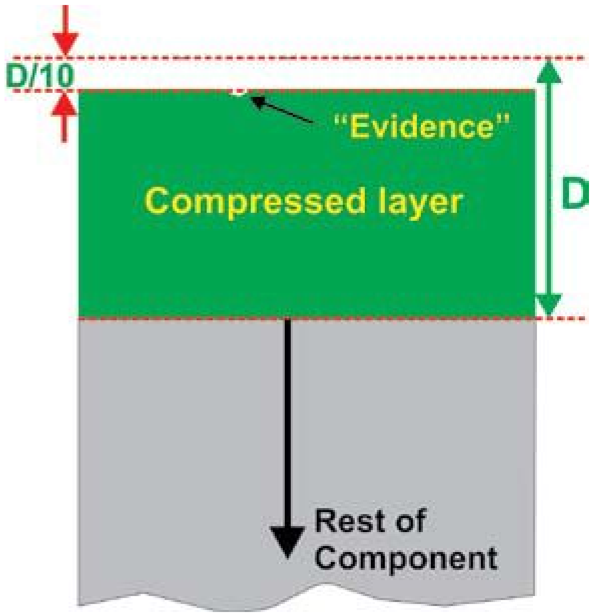

*Fig.8. Fine-finished surface with 10% removal of compressed layer depth, **D**.*

With 10% of the compressed layer depth, **D**, removed we have the situation represented in fig.8. The required "evidence" of shot peening is indicated in fig.8.

Normally, significantly less than 10% of the compressed layer depth would be removed by fine finishing. It is noteworthy that permitted material removal only involves 'slicing off the tops' of the roughness profile.

Compliance with the requirement to provide "evidence of prior peening" requires some expertise in identifying such "evidence". A simple way to obtain this expertise involves fine-finishing shot-peened Almen strips. Fig.9 shows an Almen 'A' strip that has been hand-polished in just a part of its convex surface - Blu Tack™ being used on the concave surface to provide grip. After just twenty strokes on medium-grade wet-and-dry emery paper the central region was completely devoid of any "evidence" of shot peening. Away from this region "evidence" progressively appears.

Fig.9. Hand-polished Almen 'A' strip showing area of complete indentation removal.

DISCUSSION

It has been shown that reasonable estimates of compressed layer depth can be obtained using the corresponding Almen peening intensity values. Such estimates would be of particular value in the planning stages of specifying a shot peening treatment for new components. It is important to realize, however, that final implementation should involve confirmation. This is classically available using x-ray diffraction techniques. They do require multiple layer removal and are, therefore, necessarily, expensive.

The analysis presented in this article relies entirely on the published values of layer depth versus Almen intensity presented in AMS 2432B. Further evidence can be acquired by comparing individual published values with the diagrams that have been presented.

Fine-finishing of shot-peened components is occasionally necessary. One question that has been asked is "How much of a shot peened surface can be removed without adversely affecting fatigue performance?" This article shows that, by following the AMS 2432B guidelines, less than 10% of the compressed layer depth will have been removed. Removal "slices off the tops" of the roughness 'hills'. These contain a relatively-low level of compressive residual stress. Fine finishing, of itself, introduces a high level of compressive residual stress. It follows that controlled fine finishing should not reduce fatigue strength and might even improve it.

by Brigitte Labelle & Sylvain Forgues | Shockform Aeronautique Inc.

Customer Insights on the FlapSpeed® PRO

THE ORIGINAL FLAPSPEED® CONTROLLER was introduced in 2008 to provide more control and visibility to the flapper peening process. In the last few years, hundreds have been sold to OEMs, MROs, airlines and contract peening shops. A new version, the FlapSpeed® PRO, has been released and it offers several new features including an integrated saturation curve solver.

We invited two clients with much know-how in flapper peening to discuss their work and experience using the FlapSpeed® Controller and to give us their thoughts on the new FlapSpeed® PRO.

Olivier Gauthier is a Maintenance Supervisor at Nolinor Aviation, an air transport company that specialises in commercial charter flight. **Lance Welsh** is an Aircraft Maintenance Technician in a large MRO facility for military and commercial aircraft.

Interview with Olivier Gauthier

Hello Olivier, tell us about Nolinor

Nolinor is an airline operating mostly in Canada's Northern territories. We transport miners, workers, outfitters and cargo. Our pilots land on airfields, gravel roads, frozen lakes and often in extreme weather conditions. Nature offers enough challenges that we do not want our flight team to ever worry about their aircraft. Our fleet of Boeing 737-200 and Convairs 580 are scrutinized after each flight and when an aircraft leaves the hangars after maintenance we want to be sure it is in mint condition. We are very careful with our inspection and repairs.

The FlapSpeed® PRO kit gets a lot of use at Nolinor. The Canadian airline now does all of their rotary-flap peening in-house and no longer depends on an outside resource.

What is a typical repair at Nolinor?

We do a thorough inspection when an aircraft comes in. We find corrosion on machined parts, extrusion, flap tracks and on primary structural components. After we document the locations that need repair, we remove the corrosion or damages by blending the components. After blending, we peen the parts. Some parts were not originally peened, like the extrusions, but after blending, these parts are peened, too. We normally have to peen at a 10A to 16A intensity.

How does a FlapSpeed® Controller help in your maintenance procedures?

We used to subcontract our flapper peening. We were dependant on the availability of the subcontractor and we did not have any way to confirm the quality of the work. At the end, I was the one signing off the aircraft but without any guaranty of quality of the repair. Our subcontractor would show up with a grinder and few consumables, and that was it.

After one questionable repair, we decided to acquire our own flapper peening equipment. On the Internet, we found

Olivier Gauthier, a Maintenance Supervisor at Nolinor, uses the FlapSpeed® PRO to peen a part after repair.

references to standard grinders and electric motors as well as the FlapSpeed® Controller. At first, we tried flapper peening with a standard grinder. We quickly realised that it was not giving us the repeatability, the reliability and the visibility we needed. That is when we contacted Shockform Aeronautique to learn more about their FlapSpeed® Controller. Having a way to measure and record the RPM during our repair was what we were looking for.

Investing in our own equipment not only allows us to take care of our peening repairs during major overhauls but also to make emergency repairs. We are able to get our aircraft back in service more quickly.

In addition, Shockform offered on-site training so it was a turnkey solution for us.

What features do you find the most useful in the FlapSpeed® Controller?

I like the time savings that the FlapSpeed® provides. Doing a saturation curve often takes more time than the repair itself. Using the FlapSpeed® Controller helps get the right RMP right away and the countdown timer allows us to use one operator instead of two. In the past, one operator would monitor the timer and the other performed the flapper peening. The countdown timer helps us make more productive use of our operators' time.

Using the FlapSpeed® helps us maintain the parameter and stability of the process, thus giving us a better feeling of security over our repairs. The USB Key allow us to print the repair data, with all the details of the job including repair order, name of operator, date, time, desired intensity, RPM selected and actual RPM. That is proof that the repairs were done under optimum conditions. We like that for audits.

What do you think of the new FlapSpeed® PRO?

I noticed that your new FlapSpeed® PRO has a built-in Saturation Curve Solver Software. How cool! Can you image all the time savings? You no longer have to write all the points and calculate the 10%! Now everything gets calculated and it gives you a graph that you can print with your data. This is awesome!

The new screen is also much bigger and in color so it is very nice to use. You also added the choice of magnetic correction for 3M and Boeing (.77). It is very nice since we do a lot of work on our Boeings.

I also like the small handpiece grinder and the fact that everything you need for flapper peening fits in one small case. You grab the FlapSpeed® PRO case and you are ready to go!

Insights from Lance Welch

I am employed by a Northeast Texas company that is a leading provider of a broad range of electronic systems used on military and commercial platforms. I am mostly involved with the repair, refurbish, and modifications of older Boeing aircraft. We also see occasional newer productions. The majority of flap peening I do is related to re-work of corroded aluminum aircraft structures, generally in locations that would not be financially viable to shot peen. At the 2009 Electronics Inc. Shot Peening Workshop, I met Brigitte Labelle and Sylvain Forgues from Shockform Aeronautique Inc. After one demonstration, I knew the original FlapSpeed® Controller was the tool we needed, and I was right.

Lance Welch
Aircraft Maintenance Technician

Upon receiving the FlapSpeed® PRO, I was impressed with the inventory of the kit. Everything needed for the task was at hand with no need to drag around multiple containers. The 25 ft. cord is also a big help. It doesn't even have to be fully extended to work properly. Plus the curve solver integrated with the system is a big time saver. No more searching for an open computer with a printer.

Next, as expected, the functionality of the machine is just as infallible as the original. Even with the extended and altered mandrel, performance was flawless. My overall rating would be 4.99873 out of 5.

Peen Forming of Ceramics—A New Chipless Shaping Technique

DR. WULF PFEIFFER, the head of the business unit and a researcher with Fraunhofer IWM, presented his latest research on the shot peening of ceramics at the 38th International Conference and Exposition on Advanced Ceramics and Composites in Daytona Beach, Florida in January.

The mission statement of Fraunhofer IWM states that the research company characterizes, simulates and evaluates the behavior of materials, components and systems under the influence of external forces in different environments. They work with companies and public agencies to develop solutions that improve the safety, reliability, durability and functionality of technical components and systems, thus making them more cost-effective, energy-efficient, and economical with natural resources. Given these goals, we asked Dr. Pfeiffer about his work.

The Shot Peener: First of all, congratulations on the opportunity to present your research at the conference. We know this research is a continuation of your work on ceramics. Why are you studying this material?

Dr. Wulf Pfeiffer: High-strength ceramics provide benefits metals cannot provide. Unfortunately, ceramic components often cannot compete with metal components due to their brittleness and costly manufacturing procedures. Our research focuses on manufacturing processes which reduce the cost of hard machining and simultaneously overcome the limitations of brittleness. Shot peening may be such a fabrication procedure and it is fascinating to apply it to materials which have been thought to be unsuitable.

The Shot Peener: We reviewed the conference program and didn't see research other than yours on the shot peening of ceramics. Why do you think that is?

Dr. Wulf Pfeiffer: Shot peening is still thought to not work on ceramics although we have been continuously reporting about successful applications for more than 15 years. People from the ceramics industry are just not used to thinking like people from the metal world. Nevertheless, ceramics are non-forgiving materials when it comes to the effects of single cracks and local stress peaks. Thus, the selection and control of peening parameters are more demanding for ceramics.

The Shot Peener: How was your paper received at the conference?

Dr. Wulf Pfeiffer: After the technical session, we had a workshop on root technologies for ceramics. Within that workshop it was stated that unconventional thinking is needed to reduce manufacturing costs and establish new products made of ceramics. Shot peening and peen forming may be the offbeat technologies needed to extend the market for ceramic components.

The Shot Peener: Can you tell us about your upcoming research?

Dr. Wulf Pfeiffer: The next step will be to establish projects with industry to explore how the results of our research may be transferred into production processes. To promote the use of shot peening in industry we peen formed a leaf spring and a concave mirror made of silicon nitride. These demonstrators should illustrate the possibilities of chipless forming of ceramics by shot peening.

The Shot Peener: Thank you for your time, Dr. Pfeiffer. We look forward to reading about your continued work on ceramics and shot peening.

Peen Forming of Ceramics—A New Chipless Shaping Technique

Dr. Wulf Pfeiffer and Heiko HÖpfel
Fraunhofer IWM

ABSTRACT*
Thin ceramic components are often distorted during production due to anisotropic shrinkage and/or residual stresses due to machining. If unwanted distortion is detected in a component in its final shape, the distortion cannot be eliminated by additional material removal. Such ceramic components are usually discarded since their brittleness does not permit further flattening. Ceramic parts with complex shapes must be fabricated by, for example, sintering close to the desired shape followed by a costly 3D machining process.

This paper describes the first successful experiments aimed at shaping ceramic specimens using shot peening. Strips of different thicknesses made of silicon nitride ceramic were shot-peened using different shot peening parameters. The residual stress-depth distributions were determined using X-ray diffraction. Based on the experimentally determined stress states, the curvatures of the strips were determined analytically and using Finite Element (FE) calculations. Silicon nitride flat springs and a concave mirror could be peenformed without the need of additional hard machining. FE calculations demonstrated the capability of designing peen forming processes on basis of experimentally determined peening stresses.

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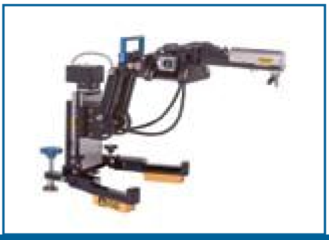

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