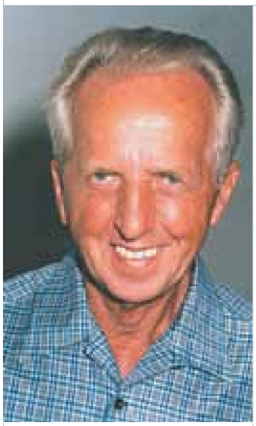

Variability of a Shot Stream's Measured Peening Intensity

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INTRODUCTION

A particular shot stream should always be regarded as a combination of shot particles carried along in a stream of fluid. The fluid is normally air but is sometimes water and could, conceivably, be any one of many other fluids.

Shot streams differ from one another in terms of their average peening intensity. The principal causes of this difference are generally well-understood being: shot size, velocity and density. An independent increase in any one of those parameters will increase the average peening intensity. The measured peening intensity for one particular shot stream is not, however, constant – it is a variable quantity whose variability is less well-understood. This variability of peening intensity – as derived from a saturation curve – depends on three factors: position, angle and time. A useful acronym to bear in mind is "**PAT**", with the **P** standing for **Position**, **A** for **Angle** and **T** for **Time**.

Shot peening requires strict control of each shot stream's peening intensity. This article therefore attempts to explain how and why the peening intensity of a particular shot stream varies.

SHOT STREAM CONSTITUENTS

A shot stream has two basic constituents – a fast-flowing fluid and entrained shot particles. The combination of the two can be expressed as a pictorial equation, see fig.1.

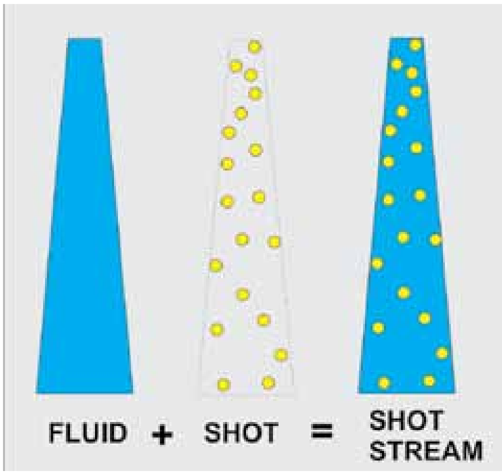

Fig.1 Fluid and shot constituents of a shot stream.

The portrayal of a fluid shown in fig.1 is idealized. The shape of real fluid streams depends on factors such as the type of propulsion – wheel or air-blast – and the particular variant of propulsion unit being employed. With wheel-blast equipment the air is not compressed so that the shape of the air stream is largely a function of blade design. With air-blast equipment the primary factor influencing the air-stream pattern is the shape of the nozzle.

A very important question is: "Which is moving faster – the fluid or the shot particles?" The answer is not immediately obvious. As the particles leave either the nozzle or the blade tip there are alternative answers. For suction-fed air-blast machines the fluid (air) is moving much faster than the shot particles as it emerges from the nozzle. For direct-feed air-blast machines the air is, on emergence, moving faster than the shot particles and for wheel-blast machines the particles are moving faster than the air (which in this case is simply incidental rather than the propulsive agent). Using a venturi-type air-blast nozzle to induce supersonic air speeds will mean that the emerging air is moving very much faster than the shot particles.

VARIATION WITH POSITION

Peening intensity varies with position in a given shot stream. This variation corresponds to the unavoidable variation of shot particle velocity with its position in the shot stream. The governing factor is the "Law of shot stream particle acceleration". This law, stated in words, is that "Any given shot particle will be accelerated if the surrounding fluid is moving faster than the particle, and vice versa". Stated as an equation we have that the accelerating force, **F**, of the fluid acting on a shot particle is given by:

$$\mathbf{F} = \mathbf{k}(\mathbf{v_F} - \mathbf{v_P}) \qquad (1)$$

where **k** is a positive constant, $\mathbf{v_F}$ is the velocity of the fluid and $\mathbf{v_P}$ is the velocity of the particle. If $\mathbf{v_F}$ is greater than $\mathbf{v_P}$ then $(\mathbf{v_F} - \mathbf{v_P})$ is positive so that **F** is positive – therefore pushing on the particle to accelerate it. If, however, $\mathbf{v_F}$ is less than vP then $(\mathbf{v_F} - \mathbf{v_P})$ is negative so that **F** is now negative – meaning that the particle is now pushing on the fluid and is therefore being decelerated. The difference between $\mathbf{v_F}$ and $\mathbf{v_P}$, $(\mathbf{v_F} - \mathbf{v_P})$, is the 'relative velocity'.

A mental picture of equation (1) can be obtained by using an analogy. Imagine walking along a long straight road at a steady 5 kph with a wind of strength 10 kph on one's back. There is now a force proportional to (10 – 5) trying to accelerate one's forward movement. If the wind dropped to 5 kph there would be no accelerating force at all. If, further along the road the wind dropped to 2 kph there would be a force proportional to (2 – 5), a negative quantity, resisting forward movement and trying to slow one down - deceleration.

The shot peening equivalent of this analogy is illustrated in fig.2. Air velocity and shot velocity are represented as vectors so that velocity magnitude is indicated by the length of each arrow. Bear in mind that the air velocity decreases rapidly with distance from the nozzle.

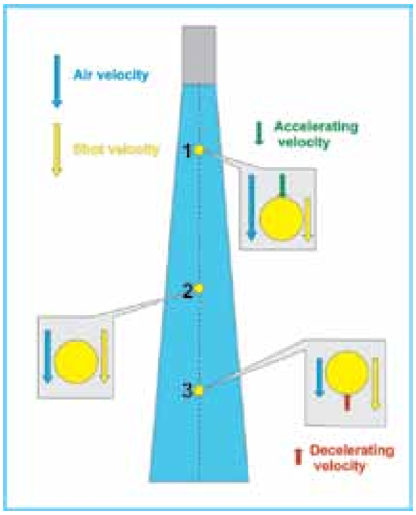

Fig. 2 Vector diagram showing change of relative air/ shot velocities with position.

Imagine a shot particle at position 1 where the air velocity is greater than the shot velocity. There is, therefore, a net accelerating velocity causing the particle to increase its velocity. When the particle reaches position 2 the air and shot velocities are the same so there is now neither acceleration nor deceleration. At position 3 the air velocity has slowed down so that the shot particle is now travelling faster than the air. This gives rise to a net decelerating velocity causing the particle to slow down.

A shot stream contains a vast number of individual particles. Each particle will have a different relative velocity - depending on its position in the shot stream and its own size and shape. It should also be borne in mind that the air flow at the outside of the stream is being slowed dramatically by the static air surrounding the stream. Getting a mental picture of the overall effect for all of the particles in a given stream is very difficult. One analogy (conjured up by the Annual Boxing Day Duck Race held in the author's home town) is of thousands of plastic ducks being dropped into a fast-flowing stream of water. The water flow is fastest at the center of the stream and very slow at the banks of the stream. As the stream widens the average water flow rate decreases. An overall picture emerges of ducks moving in a pattern that can be visualized. This pattern is the same as the iso-intensity diagram shown for suction-fed shot particles, fig.3.

The maximum shot velocity/peening intensity for suction-fed particles occurs in the center of the stream at a particular distance, D, from the nozzle.

Measuring the variation of peening intensity with stand-off distance, D, for a particular shot stream, is fairly straightforward. An Almen strip holder can be placed at different measured distances from the nozzle/blade-tip. Care should be taken to ensure that the axis of the shot stream always passes along the major axis of the Almen strips. Full saturation curves can be produced for each of several distances. Fig.4 shows an example of intensity variation established for S170 shot, straight 5mm diameter nozzle, 2kg/minute feed rate and suction-fed air acceleration pressure-adjusted to give approximately a 10-12A intensity. The most important feature is that a maximum peening intensity, h_{max}, occurs at a definable stand-off distance – 245 mm for this particular shot stream.

At each distance from the nozzle the shot velocity/ peening intensity will also vary across the shot stream, as indicated in fig.5 (page 28).

The measured peening intensity will also vary with position of the Almen strips. A 'High' value will therefore be obtained if the major axis of the strip coincides with the

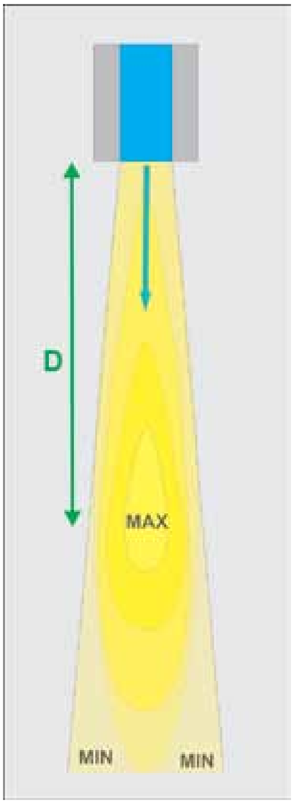

Fig.3 Schematic iso-intensity diagram for suction-fed shot particles.

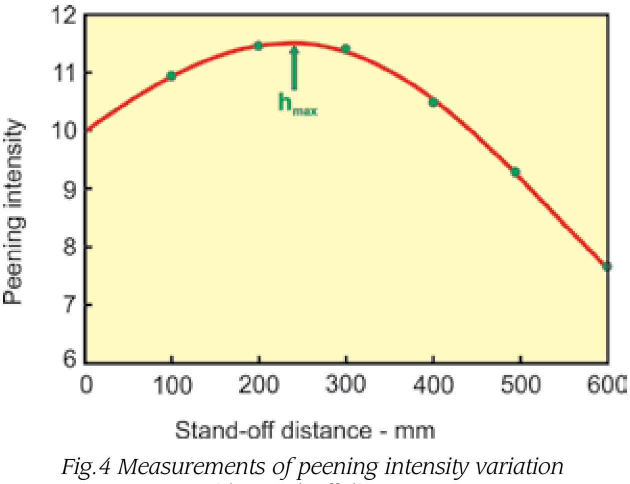

Fig.4 Measurements of peening intensity variation with stand-off distance.

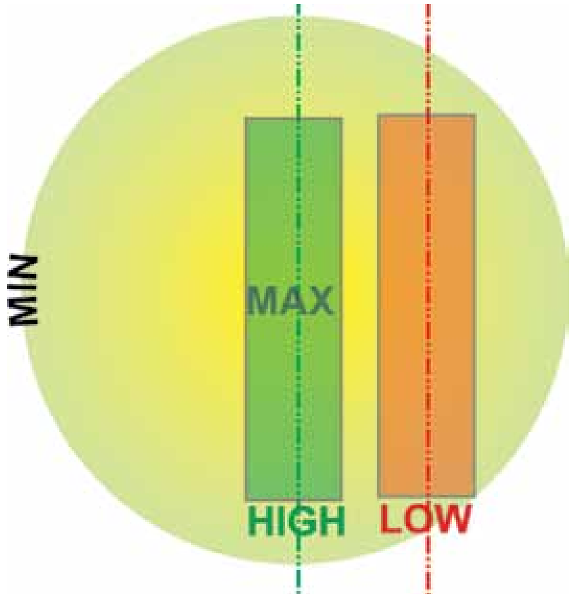

Fig.5 Cross-section of shot stream showing maximum intensity at center.

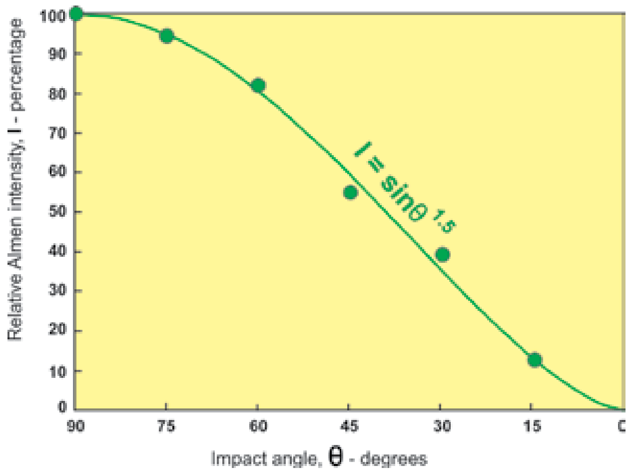

Fig.6 Effect of impact angle on Almen saturation intensity, N strips, S110 shot.

central maximum of the shot stream. A 'Low' value will occur at other relative positions.

Iso-intensity distributions vary with the type of shot acceleration. With direct-feed air blast the air/shot velocity difference at the nozzle is much smaller than it is for suction-feed air blast. A different situation exists with wheel-blast machines. Particles leaving the blade tips are travelling faster than the blade-driven air (centrifugal speed being added to the blade tip's tangential speed). This means that deceleration takes place continuously after leaving the blade tip.

Measuring the variation of peening intensity across a shot stream is experimentally difficult. An indirect estimate can easily be obtained by measuring the variation of indent diameter (indent diameter being directly related to peening intensity). Measurements have been carried out that involved using a 'sliding shutter' between stationary Almen strips and a fixed air-blast nozzle. These indicated that the indent diameter – and hence peening intensity – fell by some 30% between the center of the impact zone and its outside edge. This translates to a corresponding variability to the peening intensity.

VARIATION WITH ANGLE

Shot particles striking a component other than perpendicularly induce shallower indents. This means that the depth of deformation is reduced with a consequent reduction in peening intensity. Fig.6 shows an example of how measured intensity varies with impact angle. This phenomenon has been described in detail in a previous article (The Shot Peener, No.3, vol.19, 2005).

VARIATION WITH TIME

The measured peening intensity of a shot stream depends on three time-dependent factors, each of which can have long-term, short term or immediate influences. These can be categorized as:

1 **Shot characteristics**,
2 **Velocity control** and
3 **Intensity measurement regime**.

1 Shot Characteristics.

Shot characteristics - average size, size distribution and shape - vary continuously with time. Fig.7 is a schematic representation of several factors that conspire to ensure that every characteristic varies with time. These can induce either long-term (slow), short-term (rapid) or instant changes in a given shot stream's intensity.

One example of long-term intensity change is that due to shot wear. Gradual wear of the shot charge particles is the simplest to understand. Every shot particle circulating in the system will suffer wear. Over a long period of usage the shot charge would eventually fail to meet specification size requirements. Fig.8 (page 30) is an example of the effect of long-term wear of S110 shot on average shot stream intensity – assuming that all other parameters remain constant. A new charge of S110 shot set to give a shot stream with a peening intensity of, say, 11A might eventually wear down to a size of S70. If no other peening parameters were changed the intensity would then be approximately 7A (imperial units). In practice, however, peening parameters would be adjusted to take account of this size reduction.

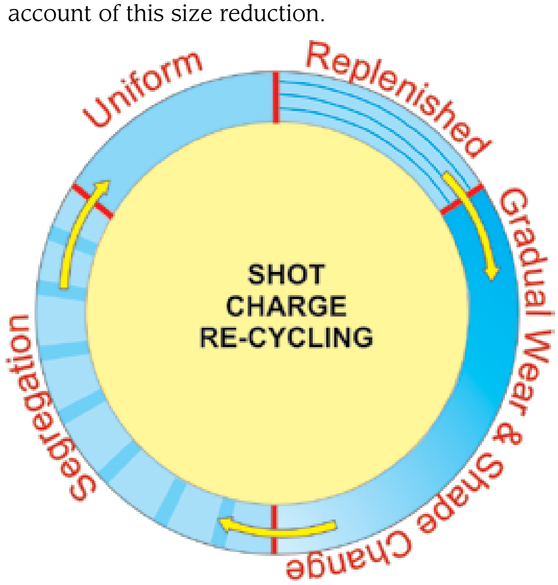

Fig.7 Time-dependent factors affecting shot stream characteristics.

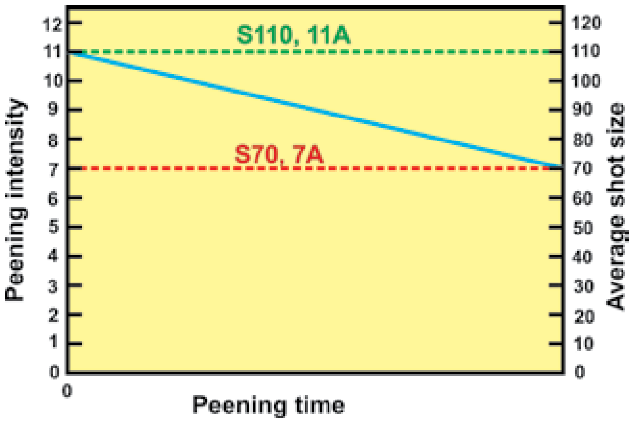

Fig.8 Effect of long-time wear on shot size and induced peening intensity.

Shape change over long time periods is particularly significant for cut wire shot streams. Cut wire particles gradually become more spherical. This type of shape change will be greatest for conditioned cut wire and least for spherical-conditioned cut wire. Theoretical considerations would predict that the measured peening intensity of a given cut wire shot stream would therefore decrease slightly with time – due to shape change.

Segregation induces short-term changes in peening intensity. Shot particles seize every opportunity to segregate – obeying the laws of physics. Several segregation opportunities arise during each complete re-cycling of shot. Natural segregation is represented in fig.7 as 'banding' of the average shot size delivered to a shot stream's nozzle. Forced segregation occurs by the act of replenishment with new shot.

Fig.9 illustrates how short-term shot size changes can affect saturation curve measurements. One particular example of change, based on actual industrial experience, has a 'finer' band of shot always being accumulated at the feed entry region of the hopper. Thereafter 'coarser-than-average' shot was fed into the nozzle. For that particular situation the path of arc height change with peening time would follow 0ABC. A whole range of peening intensities could then be deduced – depending on the selected peening times. If, on the other hand the 'coarser-than-average' band of shot had arrived first then the path would be 0DBE – with different peening intensities being indicated.

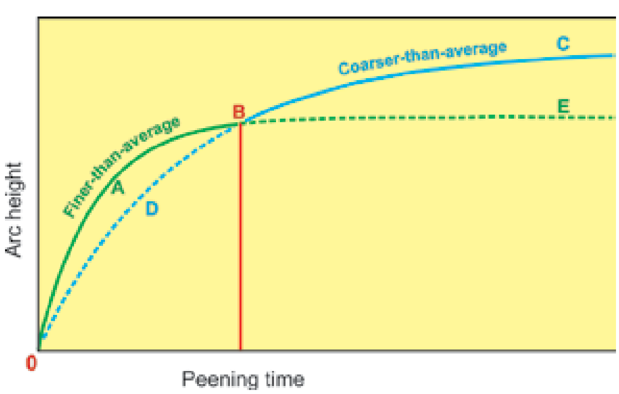

Fig.9 Schematic representation of shot characteristic effects on shot stream intensity.

Replenishment will give an almost instantaneous increase in the measured intensity of a given shot stream – equivalent to switching from the 'finer-than-average' to the 'coarser-than-average' curves of fig.9.

2 Velocity Control

The peening intensity of a shot stream is directly related to the average shot velocity, mass and diameter. Equations (2) and (3) are empirical equations that indicate the effect of shot velocity, v, on the peening intensity, I, that might be expected when using cast steel shot of a given nominal size, S:

$$I = S*0.0036659(1 - \exp(-0.010482*v)) \quad (2)$$

where **I** is in mm and **v** is in ms^{-1}.

and

$$I = S*0.00014432(1 - \exp(-0.0031949*v)) \quad (3)$$

where **I** is in inches and **v** is in feet per second.

As an example, using S170 shot **(S = 170)** having a velocity of 300 ft/sec **(v = 300)**, equation (3) predicts an intensity of 0.015". A 10% reduction in shot velocity **(v = 270)** predicts an intensity reduced to 0.014. Fig.10 is a graphical representation of the variation of predicted intensity versus shot velocity for a range of shot sizes, obtained using equation(2).

Shot velocity is, however, rarely controlled directly. Reliance is normally placed on maintaining either a given air pressure or a given wheel speed together with an assumption that the shot feed rate remains constant. Unfortunately all three factors (air pressure, wheel speed and shot feed rate) vary, to a greater or lesser degree, over short-, medium- and long-term time periods. Contributory factors include the fluctuating demands on air ballast tanks, ballast tank pressure cycling, voltage supply variations, deterioration of wheel blades and shot supply pipes, nozzle wear and shot feed control pulsation.

3 Intensity measurement regime.

There is a range of time-dependent intensity measurement

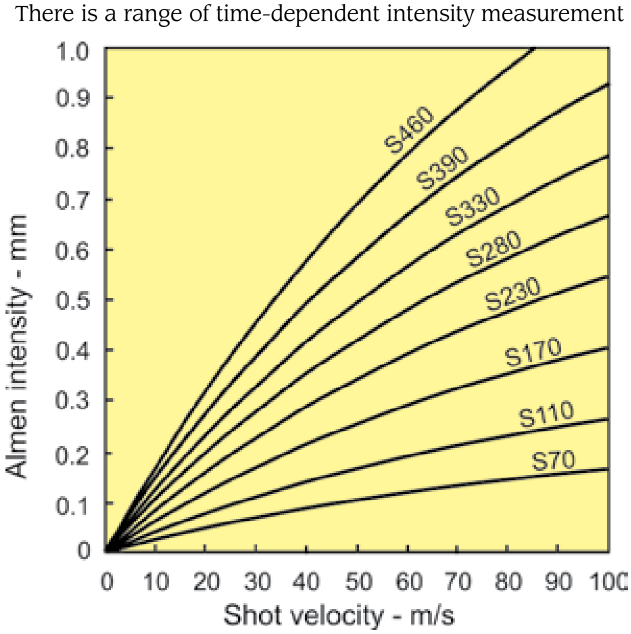

Fig.10 Almen intensity versus shot velocity.

factors. These have been extensively documented elsewhere so that they need not be described in detail here. Long-term factors include ball wear and indicator drift. Short-term factors include individual strip variation and strip placement. These time-dependent factors can, however, be monitored if the measurement regime incorporates appropriate calibration test pieces.

DISCUSSION

This article should not be regarded as being either comprehensive or authoritative. The intention was simply to highlight the fact that there are a large number of factors that cause variability of any particular shot stream. Evidence of that variability is experienced by every shot peener.

A recurring theme is that intensity control can be made more effective if every peening intensity measurement and set of machine parameters is stored in some form of data base. Changes in peening intensity for any given machine can then be assessed against the several possible causes of intensity change. ●