Spring 2013
Volume 27, Issue 2 | ISSN 1069-2010

The Shot Peener

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

Advice for New Shot Peening Technicians

Elmer Smith, Process Engineer with Spirit AeroSystems

Coverage Measurement Device

*PC is not included

Easy USB connection to your PC

COVERAGE CHECKER

Coverage Measurement Device

*Device image

COVERAGE CHECKER

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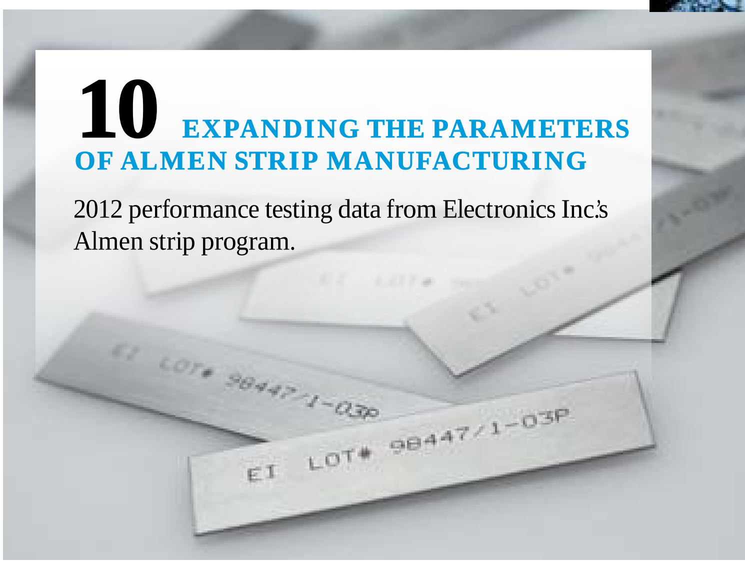
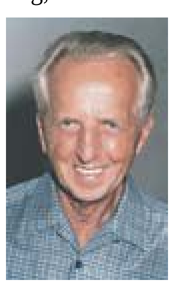




THE SHOT PEENER

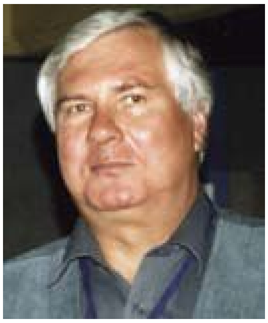
Sharing Information and Expanding Global Markets for Shot Peening and Blast Cleaning Industries

Strength in Numbers

JACK CHAMPAIGNE

Many years ago, when I joined the Aerospace Metals Engineering Committee (AMEC) of the Aerospace Materials Division of the Society of Automotive Engineers, I found that shot peening was scarcely mentioned. There were times that I was accompanied by only three or four "shot peeners" at the meeting. The AMEC task group focused primarily on heat treating issues, but had inherited the task of reviewing and editing the shot peening documents that we know as AMS specifications. Despite the lack of focus on shot peening, I enjoyed attending the meetings, especially when we went to the Asilomar Conference Center in California.

In 2008, I suggested we form a subcommittee to handle the shot peening specifications and that was the launching of AMECSE, Aerospace Materials Engineering Committee Surface Enhancement. The committee roster now stands at 125 people with members from Canada, France, Germany, India, Israel, Japan, the Netherlands, Singapore, Spain, Sweden, the United Kingdom and the United States. With this increase in numbers, we now have more high level technical input for the revisions of the shot peening specifications. The result is Strength in Numbers.



Prof Aleksander Nakonieczny

I recently learned of the passing of one of our valued contributors to the industry—Prof Aleksander Nakonieczny. We had become close friends, meeting in San Francisco in 1996 for the Sixth International Conference on Shot Peening (ICSP-6), for which I was host. We elected Aleksander to membership in the committee at that time and then selected him to host the conference in 1999 in Warsaw, Poland. We extend our deepest sympathy to his family, friends and co-workers. He will be greatly missed.

The Twelfth International Conference on Shot Peening (ICSP-12), hosted by Clausthal University of Technology, will be held September 15-18, 2014, in Goslar, Germany. For more information, go to www.shotpeening.org/ICSP-12. We encourage everyone to participate in the only international conference dedicated to shot peening. Again, Strength in Numbers.

THE SHOT PEENER

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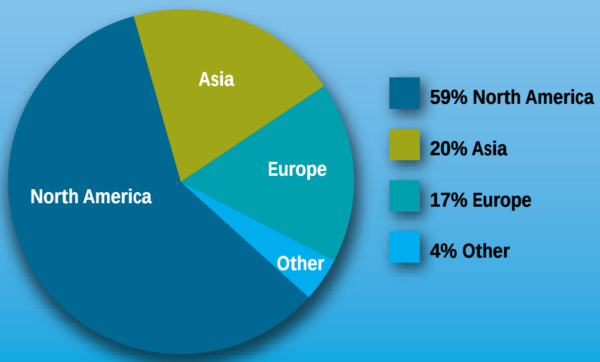

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MANUFACTURING TOPICS

Elmer Smith | Process Engineer | Spirit AeroSystems

Advice for New Shot Peening Technicians

and the people that hire them

Elmer Smith, a Process Engineer with Spirit AeroSystems in Wichita, Kansas, exemplifies the best of the manufacturing workforce. He is an experienced technician that enjoys his job and does it well. His advice to shot peening operators addresses an important issue to everyone in manufacturing: the transfer of knowledge from a skilled workforce to new employees.

ELMER SMITH is a Process Engineer for one of the largest non-OEM designers and manufacturers of aerostructures for commercial aircraft—Spirit AeroSystems in Wichita, Kansas.

The Wichita site has manufacturing operations for all Boeing models now in production, as well as the Bombardier CSeries and the Mitsubishi Regional Jet; Maintenance, Repair and Overhaul (MRO) support and services; and other manufacturing, administration and support facilities.

Elmer has been with Spirit for over 39 years and has worked in their shot peening division for 35 years. He is one of nine certified shot peening technicians that operate four wheel- and air-blast machines. To be certified, a shop peening machinist must first take classroom training, then he receives on-the-job training. When the on-the-job training requirements are met, he is certified by Spirit's training department.

Elmer and his department are responsible for every component that needs to be shot peened in the Wichita facility. "We peen everything that needs to be peened that we can fit in our work zone," he said. A typical workday for Elmer starts with setting up a shot peening machine to process a part and then troubleshooting any concerns that come up during the peening process. He oversees the machine operators and the process, and will run the machines, when needed. He is responsible for meeting Nadcap requirements and, if it is a new procedure, he will develop the technique sheets. He also participates in Research and Development relevant to his department.

An Interview with Elmer

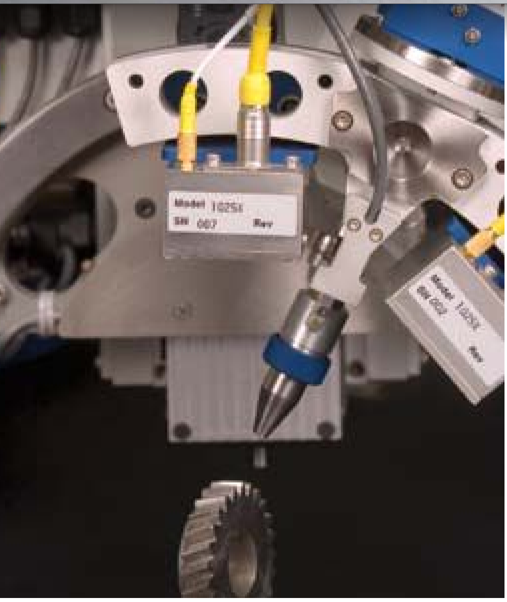
The Shot Peener staff is very appreciative to Elmer and Spirit's Corporate Communication staff for letting us pull Elmer from the busy shop floor to answer a few questions for us.

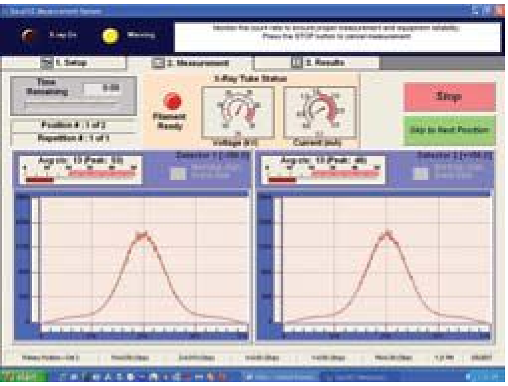
The Shot Peener: What do you like best about your job?

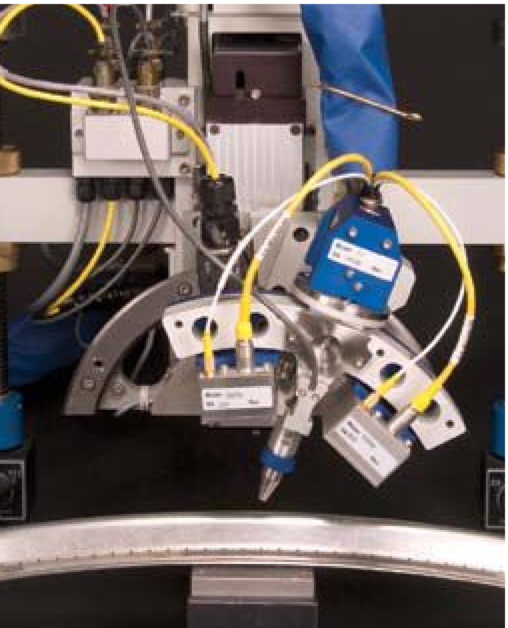
Elmer: I like to set up complicated parts that require shot peening to specific requirements. I also enjoy the opportunity to meet people that I respect because of their knowledge in surface enhancement.

The Shot Peener: What resources do you depend on when you have a question or problem with a shot peening job?

Materials Testing Services







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Elmer: I can get answers from our engineering department or the customer's requirements.

The Shot Peener: What additional resources would be helpful to you?

Elmer: The testing results from various metals peened with different media by a university or engineering lab. We could use the results as reference when making a new setup and save a lot of time.

The Shot Peener: You mentioned that you're responsible for developing technique sheets. Tell us more about them.

Elmer: Technique sheets help new and experienced operators process parts according to customer specifications, Nadcap requirements and our own specs. I call them the "Bible of Parts Processing."

The Shot Peener: What kind of training did you receive when you started in Spirit's shot peening division?

Elmer: I was trained by a shot peening operator who had 20 years of experience in all aspects of shot peening. I'm always reading books and magazine articles on advancements in surface enhancement. I read *The Shot Peener* and when you Google "shotpeen," it opens up a whole world of information, even YouTube videos.

The Shot Peener: Are you responsible for training new employees?

Elmer: Yes, but we prefer to do it as a group of senior operators. We believe in teamwork!

The Shot Peener: Spirit AeroSystems is a world leader in the aerospace industry. Do you ever think about your contribution to shot peening and the role shot peening plays in the integrity of aerospace components?

Elmer: From Engineers to machine operators, we are all held to very high standards by our Quality Assurance staff. We shot peening operators especially hold ourselves to a very high standard because if the component is not processed per customer specifications, if something goes wrong and that part fails, lives can be at stake. That is not an option!

The Shot Peener: What advice would you give to a new shot peening operator?

Elmer: Learn from the old dogs and read any research you can get your hands on to improve the process. Never be satisfied with "that is how it has been done for years." If you see something that can help the process, speak up and run tests to show the improvement. Always look for better quality within the specifications you are given by the customer.

KNOWLEDGE TRANSFER

***Knowledge transfer* means replicating the expertise, wisdom, and skills of critical professionals in the heads and hands of their coworkers.[1, 2]**

"Old Dogs" and Knowledge Transfer

Elmer said that it's important for new employees to learn from the "old dogs." He was fortunate to begin his career with the help of an experienced shot peening operator. But he makes another good point: "Never be satisfied with the way things have been done for years." Relying on the current workforce to properly train new workers isn't 100 percent reliable. What if the "old dog" has performed a process improperly for 20 years?

From our conversation with Elmer, we can see several steps that Spirit has taken to protect the integrity of their shot peening processes:

1) New operators must pass a two-step certification program that includes classroom training and on-the-job training.

2) Elmer trains new employees as part of a team of senior machine operators. A team approach reduces the likelihood of passing along poor work habits and it distributes training responsibilities among the staff.

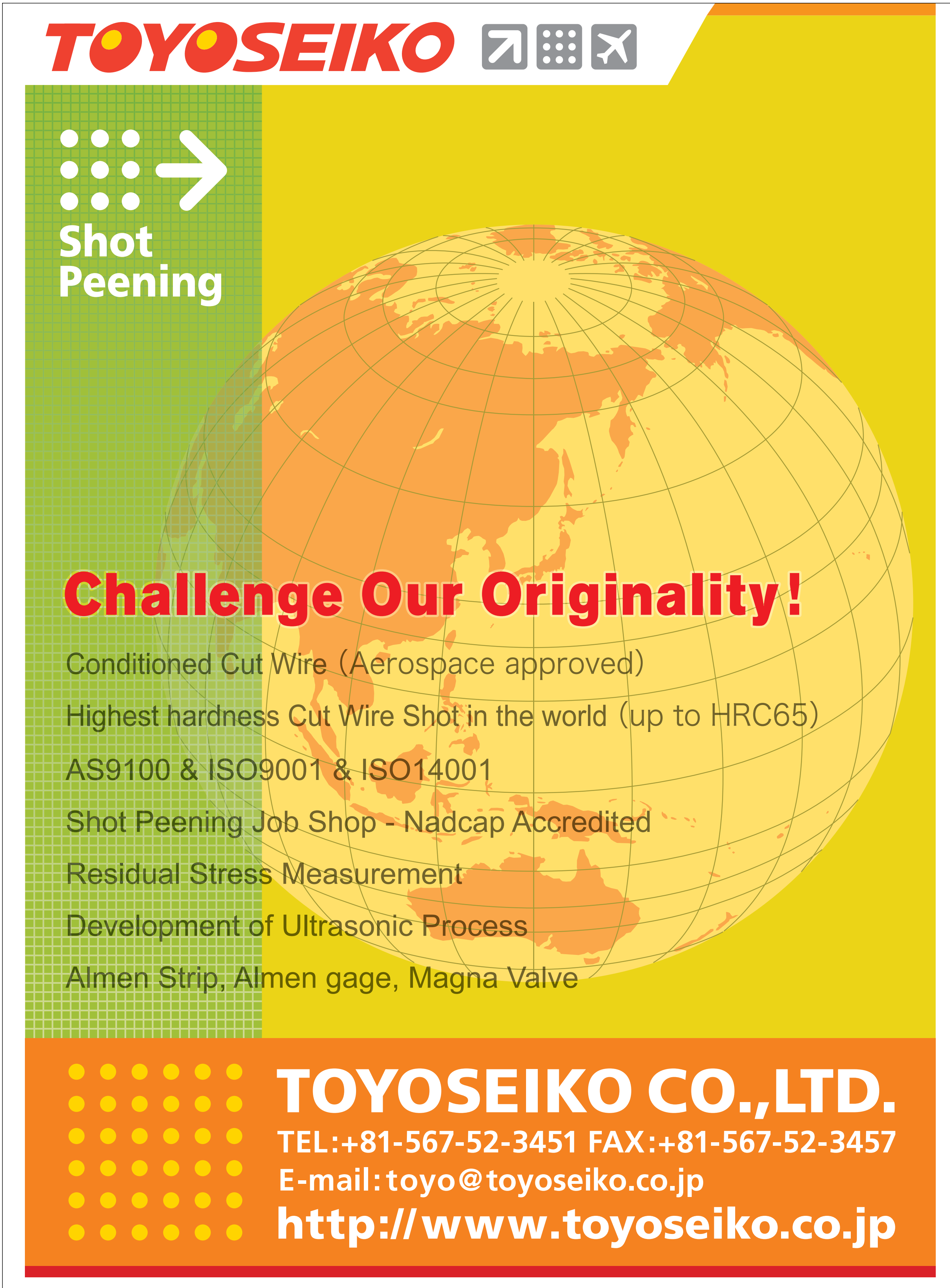
3) Process engineers are responsible for developing technique sheets of successful setups. Technique sheets are required for Nadcap and other audits, but they are valuable knowledge transfer tools, too.

The Wichita, Kansas facility is just one of many Spirit AeroSystems facilities around the world and Spirit has resources that are out of the reach of most manufacturers. In addition, Elmer has taken the initiative to keep abreast of innovations in surface enhancements, and not all employees are that motivated. But if this claim is true, that few organizations can say with any degree of certainty that they will have the workforce they need to hit their strategy 1-3 years from now,[1] every manufacturer needs a knowledge transfer plan. Maybe your shop floor is populated with young workers, not old dogs on the verge of retirement. You're still at risk since younger workers move on to new jobs more frequently than older workers.

Fortunately, the basis for safeguarding the future of your business is similar to creating a quality shot peening process: Training, documentation, quality control and the instillation of pride in a job well done.

[1] Knowledge Transfer - Preserving Your Secret Sauce. The Steve Trautman Co.

[2] Knowledge transfer has a different meaning in the United Kingdom. In the UK, it is defined as the means by which expertise, knowledge, skills and capabilities are transferred between academic institutions and businesses.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Expanding the Parameters of Almen Strip Manufacturing

AN ALMEN STRIP that meets specification parameters in flatness (prebow), hardness and thickness isn't always good enough. The following is a real-life example of strips that met specs, but failed to accurately verify the shot peening process.

Within a time frame of a few weeks, operators in shot peening facilities worldwide weren't able to reach previously attainable intensity levels. An aerospace manufacturer that uses a large number of strips conducted a comprehensive review of all the factors that influence intensity. They asked the operators about their shot peening processes. They inspected the media and questioned the manufacturers about changes in media production. They looked at every aspect of their shot peening equipment that determines intensity and OEMs were brought in to inspect their machines. They found nothing. The operators, media and equipment could not be held accountable for the failure to achieve the specified intensity ranges. Then an engineer at the aerospace facility picked up an Almen strip. "Maybe it's not the factors that influence intensity, maybe it's the intensity testing tool," he thought. He analyzed a strip and found inconsistent hardness levels and areas of decarburization. He had uncovered the problem.

Changing the Almen Strip Status Quo

Unfortunately, the problem didn't go away because many strip manufacturers continue to manufacture strips in the same way. These strips meet specifications, but they could have troublesome inconsistencies in hardness levels. In 2006, Electronics Inc. (EI) began research and development on a manufacturing process that would produce Almen strips that never deviated from a high standard, whether they were manufactured last month, last year or three years from now. EI formally introduced their own brand of strips in 2007.

Almen strips are shot peened in a custom air blast cabinet in Electronics Inc.'s test laboratory as part of EI's performance testing program.

Performance Testing Beyond the Parameters

EI started its rigorous Almen strip performance testing program in 2006. It is EI's tight manufacturing controls, backed by this testing program, that make EI's strips so dependable. EI peens approximately 2,000 strips every year in their custom air blast cabinet. The cabinet has a variable-

The Origins of the Almen Strip Grading Program

In 1995, Jack Champaigne, President of Electronics Inc., developed an Almen strip grading system to help EI's customers obtain strips that would accurately meet public and private specifications. Before the EI Almen strip grading system, it was difficult to fulfill an order for Almen strips when two or more specs were cited and the requirements were in conflict.

Electronics Inc. established a measuring system for Almen strips using an extensive sampling program that allows the sorting strips into three grades.

The grades differ in hardness, flatness (prebow) and thickness, and their ability to meet rigorous performance requirements of peening tests. EI trademarked the terms Grade 1, 2 and 3 to differentiate these quality levels in a simple manner. The grades are as follows:

- Grade 3™ - Bulk (A-3™, N-3™, C-3™)
- Grade 2™ - Standard (A-2™, N-2™, C-2™)
- Grade 1™ - Premium Grade (A-1™, N-1™, C-1™)
- Grade 1S™ - Special Grade (A-1S™, N-1S™)


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speed rotary table with 26 Almen strip holders, a fixture for adjusting nozzle distance from the strips, a MagnaValve® for media flow rate control, and adjustable air pressure. The machine is configured to give a consistent exposure time to each Almen strip and assure uniform impact treatment. After the strips are peened, arc heights are measured on a calibrated Almen gage and prebow compensation is applied. The values are put into histograms for analysis.

Histograms created over the past six years exhibit nearly identical lot-to-lot arc height results, thereby verifying the uniformity of the strips. The histograms on page 14 illustrate the performance consistency of the strips as defined by nearly identical mean values and narrow standard deviations.

Traceability and Audit Program

To meet the demands of increasingly sophisticated shot peening processes, especially in aerospace, EI introduced their numbered Almen strips with Coverage Check finish in 2011. The lot numbers are printed on the strips. Electronics Inc. has developed a traceability program, represented by the strips' lot numbers, to track Almen strips back to their heat number. A heat number is a unique identification code for a piece of metal that holds information about its origins. The heat number provides a method for tracking materials and is an important part of quality assurance and control. In addition, EI audits four documents from their steel supplier:

1) Material certificate - steel composition must conform to SAE 1070 specifications.
2) Inspection records for thickness, width and length.
3) Process control charts for hardness.
4) Decarburization report that confirms zero surface decarburization.

Decarburization is a change in the structure and content of steel in which some of the carbon in the surface layer or layers of the steel is lost. If an Almen strip has decarburization, its hardness is compromised and its performance will be unreliable.

EI's steel supplier is a global industrial group with advanced steel production capabilities and they are happy to comply with EI's audit program. Most EI customers will never need to take advantage of the traceability and audit program. Nevertheless, if a supplier or manufacturer in the aerospace, automotive or medical industry faces a liability situation, they can have confidence in the completeness of information on every step of the EI Almen strip manufacturing process, and be assured that the strips were manufactured to the highest standards.

EI's Intensity Control Research Library

EI's extensive research on Almen strips and intensity control has made EI a technical support resource for the shot peening industry. Here is a sampling of the data in EI's library:

- Current lot-to-lot comparison data on EI strips
- Comparisons of EI strips to other strips
- Performance data on other strips
- Analysis on the effect of variations in manufacturing parameters - hardness, flatness (prebow), thickness

EI has become the go-to resource when their customers have questions on Almen strips and shot peening intensity variables. If EI doesn't have data on a unique situation, EI will perform tests to analyze a customer's problem or even duplicate, as closely as possible, their process setup.

For example, a manufacturing engineering associate with an aerospace facility in Poland recently sent an email to Jeff Derda, EI's Operation Manager. Mr. Derda oversees Electronics Inc.'s Almen strip production and testing programs. The engineering associate needed help reaching a required intensity range of 0.014 - 0.018A. Mr. Derda asked her for the process parameters and she gave him the flow rate, media type, air pressure, nozzle diameter, part-to-nozzle distance, part rotation speed and the impingement angle. Based on tests that EI had run with similar parameters, Mr. Derda made suggestions. The engineering associate wasn't able to increase air pressure due to limitations at the aerospace facility, but she was able to slightly alter the impingement angle and decrease the shot flow. The process time was now slightly longer but an intensity of 0.015A was achieved.

"Dear Jeff, I can find no words to describe how grateful I am for all of your advice. Without your help, I wouldn't have achieved a proper intensity," the engineering associate wrote in an email.

Due to the large amount of available data, Mr. Derda was able to solve a problem in a few short emails that had been bothering the aerospace company for several weeks.

About Histograms

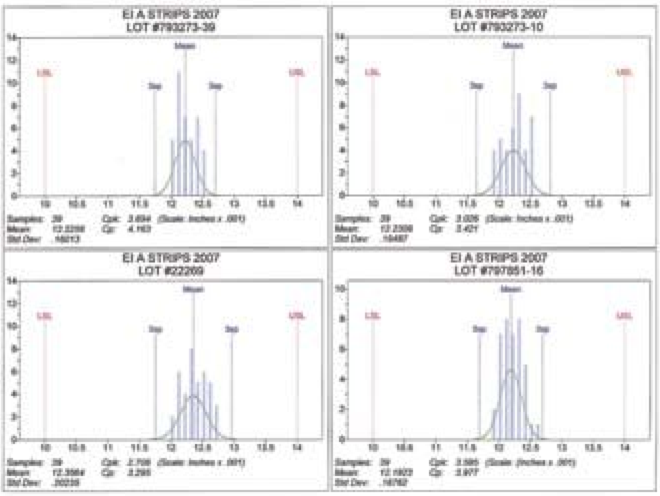
A histogram is a graphical display of tabulated frequencies, shown as bars. It shows what proportion of cases fall into each of several categories. A histogram differs from a bar chart in that it is the area of the bars that denotes the value, not the height of each bar as in bar charts.

About Mean Value and Standard Deviation

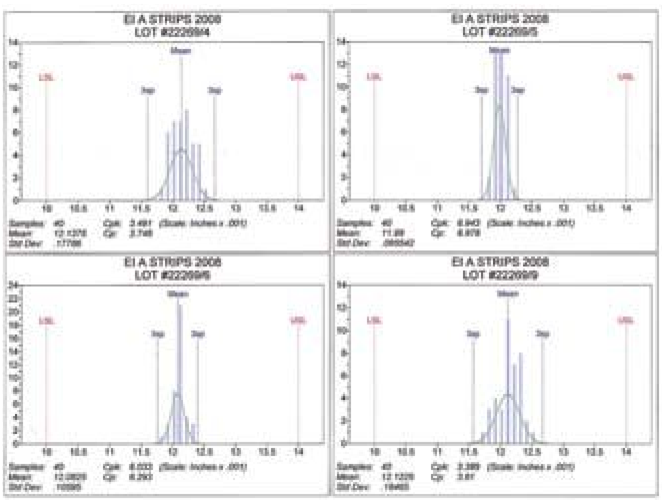
The mean is the sum of the observations divided by the number of observations. The mean describes the central location of the data, and the standard deviation describes the spread. The standard deviation is a statistic that tells how tightly all the examples are clustered around the mean in a set of data. When the examples are tightly grouped together and the bell-shaped curve is steep, the standard deviation is small. When the examples are spread apart and the bell curve is relatively flat, that signifies a relatively large standard deviation. In the case of the Almen strip testing, the tight standard deviation signifies the consistency of the arc height reading.

Electronics Inc. Almen Strip Performance Test Results

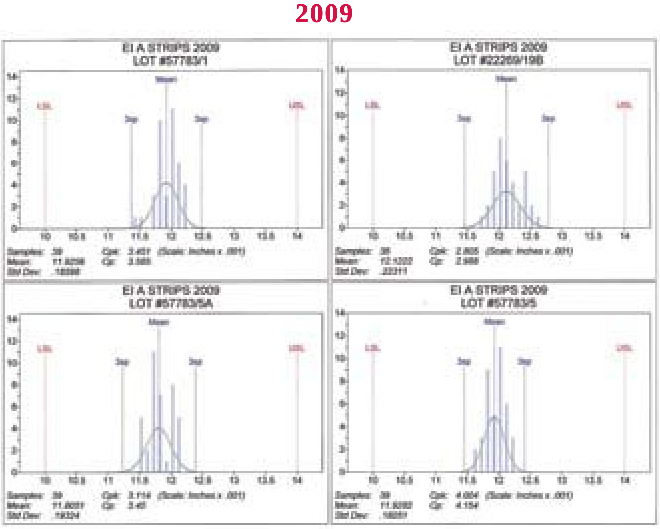
2007



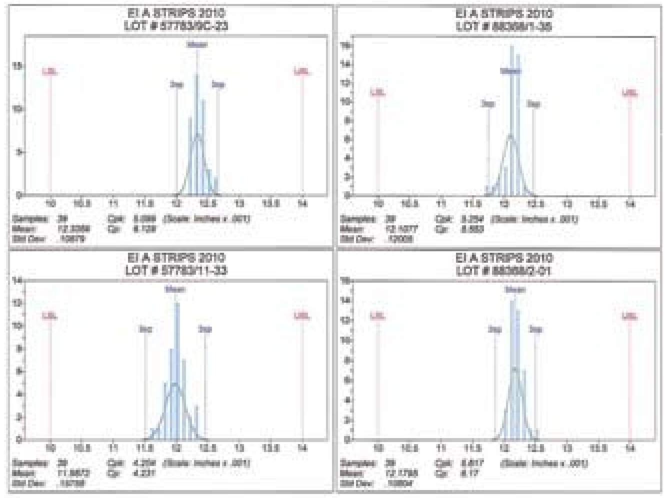
2008



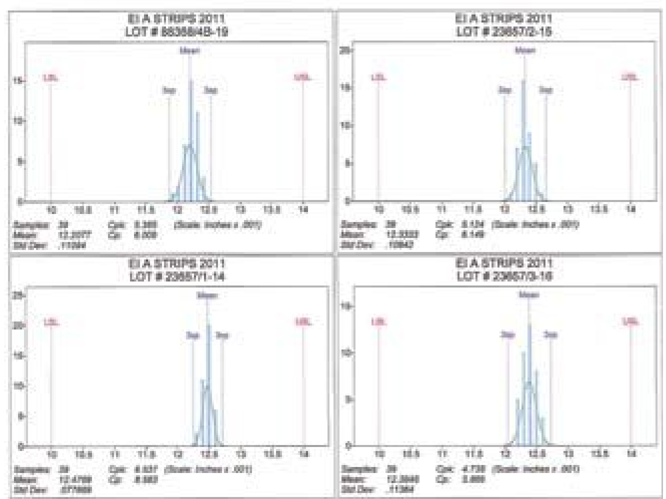
2009



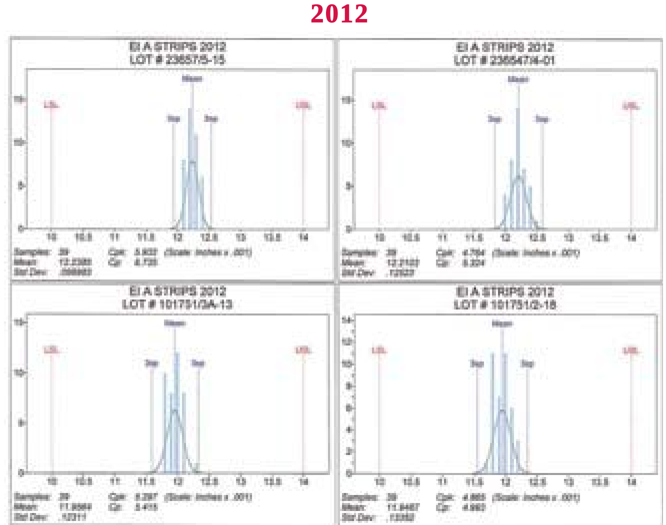
2010



2011



2012



INNOVATION IN MACHINE DESIGN
Wheelabrator Group GmbH

New Wet Blast Machine is Ideal for Aerospace Applications

WHEELABRATOR'S NEW WET BLAST turntable machine (TTW5) is ideal for the aerospace industry. The TTW5 delivers all of the benefits of wet blast peening, plus it was developed with Wheelabrator's successful Module8 Principles for Airblast Machines. It also has two advantages compared to other wet blast machines: the Module8 construction does not need a special foundation or platform, and it is the same size and shares the same footprint as similar dry blast machines.

In addition, installation is easy, user interfaces and operational controls are familiar to the machine operator—these were the reasons why one Wheelabrator aerospace customer in particular placed an order for this machine.

Aerospace Components and Wet Blast Peening

Aerospace applications for wet blast peening with the TTW5 are blades and blisks. Blades are used in the front part of the engines with a length of up to 2 m (6.5 ft). They must have extremely high stability and a good surface finish to deliver the required mechanical and aerodynamical properties. A blisk (or bladed disk) is a single engine component consisting of a rotor disk and blades, which may be either integrally cast, machined from a solid piece of material, or made by welding individual blades to the rotor disk. Blisks are used in the compressors of the engines and a special feature is that a ring with blades forms one unit. It is crucial for the aerodynamics of both products that they have a smooth surface with stability at the welded seams. In addition, a smooth surface resists corrosion. All of these benefits can be achieved using wet blast peening with ceramic beads in the TTW5.

The TTW5

The TTW5 is equipped with four blast nozzles which can be moved by two nozzle manipulators, each with five interpolating axes. Nozzle movements and the turntable allow an 11-axis process so that parts with complex geometries can be optimally blasted.

The flexibility of the new wet blast turntable machine makes it ideal for blades and blisks. Long blades need a high blast cabinet to provide uniform treatment over the complete height. However, the blisks – with the relatively close arrangement of the blades – need a solution which allows precise treatment between the blades. This is feasible with the 11-axis process and the optional use of fine-blast lances based on the flexible Module8 concept.

The aforementioned customer also liked the flexibility of the design concept. The adaptability to new applications

Wheelabrator's Module8 Principles for Airblast Machines

Wheelabrator has developed and implemented a set of concepts and strategies to aid the decision-making process and ensure that the right solution is developed for the application. The eight principles are as follows:

- Flexibility
- Wear Reduction
- Ease of Maintenance
- Safety
- Productivity Reliability
- Process Reliability
- Quality
- Short Delivery Times

The Module8 concept was developed from detailed analysis of customer requirements over a long period. The adaptable blast cabinet is created using flexible, modular wall and ceiling elements. Further components for blast media circulation and blasting technology are positioned around the cabinet so that they can be easily and safely maintained from only one level, preferably the accessible roof. Due to the modular construction, blast nozzles, workpiece transport devices and other systems can be installed on either side of the blast cabinet to create an optimized solution for each customer.

possible as machine parts can easily be replaced and upgraded to meet future expectations.

Familiar Structure and Controls Simplify Integration

The processing of the parts in the TTW5 is CNC controlled, including media flow and air pressure, to ensure that the customer's clearly defined blast result is achieved. The TTW5's Module8 machine structure and control is identical to the relevant Wheelabrator dry blast machines, so operators will recognize familiar part holders, a familiar user interface and familiar processes. This is another reason why the aerospace customer chose this machine—with several Wheelabrator dry blast machines in use, the change to the new wet blast machine was quite simple.

All the advantages of the Module8 concept are now available in wet blast technology. For more information, contact Wheelabrator Group GmbH in Metelen, Germany by telephone: +49 2556 88-0, fax: +49 2556 88-150 or email: kontakt@wheelabratorgroup.de.

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Large 84" Index Unit for high volume

12 Pressure Nozzles with MagnaValves

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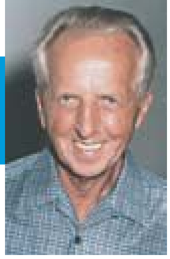
Single Cell Unit, 5 Pressure Nozzles

Bucket Elevator Sweco System MagnaValves

6 Spindles each station for high volume

Dual Swing Doors for higher volume

Large 84" Index Unit, 12 Pressure Nozzles



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

Peening Impressions (Dents)

INTRODUCTION

The SAE specification J2277 on coverage mentions "overlapping peening impressions (dents)." That specification also includes "Coverage is defined as the percentage of a surface that has been impacted at least once by the peening media." The only evidence that a surface has been impacted is the peening impressions (dents) left by the impacts. It is therefore somewhat surprising that there is no corresponding definition of a peening impression (dent).

Peening impressions (dents) are the "be all and end all" of shot peening. They govern not only coverage but also residual stress generation, surface work hardening, distortion/peening intensity, oxide removal and roughening/smoothing of components.

A previous article in this series (*The Shot Peener*, Spring 2003 "Morphology of Shot Peening Indentations") considered the scientific features of indentations. This article aims to complement that article. Individual and overlapping dents are considered as separate issues.

INDIVIDUAL DENTS

Mechanics of Dent Creation

A small proportion of a shot particle's kinetic energy, ½mv^2, is converted into plastic deformation when it impacts a component. The impact therefore generates a dent whose shape depends on the shape of the shot particle and whose magnitude depends on the amount of energy conversion. An important relationship is that:

"Kinetic Energy and Work Done have the same units and are therefore directly interchangeable."

The units for kinetic energy are kg.m^2.s^{-2}. Work done is force times distance – but force is mass times acceleration. Hence work units are kg.m.s^{-2}.m or kg.m^2.s^{-2} – the same as for kinetic energy. Fig.1 represents the work being done as a spherical impacting particle strikes a flat surface.

Initially the shot particle has zero contact area so that the force (stress times area of contact) must also be zero. With further penetration the area of contact grows and with it the force being exerted but stress is maintained at the yield strength of the component. When the particle reaches its maximum penetration both the contact area and the yield strength are at a maximum – hence we have maximum force. Thereafter plastic deformation ceases and the particle rebounds due to the stored elastic energy below the dent. At final contact the dent has a diameter **D1**.

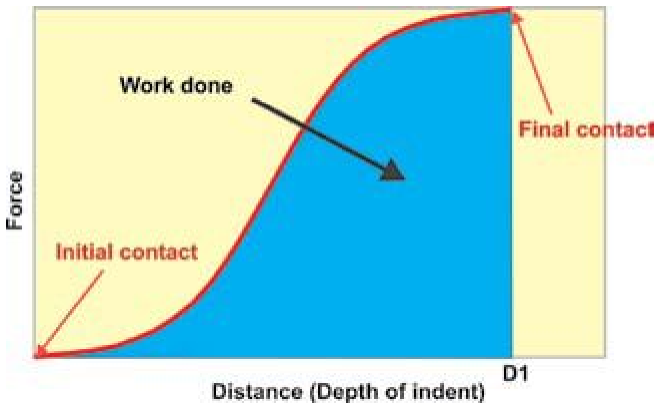


Fig.1. Work done during creation of an individual dent.

Geometry of a Direct Impact Dent

During impaction the component metal must move in order to generate the dent – it does not evaporate or become fragmented. The material of the indentation has to go somewhere! Each dent has two components: indentation and ridge. These components are illustrated by fig.2 which models a 90˚ impact. The indentation then has the geometrical shape of a 'spherical cap' whereas the ridge approximates to the geometrical shape of an annular ring. The volumes of the indentation and ridge components are not equal to one another. That is because there are two mechanisms whereby the indentation material can be moved: **outflow** and **upflow**. Outflow contributes to the distortion of a component whereas upflow generates the ridge. If outflow predominates, as in the case of thin strip material, then the distortion effect predominates and the ridge component becomes less noticeable. Conversely, for relatively thick components the ridge region becomes more noticeable.

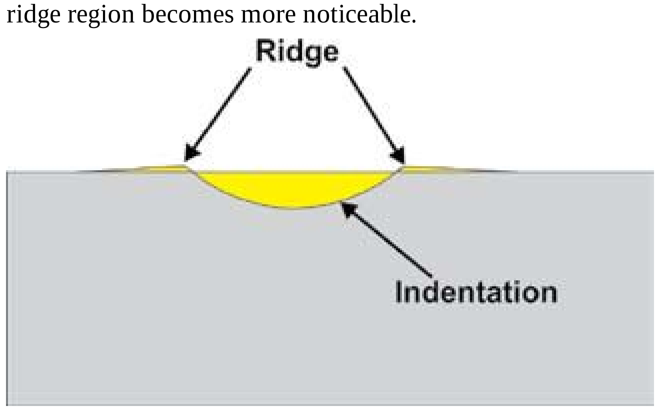


Fig.2. Cross-section of a peening impression (dent).

Outflow of Material during Impaction

Fig.3 represents a thin elementary disc where the outflow component is imagined to be 100% of the total flow. Outflow is not uniform – it is easiest at the extreme surface and becomes more difficult below the surface (setting up the resistance that generates compressive residual stress). An original flat disc therefore assumes a curvature because of the outflow of a peening indentation (dent). The average outflow strain, **ε**, varies with the radius of the impacting sphere, **r**, the depth of the indentation, **h**, the thickness of the disc, **t**, and the diameter of the disc element, **D**. Equation (1) quantifies these factors.

$$\varepsilon = 2*h^{2}*r/(t*D^{2}) \qquad (1)$$

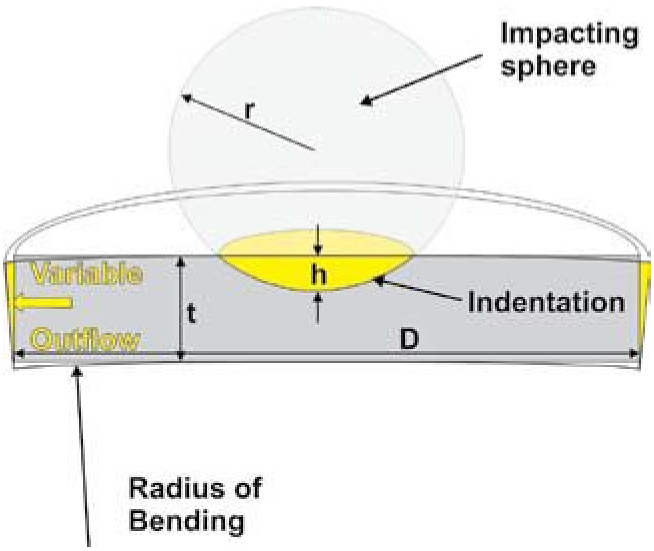


Fig.3. Model of variable outflow generating curvature of a disc element.

Equation (1) can be used to predict the magnitude of plastic expansion induced by a single indentation. For example, assume **h** = 0.1mm, **r** = 0.5mm (S230 shot), **t** =1.3mm (A strip) and **D** =1.754mm. Substitution in equation (1) predicts a plastic strain of 0.0025 (0.25%). An Almen A strip with an arc height of 0.254mm (0.010") has a radius of 256mm. If this was induced solely by plastic bending then the surface strain would be precisely 0.0025 – the same as predicted for pure outflow (using the assumed indentation values). This example only indicates that pure outflow predicts similar plastic strains to those that are actually observed.

Upflow of Material during Impaction

The second mechanism of material movement is upflow - to form a ridge around the indentation. Material movement then has several similarities to those associated with a tsunami. For a tsunami there is a sudden displacement of a large volume of water leading to a wave that has small amplitude and very long wavelength. Fig.4 represents just two stages of ridge formation. In the early stages of indentation, A, a tiny ridge is created by upflow of plastically-deforming component material. As indentation progresses this is squeezed outwards and grows continuously towards the final stage B. Throughout the process there is continual upflow of component material.

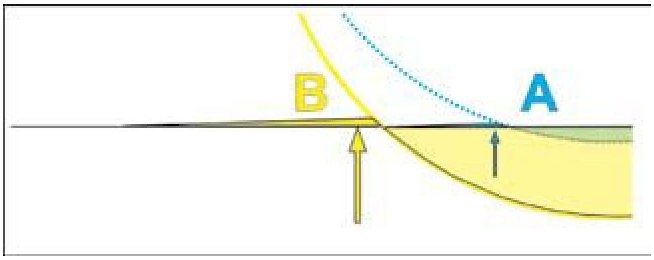


Fig.4. Early and final stages of annular ridge formation.

The shape of the annular ridge is similar to that of a modified scalene triangle (a triangle with three unequal sides). Some modification is required in order to accommodate the curvature of the impacting sphere and the established flow characteristics of metals. Fig.5 shows the cross-sectional shape of a typical annular ridge.

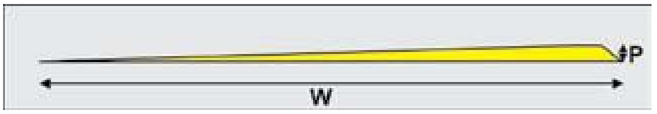


Fig.5. Cross-section of a typical annular ridge caused by upflow of component material.

Measurements have shown that typical annular ridges have a volume about 19 -24% of that of the indentation, a width, W, about half the diameter of the indentation and a height, P, about 15% of the indentation depth. The relatively-large width of the ridge matches the plastic deformation zone that surrounds every indentation. That zone has been shown to have twice the diameter of the actual indentation.

Individual Dent Created by Angled Impact

Shot particles striking a flat surface at an angle create an elliptically shaped indent. The depth of the indent is lower than for perpendicular impact by an equivalent shot particle. This therefore generates a lower peening intensity. As well as having an elliptical shape, the dent's ridge geometry is drastically different. The ridge becomes asymmetric, narrower and has much greater maximum height than occurs with perpendicular impact. Fig.6 is a schematic representation of the different situations.

Fig.6. Comparison of perpendicular and 45o dent ridges.

Angled-impact ridges only occur on one side of the dent – that for the direction of impaction.

Individual Dent Measurement

A central problem in dent measurement is to be able to identify its extent. The shortest side of the ridge's 'scalene triangle' cannot be distinguished from the indentation itself. It follows that most measurements on single indentations are of the diameter of the annular ring's peak. Fig.7 illustrates the situation when using a vertical collimated light beam. Rays are reflected from the surface of the indention in 'mirror fashion'. As the angle deviates from 90˚ less and less light is returned back into an eyepiece. The "high reflectivity" zone defines the apparent diameter of the indent. A substantial proportion of light is, however, reflected from the bottom of a spherical indentation – which can cause image analysis problems.

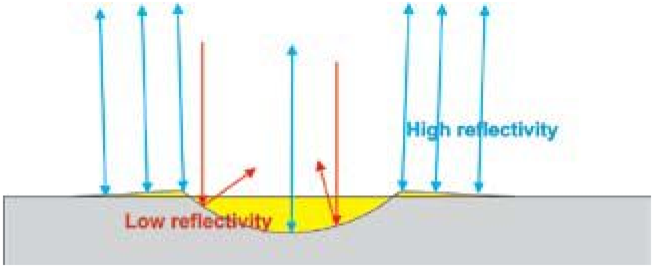


Fig.7. Variable reflectivity of a collimated light beam striking peening impression (dent).

Indent Aspect Ratio

Indent aspect ratio is the ratio of indent depth, d, to indent radius, r. Fig.8 represents the variation of aspect ratio for increasing shot particle penetration (but with ridge formation omitted for clarity).

The ratio d/r can vary between 0 and 1 (when the particle reaches the maximum feasible depth). In practice the aspect ratio for commercial shot peening is of the order of 0.1.

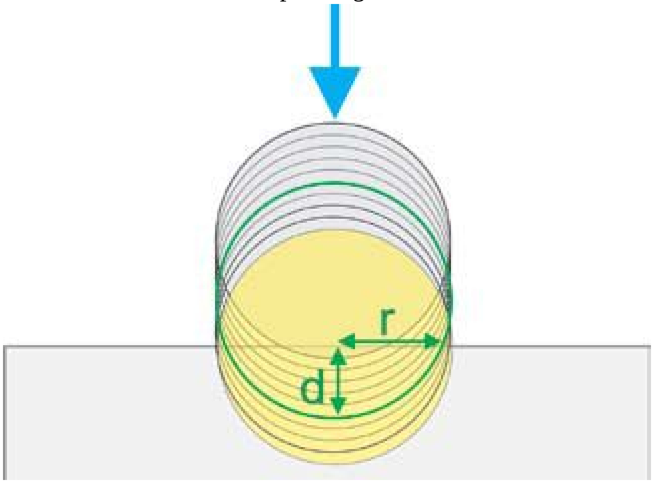


Fig.8 Variation of dent aspect ratio with increasing shot particle penetration.

As the dent aspect ratio increases so does the relative height of the surrounding impact ridge. This effect is represented in fig.9 – being similar to the effect shown in fig.6 except that the ridge is symmetrical. With a high aspect ratio the impact ridge surrounding the dent becomes dangerously high. That is because neighboring subsequent dents will introduce "peened surface extrusion folds."

Fig.9 Increase of impact ridge height with increase of indent aspect ratio.

OVERLAPPING DENTS

Coverage prediction programs are generally based on the assumptions that indents are circular and of constant diameter so that an overlapping indent has the same diameter as that of the one being overlapped. None of these assumptions are 100% correct. The diameter of an overlapping indent depends primarily on the degree of overlap.

Dents Involving 100% Overlap

The greatest degree of overlap is when a second impact coincides exactly with the first indent. This situation is illustrated in fig.10 (ridges being omitted for reasons of clarity).

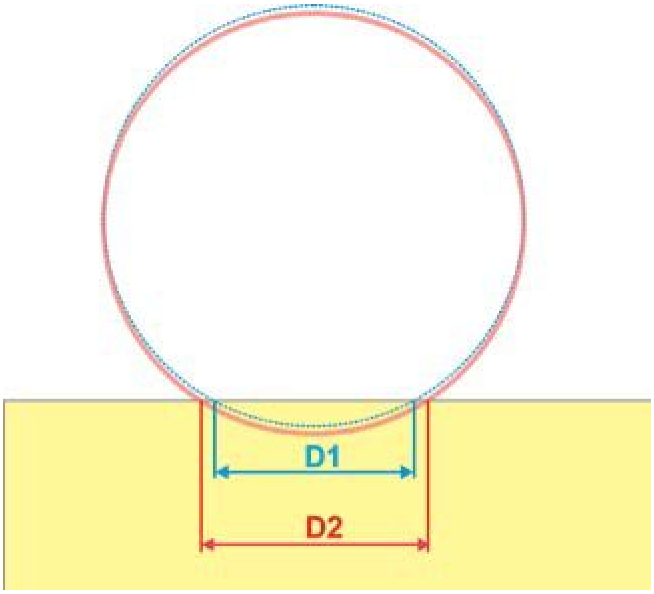


Fig.10. Increased dent diameter with 100% overlapping of second impact.

The generation of the work done during this second impact follows a very different path from that shown in fig.1. Fig.11 illustrates the work done and its effect on dent diameter. On initial contact the shot particle makes the same contact

area as at the final contact stage of the first impact. Thereafter the force rises as both the area of contact and the degree of work-hardening increase. At final contact, when the particle starts to rebound, the dent has its diameter increased from **D1** to **D2** (see fig.10). Less plastic deformation work is done during the second impact because the underlying material has been work-hardened – which increases the fraction of elastic energy. Third and subsequent impacts on exactly the same center will produce smaller and smaller increments of diameter.

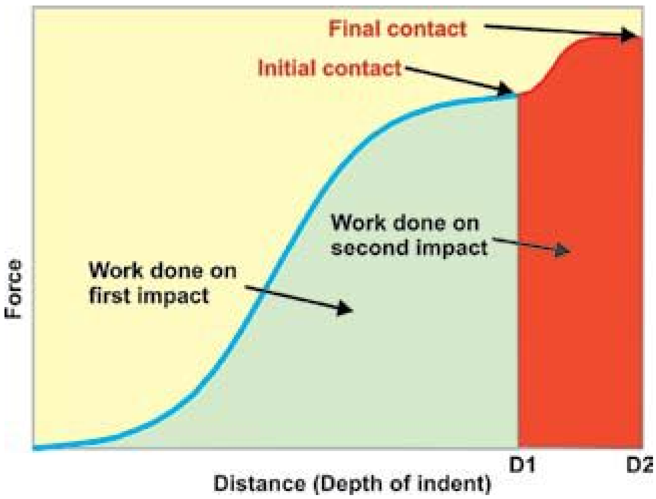


Fig.11. Progress of work done during second impact with 100% overlapping.

Dents with Less Than 100% Overlap

Dents with less than 100% overlap display a wide range of features – too complicated to analyze in detail here. Fig.12 illustrates the range of features produced at a low coverage level. The component material is polished mild steel – chosen because of its ability to display deformation zones around the dents.

When there is considerable overlap, as at A, asymmetric ridges are produced. These are similar to those produced by angled impact (see fig.6). Close inspection shows up the peaks of ridges as light-reflective regions with the remainder appearing to be shadows. With small overlapping, as at B, deformation is symmetrical.

It is impossible to determine the effect of degree of overlap on indent diameter using ordinary peening conditions. That is because particles have different diameters and impact velocities. Under laboratory conditions it has been found that: (1) as the degree of overlap decreases, the diameter of the second dent increases to a maximum and then decreases and (2) when the overlap just becomes zero then the second dent has the same diameter as the first dent. This second finding is surprising because the work-hardening associated with a first impact would have been expected to reduce the diameter of an adjacent second impact.

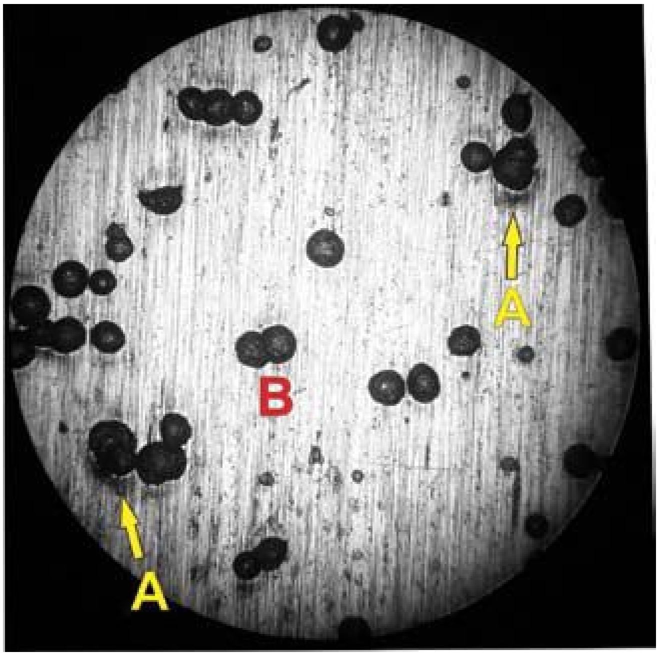


Fig.12. Range of effects associated with overlapping dents.

Peened Surface Extrusion Folds

Peened surface extrusion folds are known to detract from component service performance - normally. One exception might be for the case of surgical implants. Useful tissue growth could be enhanced by the presence of folds – analogous to enhanced seedling initiation on rocks.

Reduction of harmful extrusion fold formation is difficult. Wherever possible, angled impact should be avoided. Indent formation involves three-dimensional deformation mechanics with induced compressive stress parallel to the surface encouraging super-ductility – and hence fold formation.

STRESS STATE CHANGES DURING PEENING

Two important component factors change during shot peening:

Yield strength and
Residual Stress parallel to the surface.

Both of these factors affect the state of stress and therefore the size of induced dents. Fig.13 (page 32) represents (in two dimensions only) the state of stress for a representative tiny cube of component material. – i is the perpendicular compressive stress being imposed by the impacting shot particle, - q is the induced compressive stress resisting outward flow of material and – r is the induced compressive residual stress that develops as a consequence of the outward flow of material. The two induced compressive stresses combine to give a magnitude of – (q + r).

Fig.14 (page 32) represents all three stresses that make up the stress system that causes dent formation during impact.

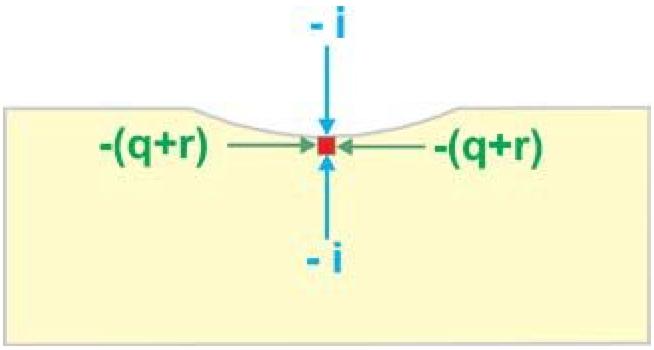


Fig.13 Stress state during impact showing two of the three orthogonal stresses.

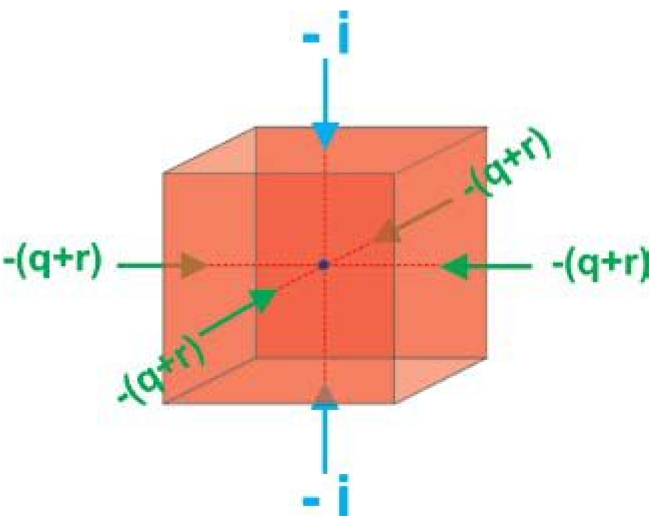


Fig.14 Three-dimensional stress system causing dent formation.

Application of a yield criterion shows that:

$$\mathbf{i = Y + (q + r)} \qquad (2)$$

Equation (2) is important. Stated in words it is that: The stress being imparted by the shot particle must reach the sum of the component's tensile yield strength plus the sum of the induced reaction stress and the induced residual stress.

As the component is repeatedly bombarded the yield strength increases and so does both the reaction stress and the residual stress. This means that the dent diameter must progressively decrease – for a fixed peening intensity.

Because the sum of the reaction and residual stresses increases during peening so does the "hydrostatic component" of the stress system. The hydrostatic component of any three-dimensional stress system explains why rolling allows far greater extensions than does tensile stretching and why extrusion allows enormous plastic extension. For peening this hydrostatic component has a magnitude of – (q + r). Because it increases during shot peening it increasingly offsets the reduction in component ductility caused by work-hardening.

DISCUSSION

As stated previously, peening impressions (dents) are the "be all and end all" of shot peening. They govern not only coverage but also residual stress generation, surface work hardening, distortion/peening intensity, oxide removal and the roughening/smoothing of components. Dents themselves are, however, immediately apparent on a shot-peened component. Component properties that depend on dent characteristics have to be determined experimentally. Because of their primary importance dents deserve to be considered and specified more closely than is generally the case.

Upflow of material during impact generates annular ridges that have the potential to become harmful extrusion folds. The significance of the ridges depends upon the aspect ratio of the dent. A reduction of the aspect ratio of dents, whilst maintaining a required peening intensity, can be achieved by using a larger shot size.

The relationship given as equation (2) epitomizes dent creation. As peening progresses, factors such as yield strength, reaction stress and residual stress all increase. These combine to reduce the dent size and increase the ductility-enhancing hydrostatic effect. As a consequence, some features, such as coverage curves, must deviate from a simple two-parameter function. The deviation is predicted to be small but may be significant. This agrees with numerous practical observations.

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EMERGING TECHNOLOGIES

by Kathy Levy | *InfoProse*

WaterJet Peening

ALEX CHILLMAN, PhD, Staff Mechanical Engineer and Research Platform Lead with Flow International, Inc., presented a paper on potential industrial applications for waterjet peening at the 2012 BHR Group conference. (See sidebar on the right.) Because *The Shot Peener* has been following the development of waterjet peening for industrial and medical applications, we were pleased to have the opportunity to interview Dr. Chillman regarding the emergence of waterjet peening as a mainstream solution for fatigue enhancement.

Alex Chillman, PhD, is a Staff Mechanical Engineer and Research Platform Lead for Flow International, Inc.

The Shot Peener: What are your job responsibilities at Flow International?

Dr. Chillman: I serve on a team that conducts application-focused research supporting "emerging applications." At Flow, emerging applications are opportunities that are outside the bounds of our typical abrasive waterjet shapecutting market. These applications may require new process and/or hardware development.

The Shot Peener: Why are you an advocate of waterjet peening?

Dr. Chillman: I had the opportunity to first evaluate the waterjet as a tool for peening from a scientific perspective, then from the commercial aspect. Many of the problems that can occur with traditional peening methods are minimized (or negated) with waterjet peening. Some examples:

- Surface dimpling with shot peening can lead to the need for secondary machining (thus removing the shallow subsurface layer containing the highest level of compressive residual stress). With waterjet peening, process conditions can be tailored so there is no notable change in surface topography.
- Concerns like rollover at geometric transitions are minimized. (Editor's note: Rollover is an edge condition in which

Potential of Waterjet Peening for Mainstream Industrial Applications

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Flow International Corporation, Kent, Washington USA

M. Ramulu
University of Washington Dept. of Mechanical Engineering, Seattle, Washington USA

ABSTRACT

While not yet been adopted as a mainstream solution for fatigue life enhancement, waterjet peening has been proven to provide an effective means for life improvement without inducing large scale degradation in surface topography. As opposed to many conventional peening processes that use solid particulates to induce compressive residual stresses in the subsurface layer, waterjet peening relies only on droplet impact. However, nozzle selection, jet manipulation methodologies, and waterjet process parameters must all be carefully selected for proper waterjet peening. In this paper, a brief look at the history of waterjet peening is presented, dating back to Salko's early discoveries that took place in the 1980s. Considerations for industrial application are presented, as well as case studies highlighting the potential benefits that exist when waterjet peening is properly employed.

INTRODUCTION

Enhancement of life for fatigue critical components is currently, and will remain, a key demand for industrial applications. Fatigue enhancement can occur due to surface finish improvement (reduce flaw sizes to slow crack initiation) as well as subsurface modification (induce compressive residual stress state to reduce mean alternating stress). When considering the latter of the two means of life improvement, traditional methods such as shot peening have gained wide-spread acceptance across a breadth of industrial families – spanning aerospace, automotive, and power industries to list a few.

Waterjet (WJ) peening, which relies on the breakdown of a high-velocity waterjet stream into a droplet field, has begun to emerge as an alternate means of subsurface modification; yet it seems it has not gained the acceptance of the traditional shot peening process. When discussing the rationale, reasons for waterjet peening lacking widespread acceptance may include:

- Many view waterjets as 'purely cutting and/or cleaning tools.'
- Lack of understanding how waterjets can be integrated and/or manipulated for industrial application.
- Minimal waterjet process know-how, which leads to fear of process drift or lack of control over the output surface modification.
- Industrial champions with vision to implement new technology.

In this paper, further definition to the waterjet tools as well as means of waterjet manipulation will be provided. A brief overview of past peening studies, dating back to 1984, will be discussed. Finally, a look at an industrial application and the benefits that were achieved with waterjet peening will be presented. The hope is that the material contained in this paper will help provide a continued step to understanding that waterjet peening is emerging from the realm of scientific discovery to a proven industrial solution.

Paper was presented at the PHR Group 21st International Conference on Water Jetting 2012. Reprinted with permission. Paper is available for download at www.shotpeener.com library.


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the metal is deformed such that the edge starts to curl or fold over.)

- Waterjet is a flexible tool and can be easily integrated with a variety of motion systems, depending on the application.
- Waterjet peening can access tight spaces and internal cavities.
- Waterjet peening can be turned into a closed-loop process with proper filtration techniques, leading to reduced environmental impact.

The Shot Peener: You mentioned that waterjet peening can have a less of an impact on the environment than traditional shot peening methods. Obviously, water is easily recycled, but would it contain metal particles from the peened component?

Dr. Chillman: There are commercially available filtration systems that screen out particulates. With waterjet peening, there is often no material removal (depending on end goal of the application). To expand on this, let's consider two goals:

1) Waterjet peen a surface to induce residual stress without need for secondary machining (example: transmission shaft). In this case conditions would be selected to ensure no material erosion occurs while optimizing the compressive residual stress field.
2) Roughen a surface for a secondary coating while also inducing residual stress to offset surface roughening effects on fatigue performance. This transitions to a pure waterjet material removal application, and filtration of a closed-loop water supply would be required.

The Shot Peener: Energy consumption is another environmental consideration, as well as a cost factor. Does a waterjet peening process require less compressed air than conventional air blast peening?

Dr. Chillman: The compressed air requirements for waterjet peening are very low. The high-pressure water is created by either 1) a hydraulically powered intensifier pump or 2) a crankshaft- driven direct-drive triplex pump. Both pumps are documented at our website (www.flowwaterjet.com).

Compressed air is used to control the on/off valve (jet on/off function); however, there isn't a continual flow demand. Certain nozzle types do utilize an air flow to control the structure of the waterjet. For example, patent number 6,280,302 "Method and Apparatus for Fluidjet Formation" by Dr. Mohamed Hashish, with Flow International, covers a water-air jet nozzle.

The Shot Peener: In your paper, you write:

> Many peening applications require the precise uniform coverage of complex 3-dimensional surfaces. This requires a means of tool manipulation that is capable of meeting high levels of path accuracy. Previously, the need for high path accuracy would dictate that a Cartesian style 5-axis system should be required, which limited flexibility and often exhibited a high price point. With this type of system it is also difficult to have multiple waterjet nozzles working on the same part. Recent advancements in the accuracy levels (both path and position) of 6-axis robotic arms have led to a new viable alternative.
>
> The 6-axis robot provide high process flexibility, including ability to approach "top" and "bottom" sides of surface geometries with single fixturing. Also, various end effectors can be utilized, with quick change out at the flange. The robotic solution also allows for processing of large geometries, or local regions on a larger component, with the incorporation of a 7th axis linear rail.

You included a photo of a robotic waterjet cleaning cell in your paper (Figure 1). Could this technology be easily converted to peening equipment?

[1] The Shot Peener, Winter 2006 and Summer 2006.

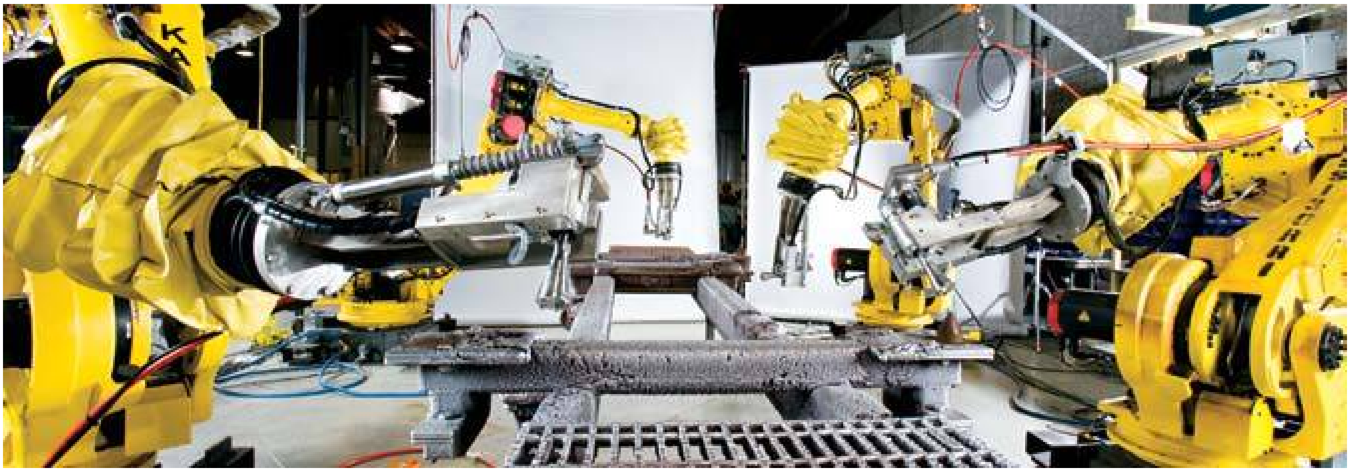

Figure 1. Robotic waterjet cleaning cell installed at a United States-based automotive facility.
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Dr. Chillman: The configuration of the peening cell will be application driven, but both pieces of equipment would utilize the same pump and plumbing technologies. The main differences between cleaning and peening machines would be the nozzles and part fixturing methods, as well as potentials for enclosures and environmental controls.

The Shot Peener: *The Shot Peener* magazine has published the research of Dr. Dwayne Arola and Dr. Michael Jenkins[1]—both have studied waterjet peening for medical applications. What do you see as the benefits of waterjet peening to medical implant manufacturers?

Dr. Chillman: Some benefits are the following:

- The only processing medium with waterjet peening is water. There is no secondary material to risk material transfer/contamination of the surface.
- The nozzle design can be optimized for the application need. This may be broad covering jets (fan jets) to process a larger surface or a small focused jet to access a tight location. The nozzle design can be modified such that the optimal peening distance ranges from 0.1" up to +6" away from the nozzle.
- Surface texturing can be obtained with only water if desired.

The Shot Peener: Are private industries funding waterjet peening research?

Dr. Chillman: Yes, however, these companies prefer not to be identified for competitive reasons. Flow International has invested a significant amount of research into waterjet peening. Notable is the 1998 patent (Patent Number 5,778,713), covering many methods of waterjet peening.

The Shot Peener: Are any industries using waterjet peening now?

Dr. Chillman: Yes. While I can't go into detail, I know it is utilized in both automotive and aerospace today.

The Shot Peener: What will be the "tipping point" that makes waterjet peening a viable option for improving fatigue life?

Dr. Chillman: The tipping point will undoubtedly be dependent on industrial buy in and this comes back to the economics of the process as well as proven technical validity for a given application. As we all know, it's tough for a corporation to consider something new when current processes work, unless they can prove out the financial benefits. Many times the true financial study gets complicated when pre/post processing, capital equipment, power consumption, consumables, waste disposal, uptime, maintenance, etc., must all be factored in.

Rösler Invests 8.5 Million Euro in Expansion

Rösler's new high-bay warehouse has 7741 individual pallet locations. The warehouse went into operation in January 2013.

RÖSLER OBERFLÄCHENTECHNIK GMBH expanded its main manufacturing plant in Memmelsdorf, Germany with the addition of a 17-story high-bay warehouse. Two new buildings for laser cutting and a compact warehouse went into operation last fall.

During the past several months, the Rösler location in Memmelsdorf, Germany resembled a huge construction site. Rösler Oberflächentechnik GmbH has invested 8.5 million Euros to expand its equipment manufacturing facility. With this new investment the company is sending a clear signal in favor of the manufacturing base in Germany. A special highlight is the new high-bay warehouse. With a footprint of 1,400 square meters (14,000 square feet) and 17 floors, this new warehouse offers a total of 7,741 pallet locations for warehousing consumables (media and mass finishing compounds) as well as machine and spare parts. With this investment in "intelligent" warehousing capacity, Rösler expects to significantly improve the response times for customer requests for aftermarket service.

Within the scheduled completion date, the high-bay warehouse went into operation during the first week of January. It allows the receiving/dispatching of 100 pallets per hour through the truck load/unload station. Rösler also expanded its manufacturing area. Last fall two new buildings were completed with a total footprint of 3,500 square meters (35,000 square feet). Essentially the complete laser cutting and warehousing operation was transferred into these new buildings. This includes the two existing Trumpf laser-cutting units with the linked compact storage systems. New equipment additions were two new press brakes, each with a pressing force of 400 metric tons.

The expansion of the German manufacturing facility reflects only part of the Rösler's growth with its global sales network of more than 60 sales branches and distributors. The company added employees at its Memmelsdorf location, requiring an expansion of the employee parking lot. For this reason, the recent expansion also included the creation of 240 additional parking spaces on the company premises with a total area of 9,500 square meters (95,000 square feet).

The expanded Rösler Oberflächentechnik GmbH campus in Memmelsdorf, Germany.

New MT Focus® Products Simplify Machine Tool Monitoring

SYSCON INTERNATIONAL has introduced MT Focus®, a monitoring system for new and legacy machine tools. MT Focus connects machines—including shot peening and blast cleaning machines—through the universal language of the internet, so a manufacturer can "see" machine performance and make decisions based on accurate data, crucial alerts, current production information and preventative maintenance trends. These insights into the plant floor can be used to improve manufacturing processes and drive innovation throughout the organization.

Machine Configuration Web-Based Screenshot

The heart of the MT Focus product line is its Adapter/Agent Module—it's a four-in-one machine monitoring tool that collects, stores, translates and displays machine status and performance data. Collected data can be viewed as web-based screenshots on smart devices such as SmartPhones, iPads, PCs and shop floor monitors (no need for external host/client computers), or provided as real-time MTConnect protocol that can be used by third-party applications.

MT Focus delivers these benefits at minimal expense, with little or no disruption to existing manufacturing efforts. "MT Focus addresses the challenges that the average machine shop faces," said Don Hemler, MT Focus Product Manager. "One day of planning and one day to install and make operational should be sufficient per machine. A maintenance technician can do the installation under the direction of a facilities or manufacturing engineer, and setup/configuration are easily accomplished via menu-driven browser pages."

An MT Focus Adapter/Agent Module costs only $695, and each machine requires its own module. MTConnect®, an open, royalty-free communication standard that utilizes Internet communications technology to link machines and systems together, comes standard in all modules. MT Focus also offers low-cost licensing of four software options that allow users to choose the amount and type of data to be extracted from their machines. MT Focus hardware options, like the Local Data Collection Hubs, HMIs and Wireless Bridges, further expand the product's functionality.

Despite its simple installation process and economical pricing structure, MT Focus is flexible and robust enough to handle small machine groupings or large plants with multiple facilities located around the world. MT Focus can even integrate the plant floor into the company's ERP system, providing historical data that can be used as a benchmark for Continuous Improvement. Some of the machine information provided by the Module includes:

- Actual vs. Targeted Performance Values (OEE, spindle utilization, average cycle times)
- Production Data (good/reject part counts)
- I/O Status and Counts(with e-mail alerts)
- Job Time Accumulators (In Cycle at Rate, In Cycle Slow, Idle, Down)
- Machine Data Summary
- Current and Next Job Data

Email alerts, provided by the Module, include Slow Cycle Time, Machine Down, Job Started, Job Completed, and Multiple Count-Activated Input Events.

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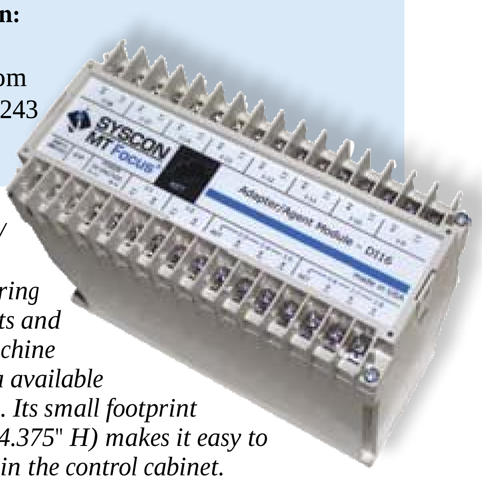

The MT Focus Adapter/Agent Module is a four-in-one machine monitoring tool: It translates, collects and stores data from the machine tool and makes the data available through http addressing. Its small footprint (5.875" L x 2.750" W x 4.375" H) makes it easy to install on a machine or in the control cabinet.