Two Strip Setting-Up and Verification Program for Peening Intensity

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INTRODUCTION

The most accurate method of estimating peening intensity is to produce and analyze a saturation curve constructed from the arc heights of four (or preferably more) peened Almen strips. There are, however, situations where it is expedient to employ a quicker, albeit less accurate, method. These include when a new set-up is being developed and when an established set-up has to be periodically verified. This article presents a simple computer program that optimizes two-strip setting-up and verification testing.

Fig.1 shows the basic features of peening intensity estimation based on the arc heights of four Almen strips peened for different time periods. These time periods can be actual times but are commonly integral numbers of passes or strokes of the shot stream over the Almen strip. The peening intensity is preferably estimated as the unique 'time' for which doubling that time produces a precise 10% increase in arc height. That unique time, **T**, will rarely coincide with an integral number of passes. Moreover, each strip's arc height falls somewhere within an error band. Computer programs, such as the Solver suite, easily and objectively derive the unique peening intensity, **H**, that occurs at the defined time, **T**. The required objective is that **H** shall lie between user-defined upper and lower values.

A feature of saturation curves is that, for a steady shot stream, they all have a characteristic shape. This shape corresponds to a mathematical equation. The set of data points (arc height versus peening time) can be computer-fitted to a known mathematical equation.

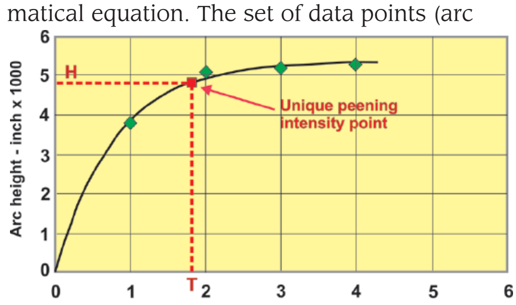

*Fig.1 Unique peening intensity, **H**, occurring at the defined time, **T**.*

PRINCIPLE OF THE TWO-STRIP PROGRAM

The simplest mathematical equations that reasonably represent saturation curve shape contain only two parameters, **a** and **b**. Two such equations are the rational and exponential functions:

$$h = a*t/(b + t) \text{ and}$$
$$h = a(1 - \exp(-b*t))$$

where **h** is arc height and **t** is peening time.

Two data points are produced having co-ordinates h_1.t and h_2.2t. Note that the second peening time, **2t**, has to be double that of the first peening time, **t**. These two data points are assumed to lie exactly on a two-parameter equation's curve, as illustrated in fig.2. The co-ordinates of the two data points are then used to 'solve' the equation for its parameters **a** and **b** and hence determine the equation's unique peening intensity value, **H**, at a corresponding peening time, **T**.

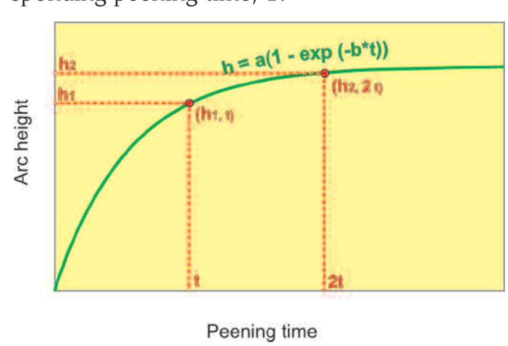

Fig.2 Two data points, (h_1, t) and (h_2, 2t), lying exactly on a two-parameter curve.

Solving of Equation for its Parameters, a and b.

The following description is only of the methodology required to solve equations. Details of the solution process are contained in the Appendix to this article.

Solving of any type of two-parameter equation is based on manipulating a pair of 'simultaneous equations'. The pair is obtained by substituting the two measured values of both **h** and **t** (**h_1.t and h_2.2t**) into the curve's equation. Manipulation of this pair of simultaneous equations allows one parameter to be eliminated - hence yielding the value of the remaining parameter. Having determined that parameter its value is substituted into the equation to yield the value of the second parameter.

The manipulation and substitution routines required for the two quoted equations yield the following general expressions for **a** and **b**:

Equation	a	b
h = a*t/(b + t)	h_1*h_2/(2h_1 – h_2)	2t(h_2 – h_1)/((2h_1 – h_2)
h = a(1 – exp(-b*t))	h1^2/(2h_1 – h_2)	-ln(h_2/h_1 – 1)/t

Peening intensity, H, at Time, T, obtained by using Parameters a and b.

For the rational function equation the unique peening intensity, **H**, is **9*a/11** at a time, **T**, of **9*b/2**. For the exponential function, **H** is **0.9*a** at a time, **T**, of **2.303/b**. Hence we have the following general expressions for **H** and **T**:

Equation	H	T
h = a*t/(b + t)	9*h_1*h_2/(11(2h_1 – h_2))	9*t(h_2 – h_1)/(2h_1 – h_2)
h = a(1 – exp(-b*t))	0.9*(h_1^2)/(2h_1 – h_2)	-2.303*t/ln(h_2/h_1 – 1)

TWO-STRIP PROGRAM

The expressions described in the previous section have been used to compile an Excel-based program. Fig.3 is a sample of the program's worksheet. For this sample, 'perfect' data point values have been used (h2 being exactly 10% greater than h1).

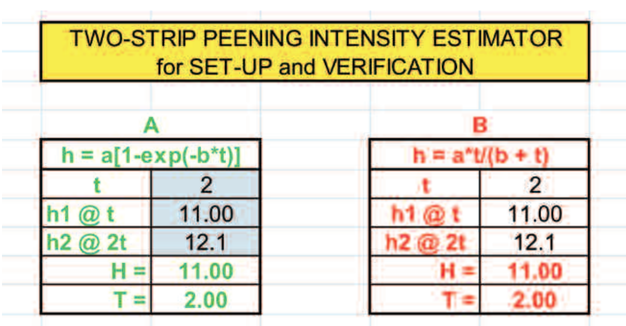

Fig.3 Example of Excel worksheet for Two-strip Estimator program

With 'perfect' values the first data point coincides exactly with the unique peening intensity, **H**, and is at the unique time, **T**. The second 'perfect' data point, at **2T** has an arc height exactly 10% greater than **H**. For such a perfect pair of data points every equation representing a saturation curve must yield exactly the same values for **H** and **T**. Normally, however, the first of the pair of data points will be different from **H**,**T**. The derived **H** and **T** values will then depend, slightly, upon the particular equation that is being used. The difference will only be substantial if the first data point is a long way away from **H**,**T**.

SETTING-UP PROCEDURE

Setting-up of a new peening project has two prime objectives. These are to ensure that the control factors (air pressure/wheel speed, shot size, feed rate, nozzle diameter, stand-off distance etc.) produce:

1) A peening intensity that is within the customer-specified range and
2) the required level of coverage in an economical time.

The level of expertise, prior knowledge and experience that is applied during setting-up will determine how closely an operator can forecast the shot stream's intensity and the time needed to reach the intensity point.

There is no direct connection between peening intensity and coverage. There is, however, a direct connection between coverage and the time, **T**, at which the unique intensity, **H**, occurs. For example, it may be known from previous experience, that a particular component/material reaches a nominal "100% coverage" in a time 50% greater than that to reach **T** (on Almen strips). If a customer requires "300% coverage" and **T** is found on setting-up to be, say, 2.4 passes then we will need 1.5 x 2.4 x 3 passes = 10.8 (or 11 as an integral number of passes).

Real test data is used in the following Case Study – everything else is hypothetical.

Case Study: Two-point Setting-Up Tests based on SAE Data Set No.3

An example of what could have been several two-point setting-up tests is shown in fig.4. This is, in fact, SAE Data Set No.3. This data set is tested using, for simplicity, only Curve A of the program.

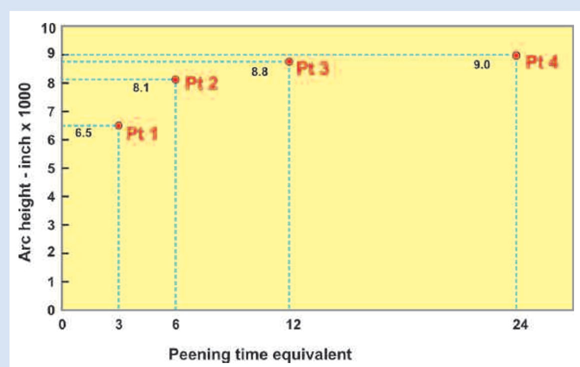

Fig.4 Four data points produced for a given shot stream.

For this study it has to be imagined that three pairs of points were produced independently by three different operators.

1 Imagine that the first operator's best guess for a two-point setting-up gave points 1 and 2. Feeding the values t = 3, h1=6.5 and h2=8.1 into the computer program <u>predicts</u> that the peening intensity point will be **H = 7.8 @ T = 4.9**.

2 Imagine next that a second operator's best guess gave points 2 and 3. The computer program now <u>predicts</u> that the peening intensity point will be **H = 8.0 @ T = 5.6**.

3 A third operator's best guess gave the points 3 and 4. The computer program now <u>predicts</u> that the peening intensity point will be **H = 8.1 @ T = 7.3**.

Case Study continued:

The three predictions can now be tested against the customer's intensity requirement and against each other.

All three predictions of peening intensity, **H**, are reasonably close to one another. If the customer's intensity requirement range had been, say, 6 to 10, then it could have been assumed that the machine settings were good–whichever of the three point pairings had actually been produced. It would then have been worth producing a full saturation curve. If, on the other hand, the customer's intensity requirement range was 10 to 14, then machine settings would have to be modified. For a required range of 8 to 10, the predictions would indicate that a slight 'tweaking' of one or more settings to increase the peening intensity would be advantageous.

The three predictions can be tested against each other by comparing them with the saturation curve peening intensity - derived using all four points. Fig.5 shows the effect of saturation curve analysis using the Solver 2EXP program.

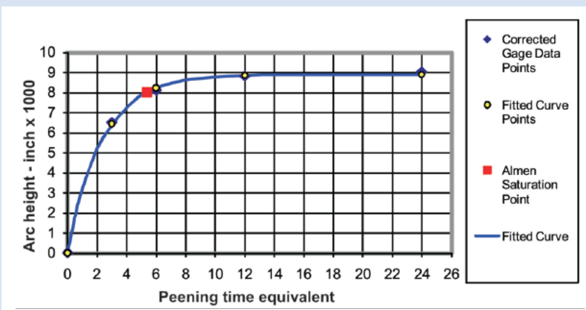

Fig.5 Solver 2EXP analysis of the four data points given in fig.4

Analysis using the Solver 2EXP program on all four data points indicates that the best estimate of peening intensity is **H = 8.0 @ T = 5.4**. The three imagined two-point predictions were **H = 7.8 @ T = 4.9**, **H = 8.0 @ T = 5.6** and **H = 8.1 @ T = 7.3**. It can be seen that the intermediate pair of points (with times of 6 and 12) gives the closest match to that from all four points. That is because the time, 6, of the first point of that pair is closest to the unique peening intensity time of **T = 5.4**.

VERIFICATION PROCEDURES

Shot peeners are required to verify, at regular intervals, that the shot stream's intensity continues to be within the specified range. A balance has to be struck between excessive and inadequate testing. The simplest verification tests require only one strip to be peened. Earlier specifications required that this strip be peened at the peening intensity time, **T**. This is clearly impossible if **T** is not an integral number of passes/strokes/table rotations. The latest version of SAE J443 addresses this problem and allows the single strip to be peened at the nearest practicable time to **T**. The arc height reading from the single strip "must repeat the value from the saturation curve plus or minus 0.038 mm (± 0.0015 in)."

A central problem with single-strip procedures is that they cannot possibly verify that the shot stream's intensity is being maintained! That is because an infinite number of saturation curves can pass through any one point (and the origin 0,0). Fig.6 illustrates this phenomenon and includes the fitted curve shown in fig.5. That fitted curve has a derived peening intensity of 8.0 occurring at a time, **T**, of 5.4 passes. Two additional saturation curves are shown in fig.6 having peening intensities of 9.0 and 13.5 respectively. Both curves pass through the point (5.4, 8.0).

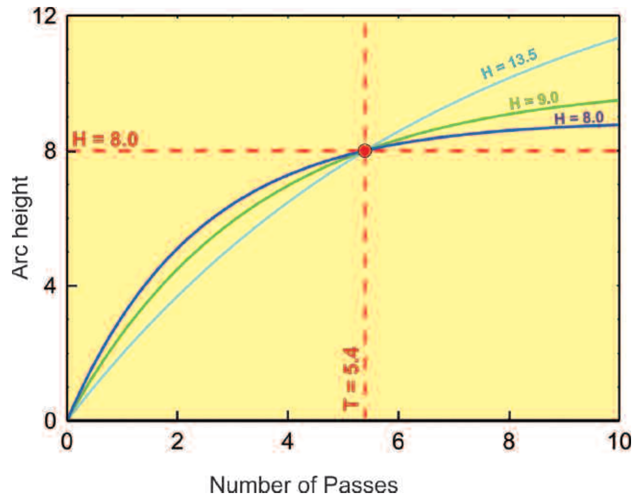

Fig.6 Different peening intensity saturation curves passing through the same point (8.0, 5.4).

If the original setting-up corresponds, for example, to a peening intensity of 8.0 then a single-strip verification arc height of 8.0 only means that the peening intensity is probably somewhere between 7.3 and a very much higher value!

An alternative to single-strip verification is two-strip verification. This is more expensive than single-strip verification. It does, however, afford some confidence that a given peening intensity is being maintained. Two-strip verification is currently employed in a number of organizations. The requirements for arc heights vary between organizations. It is suggested that the two-strip program shown in fig.2 could be employed for verification testing. The strips should be peened for times of **t** and **2t** where **t** is the nearest integral number of passes to the derived saturation peening intensity time, **T**. For example, if the full saturation curve was as shown in fig.5 then verification testing could be carried out at times of 5 and 10. If, for example, peening at those times gave arc heights of 7.9 and 8.6 respectively then those values could be substituted into the program. This, in fact, gives an estimated peening intensity of 7.8, 0.2 less than the 8.0 from the full curve but well within the J443 suggested range of ±1.5 (in thousandths of an inch). As a second example, if peening at times of 5 and 10 gave arc heights of 6.4 and 9.3 then the program would predict that the shot stream's intensity was 10.5 – 2.5 different from an 8.0 from the full saturation curve value of 8.0 and outside of the J443 suggested range of ±1.5.

DISCUSSION

The engineering industry progresses by embracing new ideas. Advances in computer-based technology and software have given rise to a huge range of new ideas and procedures. Reluctance to embrace these impedes progress and reduces competitiveness. The arc heights of peened Almen strips are an invaluable source of information when collected and stored effectively. That leads to an argument that the most effective utilization of arc height data should be computer-based. Techniques are already available for transferring arc height data directly from an Almen gage to an Excel spreadsheet. This data can then be used for a variety of purposes e.g. producing and analyzing saturation curves, setting-up and verification.

Optimum setting-up procedures require an efficient combination of operator experience and prediction technique. The two-strip program described in this article optimizes the prediction technique aspect but requires an initial 'best guess' as to the machine settings that will deliver the required peening intensity in an acceptable time. This 'best guess' can be based either entirely on an operator's prior knowledge or can invoke computer-stored data from previous setting-ups. Provided that the 'best guess' is reasonably good then peening of just two strips will be an effective guide to the adjustments necessary to complete setting-up.

Verification based on peening two strips and using the program described in this article is objective and efficient. Attempts to verify peening intensity by using only one strip are fundamentally flawed. That is because, as shown, any number of saturation curves – with different peening intensities – can pass through a single specified combination of verification time and arc height. The different peening intensity curves shown in fig.6 would arise, for example, through a combination of changes of both shot flow rate and shot velocity.

The two-strip setting-up and verification program is available, at no charge, from www.shotpeener.com.

Appendix

MATHEMATICAL SOLUTION OF TWO-EXPONENT RATIONAL AND EXPONENTIAL FUNCTIONS USING TWO DATA POINTS

Rational function: $h = a*t/(b + t)$

Substituting the two data points (h2,2t) and (h1,t) into the rational function equation gives the following pair of simultaneous equations:

$$h2 = a*2t/(b + 2t) \text{ and} \qquad (1)$$

$$h1 = a*t/(b + t) \qquad (2)$$

Dividing equation (1) by equation (2) immediately eliminates **a**, giving that:

$$h2(b + 2t) = 2*h1(b + t) \qquad (3)$$

Applying some algebraic manipulation to equation (3) yields that:

$$b = 2*t(h2 - h1)/(2h1 - h2) \qquad (4)$$

Equation (4) is the required solution for **b** as all of the terms on the right-hand side are known.

Equation (2) can be re-arranged as $a = h1(b + t)/t$. Substituting the now known expression for **b** gives that:

$$a = h1\{2*t(h1 - h2)/(h2 - 2h1) + t\} \qquad (5)$$

Again applying algebraic manipulation to equation (5) gives:

$$a = h1*h2/(2*h1 - h2) \qquad (6)$$

Equation (6) is the required solution for **a** as all of the terms on the right-hand side are known.

The unique value **H** (for which doubling the peening time increases **H** by 10.0%) is given by $H = 9*a/11$ so that the required equation is:

$$H = 9*h1*h2/(11(2*h1 - h2)) \qquad (7)$$

The unique time, **T**, that corresponds to **H** on the rational function curve is given by $T = 9*b/2$. Substituting the value for **b** given by equation (4) yields the required equation for **T:**

$$T = 9*t(h1 - h2)/(h2 - 2h1) \qquad (8)$$

Exponential function: $h = a(1 - exp(-b*t))$

Substituting the two data points (h2,2t) and (h1,t) into the exponential function equation gives the following pair of simultaneous equations:

$$h2 = a[1 - exp(-b*2t)] \text{ and} \qquad (9)$$

$$h1 = a[1 - exp(-b*t)] \qquad (10)$$

Equation (9) can be written as:

$$h2 = a[\ (1 - exp(-b*t)*(1 + exp(-b*t)] \qquad (11)$$

Dividing equation (11) by equation (10) eliminates **a** to give that $h2/h1 = 1 + exp(-b*t)$. Taking natural logarithms on both sides and re-arranging yields:

$$b = -\ln(h2/h1 - 1)/t \qquad (12)$$

which is the required solution for **b**.

Substituting the value for **b** given by equation (12) into equation (10) and doing some re-arrangement gives that $a = h1/[1 - exp(\ln(h2/h1 - 1)]$. This simplifies to:

$$a = h1/[1 - (h2/h1 - 1)] \qquad (13)$$

Equation (13) further simplifies to give the required equation that:

$$a = h1^{\wedge}2/(2*h1 - h2) \qquad (14)$$

For the exponential function the unique peening intensity is given by $H = 0.9*a$ occurring at a correspondingly unique time given by $T = 2.303/b$. Substituting the derived values for **a** and **b** (equations (13 and (12)) yields:

$$H = 0.9*h1^{\wedge}2/(2*h1 - h2) \qquad (15)$$

and

$$T = 2.303*t/(-\ln(h2/h1 - 1)) \qquad (16)$$

Equation (16) can be further simplified, by introducing Common logarithmic form in place of Natural logarithmic form to give:

$$T = t/(-\log(h2/h1 - 1)) \qquad (17)$$