Volume 6
Issue 4
THE SHOT PEENER
nter 1992/93
INTERNATIONAL NEWSLETTER FOR SHOT PEENING-SURFACE FINISHING INDUSTRY

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Shot Peening Intensity Measurement

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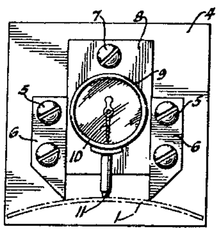
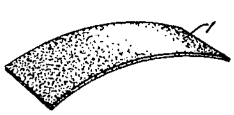
1992082

[Excerpts from U.S. Patent 2,350,440 by J.O. Almen on Shot Blasting Test]

As is well known, cold working by shot blasting improves fatigue durability of machine parts. Its effectiveness depends upon producing a thin surface layer stressed in compression by the peening action of the shot. This peening action varies with the velocity of the shot, with the size of the shot, and with the number of shot directed at the work. To assure that the operation will be properly performed, it is desirable to be able in a simple and inexpensive manner to measure intensity of shot blasting. Likewise it is necessary that manufacturing standards be set and that engineering specification show the extent of shot blasting required for a given piece of work. To meet these demands the present invention has for its object the provision of instrumentation and a plan for use whereby the effectiveness of shot blasting can be easily and quickly measured.

When the effectiveness or intensity of a shot blast operation is to be determined, whether for initially setting standards or for checking to meet given specifications, it is here proposed to submit to the shot blast one face only of a thin flat steel plate and then gage the radius of curvature of the shot blasted specimen. Prior to the test the opposite faces of the flat blade have surface layers substantially free from unequal stress. Compacting or peening the surface on one side only created an unbalance which causes the initially flat plate to bow. The extent of bowing is dependent upon the degree of compressive stress and there is a measure of the intensity of the shot blasting operation. Gaging the height of the arc between predetermined points indicates the radius of curvature of the test specimen and reflects the result of the peening action. After the procedure is accurately charted, tests may be made quickly and without the exercise of special skill.

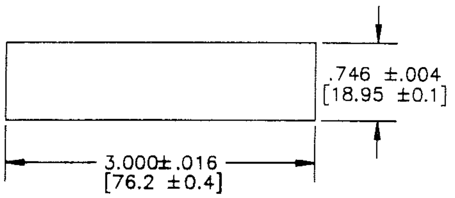




[Excerpts from SAE document J442]

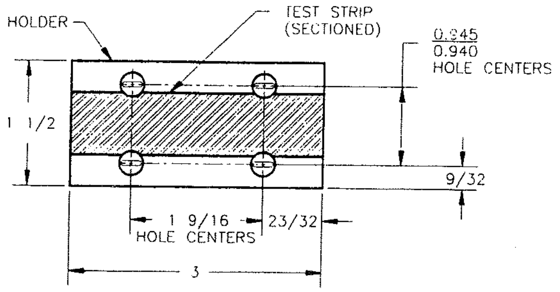
The control of a peening machine operation is primarily a matter of the control of the properties of a blast of shot in its relation to the work being peened. The basis of measurement of these properties is as follows: If a flat piece of steel is clamped to a solid block and exposed to a blast of shot, it will be curved upon removal from the block. The curvature will be convex on the peened side. The extent of this curvature on a standard sample serves as a means of measurement of the blast. The degree of curvature depends upon the properties of the blast, the properties of the test strip, and the nature of exposure to the blast, as described below. Properties of the:

Blast	Exposure	Test Strip
Velocity	Time	Dimensions
Size	Angle	Mechanical
Shape	Flow Rate	
Density		
Kind		
Hardness		



STRIP	THICKNESS (IN)	THICKNESS (MM)
N STRIP	.031 ±.001	.79 +.005
A STRIP	.051 ±.001	1.29 +.005
C STRIP	.094 ±.0015	2.39 +.02

Figure 1
Standard test strips N,A, and C



ASSEMBLED TEST STRIP AND HOLDER

Figure 2
Test strip holder

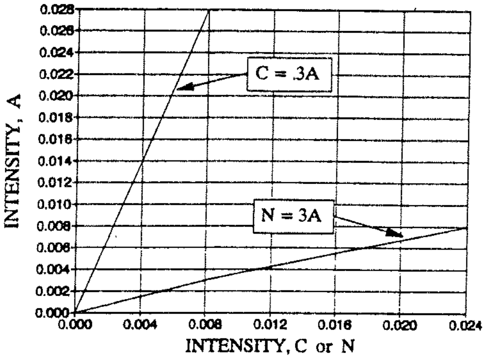


Figure 3
Relationship between test strips N, A, and C

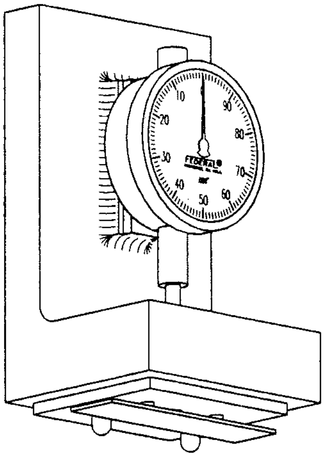
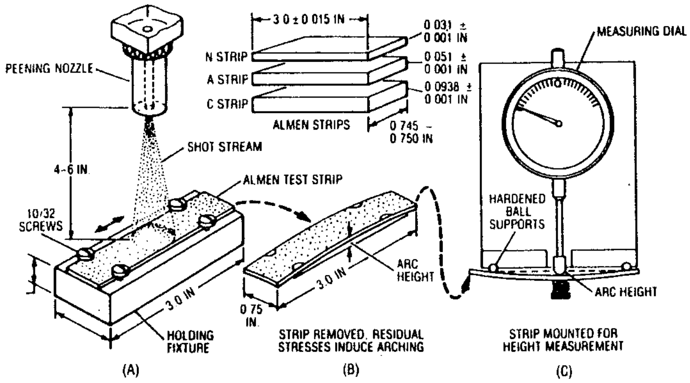


Figure 4
Gage for determining the curvature of the test strip

The curvature of the strip is determined by a measurement of the height of the combined longitudinal and transverse arcs across standard chords. This arc height is obtained by measuring the displacement of a central point on the nonpeened surface from the plane of four balls forming the corners of a particular rectangle. (This gage is commonly referred to as the Almen Gage No. 2. It supersedes the Almen Gage No. 1.) To use this gage, the test strip is located so that the indicator stem bears against the NONPEENED surface.



The standard designation of intensity measurement includes the gage reading or arc height and the test strip used. It may be explained by the following example:

0.013 A 2
2 — Almen Gage No. 2
A — Test Strip
0.013 — Gage Reading

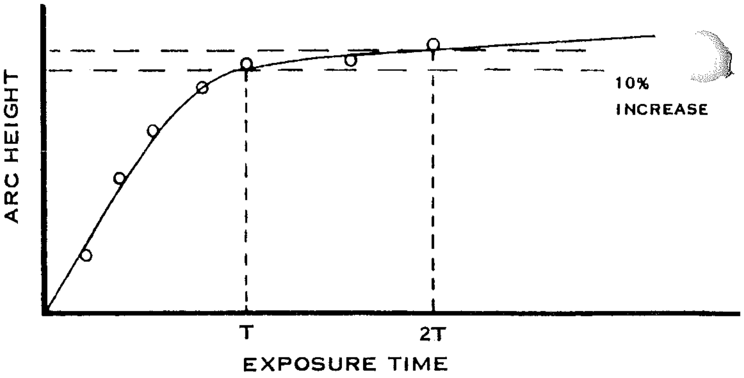
The concept of intensity is sometimes hard to grasp. It must be realized that intensity is a measure of the shot blast stream energy, proportional to mass and velocity, and is not a function of coverage. The intensity of a single shot impact is the same as the intensity of a large stream of shot. Obviously the force applied to the surface will be much higher in the latter case, but the intensity is the same. It is the intensity of the shot particle that allows the creation of a dimple in the target surface. Also, the diameter of the dimple is directly related to the shot intensity.

The use of thermometers to measure temperature is similar to the use of Almen strips for intensity measurement. Just as a thermometer must be subjected to the heat source for a sufficient time to reach equilibrium, the Almen strip must receive enough surface coverage to reach equilibrium. Once the surface of the Almen strip has received enough dimples it is said to be saturated. Additional dimpling will not produce additional strip curvature.

Measurement of human body temperature, normally near 98.6 degrees F, is made by placing the thermometer under the tongue for approximately one minute. Shorter time periods may not allow the thermometer to achieve its final (accurate) reading. The same technique must be applied to shot peening. (Be careful to not swallow the Almen strip after placing it under your tongue.)

The exposure of Almen strips to the shot blast must be done for a sufficient time to allow saturation. The only way to assure that saturation has occurred is to use several strips and expose each strip to longer and longer periods of shot blast. Graphing the results allows interpretation of the data and a reading of intensity can be obtained.

Intensity is defined as the first point of the curve that, if the exposure time is doubled, the arc height increases by 10%. Experience will also show that this is also the approximate time required for the Almen strip to receive 100% surface denting, as would be expected.



We might question why the Almen graph curve is interpreted in this way instead of referring to an asymptote. Referring back to our description of shot peening, effective peening is done when the largest and hardest shots, traveling at the highest speed strike the surface at the most direct angle. Softer or smaller shots, traveling at lower speed or striking at shallower angles, do not contribute to the peening effect. The saturation curve would approach an asymptote if, and only if, all shot were of one size and one hardness traveling at one speed and striking the surface at one angle. Since it would be extremely difficult to maintain the above conditions, one would expect the saturation curve to continue to increase until some final equilibrium had been achieved. Also, there are examples of arc heights decreasing with (extremely) prolonged exposure times.

Various methods for gaging shot blast intensity include:

METHOD 1: To Determine Intensity-
1. Expose (4) or more Almen strips to the shot blast stream for increasing amounts of exposure time and plot the data onto a linear graph.
2 Draw a best-fit curve through the data points.
3. Determine the intensity as that point on the curve (not necessarily a data point) that is at 10% of the curve when the exposure time is doubled.

The arc height at this point is called INTENSITY and the exposure time is called SATURATION time.

METHOD 2: To Confirm Intensity-

1. Expose one Almen strip at the saturation time as determined above.

Expose a second Almen strip at double the saturation time.

If the arc heights are within 10% of each other the confirmation is valid.

4. If the arc heights are different by 10% or more you must return to Method 1 to determine intensity using (4) points.

METHOD 3: To Confirm Consistency-

1. Construct SPC charts

Another process tool that is useful is statistical process control (SPC) charting. This technique is appropriate for large quantity production. One or more Almen strips are exposed to the blast stream and the arc height is charted. The exposure time can be either the saturation time or the time used to achieve piece part coverage (also called machine cycle time). Saturation time and part coverage time are not necessarily equal. Components softer than Almen strip SAE 1070 Cold Rolled Steel (Rc 44-50) will exhibit coverage faster than the Almen strip. Conversely, components harder than the Almen strip will take longer to exhibit coverage. Be sure to indicate which method is used since results are likely to be different for the two methods.

The use of SPC charts can contribute much to the maintenance of consistent processing. Changes in shot size, hardness or velocity (velocity is a combination of speed and direction), will be displayed and the process will be seen as “out of control”.

The three methods outlined above are not equivalents. Each has its proper application.

Method 1. Intensity (4-point graph)
Method 2. Confirmation (2-points)
Method 3. Consistency (SPC Chart)

Only the first procedure can truly be called intensity. It is the only method described by MIL-S-13165 or SAE J442. The use of the second or third method is done as a means of process verification or process control.

The following data and graphs will illustrate the importance of the distinctions made for the three procedures. Figure 5 shows data taken for 10 machine cycles. It appears that saturation has been achieved and intensity may be interpreted as 16. Additional exposure time, however, discloses that this may not be the intensity. See Figures 6 and 7.

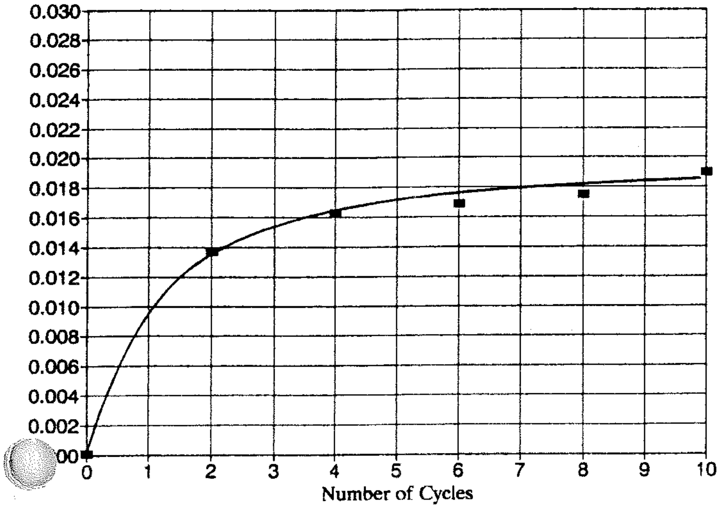


Figure 5

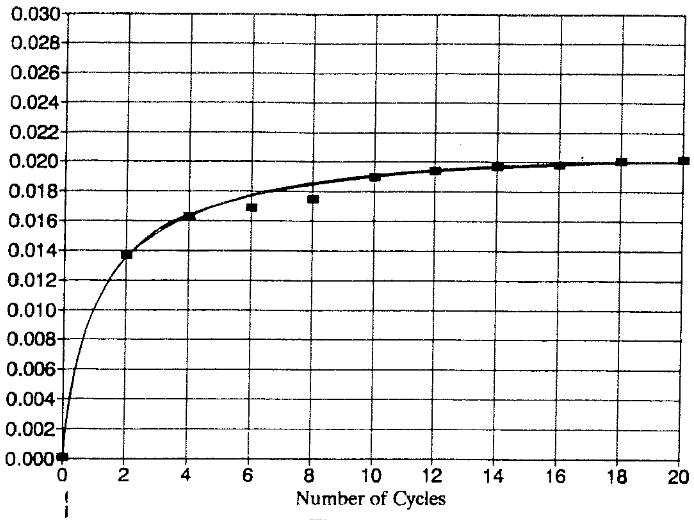


Figure 6

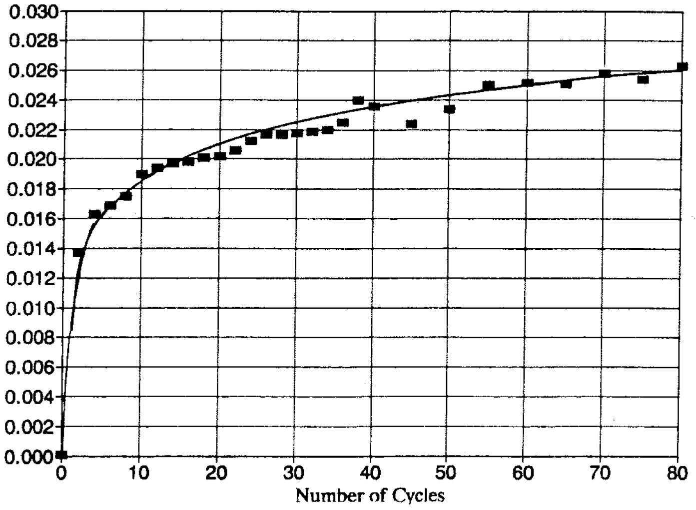


Figure 7

Before describing what is happening in this example let's explore an electrical engineering analogy. The voltage of a capacitor is a function of its charging current and time. A simple circuit consisting of a battery, a resistor and a capacitor can be compared to Almen strip saturation. However, as will be shown, a significant difference is inherent. The final voltage of the capacitor will asymptotically approach the battery voltage. But, the graph for intensity does not appear to be asymptotic.

Let's examine the capacitor's voltage response. If the capacitor voltage is initially zero and the battery is connected at time t=0, the voltage on the capacitor will rise exponentially toward the battery voltage. See Figure 8. The curve for this graph is expressed as:

$$V=V_F(1-e^{-\frac{t}{RC}})$$

t = time
V = Voltage
V_F = Final Voltage
R = Resistance (Ohms)
C = Capacitance (Farads)
e = natural number 2.7183

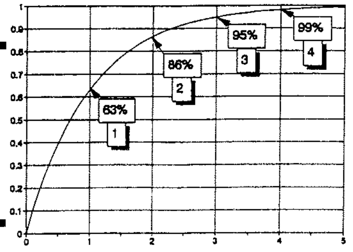


Figure 8

The term RC in the exponent is referred to as the circuit time constant. When the time is equal to one time constant the value of that term is e^{-1} or .37. Electrical engineers are very familiar with this concept, and it provides a quick estimate of capacitor voltage. The following table shows typical values.

1 time constant $= e^{-1} = .368$
2 time constants $= e^{-2} = .135$
3 time constants $= e^{-3} = .050$
4 time constants $= e^{-4} = .018$
5 time constants $= e^{-5} = .007$

As you can see, the capacitor voltage is slowly approaching the battery voltage. It is common for engineers to declare "close enough" at 4 to 5 time constants.

Unfortunately, Almen strips don't behave in the same manner, due to shot size, hardness and velocity variations. In every peening operation a small quantity of shot will be bigger, harder and have higher velocity than the average. Repeated impacts by these shots will, slowly and surely, increase the arc height.

Refer back to Figure 8 to see how these "Higher Intensity" but "Few-in-number" shots can prolong the determination of saturation. Multiple knees, false indication of saturation can readily be seen.

Another common mistake made in drawing the graph for saturation is shown in Figure 9. This graph shows (incorrectly) a point-to-point method of curve fitting. The preferred method is shown in Figure 10. A smooth curve, approximating a natural exponential response, is a better representation of actual conditions. To see this more clearly we repeat the trials shown in Figure 9 four times and plot the data points in Figure 10. It is reasonable to take the average of each data point cluster, thus producing a smooth curve as shown, rather then choosing discrete data points.

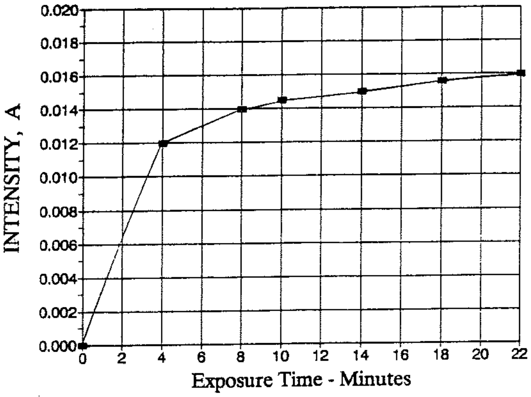


Figure 9

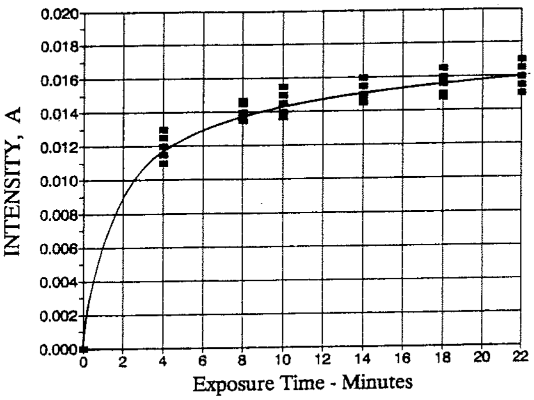


Figure 10

Using the logic above, you should be careful when choosing Method 2 which uses only two data points. Variations in intensity (size, hardness, velocity) as well as error contributions of the Almen strip itself, can cause significant data scatter. This scatter, if not assuaged by smooth curve fitting can be misleading. You must recognize what assumptions are used in Method 2 and treat the results accordingly. It is a short-cut method subject to error.

Using Method 3, SPC charting, must also be done with great care. The Almen strip exposure can be done in various ways, listed in sequence of data confidence:

1. (4) points - Method 1 with graph & analysis
2. (1) point - exposure for saturation time
3. (1) point - exposure for coverage (machine cycle) time

The above techniques can be enhanced by using multiple strips (at the same fixture location) and using averages. This allows calculation of range (max-min) and provides a more robust control capability.

It should now be appreciated why Method 1, using a minimum of (4) Almen strips and construction of a graph is the ONLY method able to determine intensity. Method 2 (2-points) may be used to confirm intensity but it may give misleading information. Method 3, SPC charts, can reveal process capability, especially if the data measurements are of high confidence. The highest confidence being in intensity (Method 1) readings, followed by single point saturation readings and finally by single point coverage (machine cycle) readings.

Finally, some other physical factors must also be considered. It is vitally important that accurate records be kept to describe Almen strip placement and nozzle (or wheel) placement and motion. If the operation is re-peening by someone other than the original equipment manufacturer (OEM), care should be taken to insure that similar techniques are used. Failure to duplicate the original set-up may produce invalid data.

CONCLUSION

Peening intensity can only be **determined** by using (4) or more Almen strips and constructing and interpreting a graph. Peening intensity can be **confirmed** by using 2 Almen strips, one at saturation time and one at double saturation time. Peening **consistency** can be exhibited by use of SPC charts. Shot size, hardness and velocity determine intensity. Exposure time for coverage may be different than Almen strip saturation time.

Appendix A. Peening Intensity Procedure

1. Previous Steps

Prior to determining peening intensity the correct set-up should be verified. Items to consider include the following:

Shot type and size
Part holding fixture
Almen strip holding fixture
Nozzle (and jet) size
Stand-off distance
Impact angle
Translation speed
Indexing table accuracy
Targeting (Peenscan)

2. Preliminary

Check the Almen gage for correct type (either No. 2 or No. 3) and check its calibration schedule. Inspect the gage for obvious defects, including worn indicator tip or balls. Use the Almen gage calibrator (flat side) to establish zero. Use the Almen gage calibration (curved side) to verify gage accuracy of 0.024 within 0.0002" limit.

Select the appropriate Almen strip type (thickness):

'N' = .032" for low intensity
'A' = .051" for medium intensity (range 6A to 24A)
'C' = .094" for high intensity

If the strips are premium grade (Group 1) or pre-certified, skip to the next section, otherwise check the following attributes:

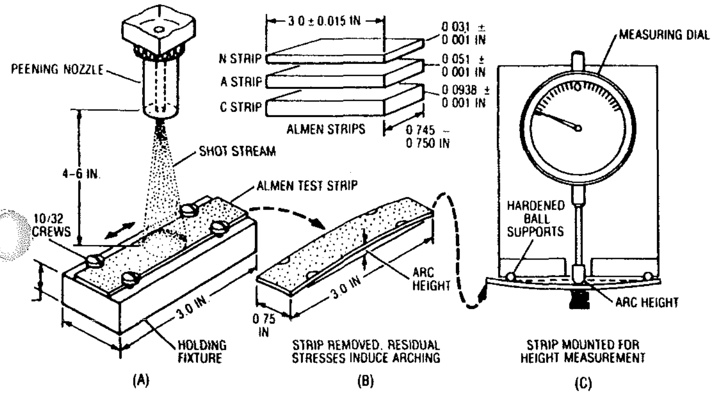
1) length
2) width
3) thickness
4) flatness
5) hardness

<u>Thickness</u>. Place the Almen gage calibrator on the Almen gage with the flat side against the indicator tip. Be sure the indicator reads zero. Insert one end of the Almen strip between the flat side of the calibrator block and the indicator tip. Be sure the calibrator block stays firmly seated on the four support balls. The new reading on the indicator is the strip thickness.

<u>Flatness</u>. Zero the Almen gage using the flat side of the calibrator block. Place the Almen strip on the gage firmly seated on the four support balls. The No.3 Almen gage has end stops to centrally locate the proper strip position. The No. 2 gage requires you to estimate the central location of the strip. The new reading on the indicator is the strip flatness (also called pre-bow). You should also reverse the strip to check curvature on the opposite side. Strips may not have uniform thickness which can be detected by this extra step. Do not use strips with flatness beyond specification limits. Do not bend the strip to make it flat since it obviously has internal stresses that will tend to corrupt its accuracy.

3. Procedure

Place the Almen strip onto the Almen strip holder and tighten the 4 screws. Do not use excessive force. Be sure the strip holder is flat (within .0002") and that no shot is trapped under the strip. Expose the strip to the shot stream for the time indicated on your procedure sheet or blueprint. Remove the strip from the holder and measure its arc height.



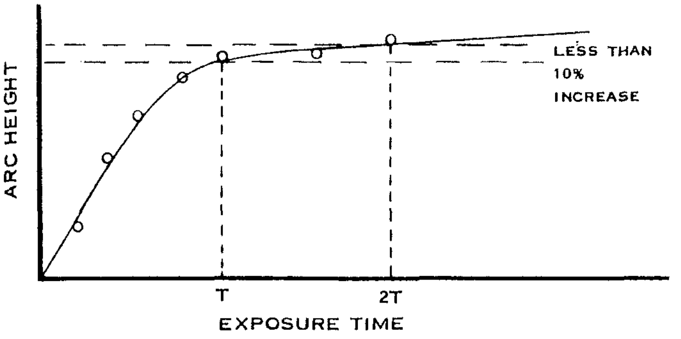
<u>Arc height</u>. Zero the Almen gage using the flat side of the calibration block. Place the Almen strip on the gage firmly seated on the four support balls with the non-peened side touching the indicator stem. The new reading on the indicator is the arc height. Record this value in a table and on the graph for saturation curve. Do not re-use an Almen strip. A new strip must be used for each data point of the saturation curve. Repeat the above process using increasingly longer exposure times.

<u>Construct graph</u>. The data points from the table are represented graphically to determine the peening intensity. Plot the arc height on the vertical axis (Y) with exposure time (or number of machine cycles) represented by the horizontal (X) axis. Use a french curve to construct a smooth curve near the data points. Do not use straight lines and connect-the-dots.

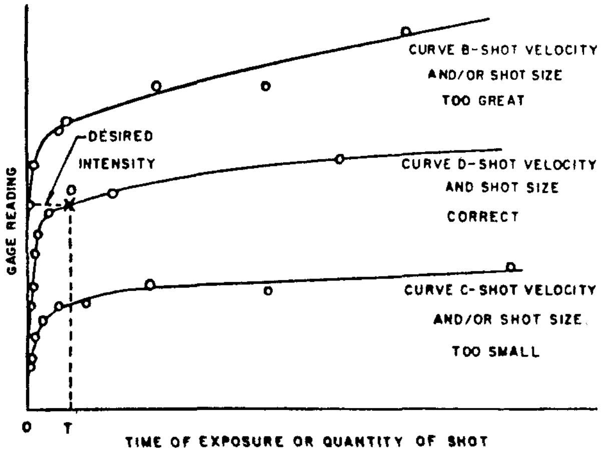
<u>Determine intensity</u>. Select a point on the curve (not necessarily a plotted data point) that appears to be near the knee of the curve. Note the arc height and exposure time. Move to the right to double the exposure time and note the arc height value. If this value is within 10% of the previous value, then the previous value is the intensity. If more than 10% increase occurs, then the original value is not intensity. You should focus on the curve and ignore the data points. It is unlikely that you might select exposure times that "exactly fit" the criteria for determining intensity.

<u>Acceptance</u>. Unless stated otherwise, the intensity should be within 4-points (± .002") of the requested intensity. Some prints or procedures may call out upper and lower limits (10A-14A). If the intensity is within the desired range you should record the following (required by MIL-S-13165 and AMS 2432):

1) Date
2) Shot type and size
3) Shot flow rate
4) Air pressure (wheel speed)



If the graph does not exhibit saturation (graph increases more than 10% for the data presented), then you must continue exposing more Almen strips for longer durations until saturation is achieved. If the graph does show saturation but you do not achieve the desired intensity you must change shot size, hardness or velocity and repeat the saturation test.



<u>Higher intensity</u>. To increase the peening intensity you must increase the shot size, hardness or velocity. Usually the velocity is adjusted by reducing the stand-off or increasing the air pressure or wheel speed. Smaller nozzles or changing the air jet size or setting can also increase the velocity. Reducing the shot flow rate will increase the shot velocity. Be sure that the targeting is correct. The highest intensity occurs at the central portion of the spray pattern. Also, be certain that the right size of shot is in use and it is not contaminated (dust, oil, water).

<u>Lower intensity</u>. Refer to above and do opposite.

<u>Archive</u>. Some procedures require that you retain the Almen strips as part of the record keeping procedure. Be sure to identify the strips adequately.

<u>Intensity confirmation</u>. The best way to confirm intensity is to repeat the above procedure used to determine intensity. However, most operators use a shortened procedure such as single point or double point confirmation. This may be a either saturation time or coverage (machine cycle) time. Although the shorter methods are prevalent, they are not described nor supported by MIL-S-13165 or by AMS 2432. If you use the shorter methods you should also include SPC charting to provide process control.

4. Problems

Occasionally, the confirmation process shows a change in intensity. If you use Method 1 (saturation curves) for intensity confirmation, you have more information available for evaluating process change. The data points on the saturation curve may be close or scattered.

Shot size - wrong size
Shot size - distribution of sizes
Shot speed
Shot angle
Shot contamination - dust & fines
Shot contamination - oil & water
Shot contamination - obstruction
Almen strip - flatness
Almen strip - hardness
Almen gage - zero
Almen gage - calibration
Exposure time - cycle timer
Exposure time - motion fault
Shot flow rate - incorrect rate
Shot flow rate - inconsistent
Targeting - nozzle fault
Targeting - motion fault
Machine modification or repair
Different brand or type of shot
Different brand or defective Almen strips
Different or damaged Almen gage
Nozzle wear or damage
Hose wear or damage
Wheel blade wear or damage
Machine fault - part not moving as expected
Machine fault - nozzle not moving as expected
Dust collector fault
Separator screen defect
[1]Pinnochio

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[1] Don't overlook the possibility of *"Fabrication of Fictional Fables"*. There have been cases where a new operator could not achieve specified intensity. In one instance, after extensive investigation it was learned that previous operators were claiming to achieve intensity - but actually were not. The new operator was unaware that the records were altered to conceal the facts.