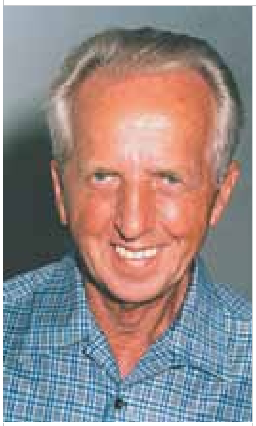
Continuous Measurement Versus Intermittent Indication of Peening Intensity Curves



Dr. David Kirk is a regular contributor to The Shot Peener. Since his retirement, Dr. Kirk has been an Honorary Research Fellow at Coventry University, U.K. and is now Visiting Professor in Materials, Faculty of Engineering and Computing at Coventry University.

INTRODUCTION

Peening intensity curves are of vital importance for effective shot peening. They can be either continuously measured or intermittently indicated. The difference in approach can be illustrated by an everyday example. Imagine that a daily outdoor temperature curve is needed. We could connect a thermocouple to a chart recorder and set that to run for twenty-four hours. That would correspond to continuous measurement of temperature changes and give us a continuous curve. Alternatively we could record temperatures intermittently using, for example, the radio signals from a digital thermometer. These recordings could be plotted on a graph but they would only be an indication of a curve. We would have to invoke a curve-fitting procedure to deduce a possible continuous curve. Fig.1 illustrates the essential difference between the two procedures.

Fig.1b can only be an indication of the actual shape of the curve shown as fig.1a. The four points of fig.1b actually lie on the continuous curve, fig.1a. An estimate of the shape of the curve indicated by just the four points might well be "Your guess is as good as mine".

Current standard shot peening practice is for a set of intermittent indications to be made involving the deflections of a set of Almen strips peened for different total times. These are then used to indicate a continuous curve which can then be analyzed for parameters such as peening intensity. It is, however, also possible to produce a peening intensity curve directly using continuous measurements. The difference is indicated in fig.2 (page 26).

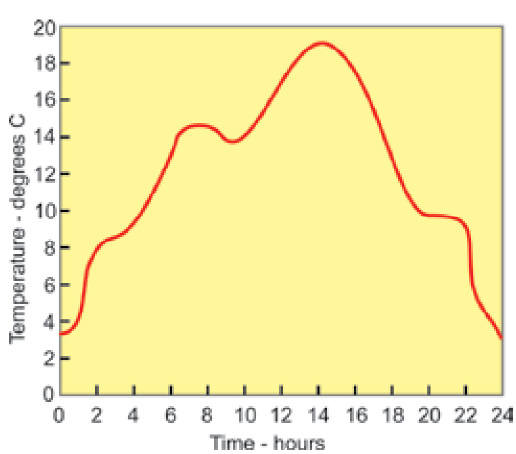


Fig.1a Continuous measurement of a temperature/time curve.

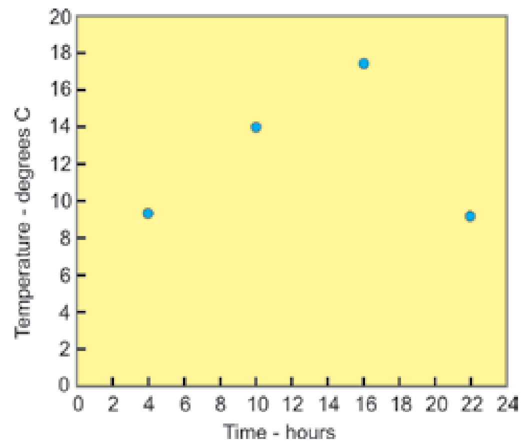


Fig.1b. Intermittent indication of a temperature/time curve.

This article aims to compare and contrast these two approaches. It is concluded that continuous measurement can be a useful supplement to established intermittent indication of peening intensity curves.

CONTINUOUS MEASUREMENT OF PEENING INTENSITY CURVES

Techniques

A continuous peening intensity curve can be produced if the shot stream is static relative to an Almen strip. This concept was introduced by the author at ICSP5. The strip deflection is monitored while the strip is still clamped to its retaining block. During peening, a clamped Almen strip adopts the complex shape shown in fig.3 (page 26).

The deflection of the central portion of the strip (between the hold-down screws) can be continuously monitored using a Linear Variable Differential Transformer, LVDT. An LVDT with an appropriate range has extraordinary sensitivity and accuracy. Hence it can easily cope with the fact that the as-clamped deflection is only about one-third of that of the entire strip after its release from the hold-down screws.

There is no fundamental reason why peening intensity must be determined using rectangular strips. That shape is purely historical, probably reflecting the ready availability of rolled strip that could easily be guillotined into standard lengths. Continuous measurement devices employing circular disks were described in detail by the author at ICSP6. Fig.4 illustrates the basic principles that are involved. Test disks are used having the same thicknesses and of the same steel as Almen strips. When the disk peening diameter is about 40mm the disk deflection is close to that of a conventional Almen strip deflection. Washers of different diameters are employed that allow the peened disk area to be fine tuned.

For both types of continuous monitoring device, calibration against standard intermittent measurements will reveal the appropriate relationship:

$$\mathbf{H_S} = k.\mathbf{H_C} \qquad (1)$$

where $\mathbf{H_S}$ is the peening intensity determined using the standard Almen strip technique, k is the derived calibration constant and $\mathbf{H_C}$ is the peening intensity determined using continuous measurement.

For continuously-monitored Almen strips, **k** is approximately equal to 3 but for continuously-monitored disks it can be arranged so as to be approximately equal to 1.

Advances in data transfer technology would now permit the use of more compact devices than those described, with deflection signals being transmitted wirelessly to a computer for automatic translation into peening intensity and critical time values. Even with basic technology, continuous monitoring will allow peening intensity to be determined in less than a tenth of the time required using the standard Almen strip method.

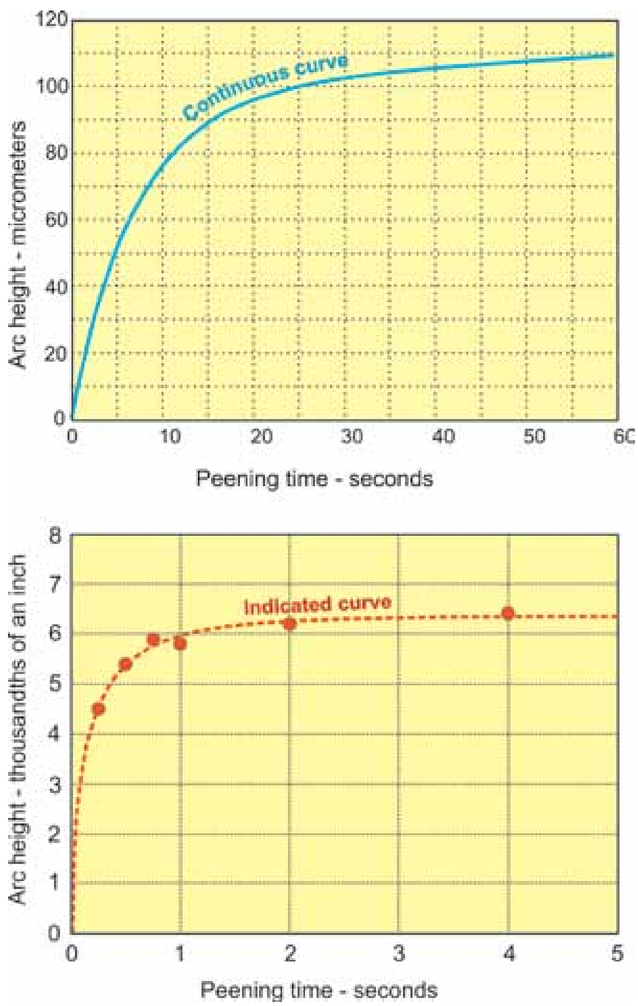


Fig.2 Comparison of Continuously measured and Indicated peening intensity curves.

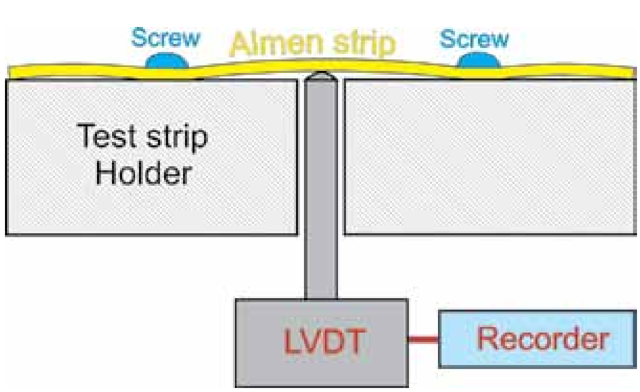


Fig.3 Schematic representation of Almen strip holder modified for continuous measurement of as-clamped strip deflection.

Applications

The following are just some of the several applications that can be envisaged for continuous monitoring of peening intensity.

1) OEM & Setting-up: The enormous saving in time afforded by continuous monitoring could be very useful for OEM's and large peening organizations. They require a very large number of peening intensity measurements when verifying new facilities and when setting-up for a new scale of component. Occasional cross-checking with conventional intensity measurement would, however, be necessary.

2) Single-pass peening: Many organizations achieve specified levels of coverage in a single pass for which a

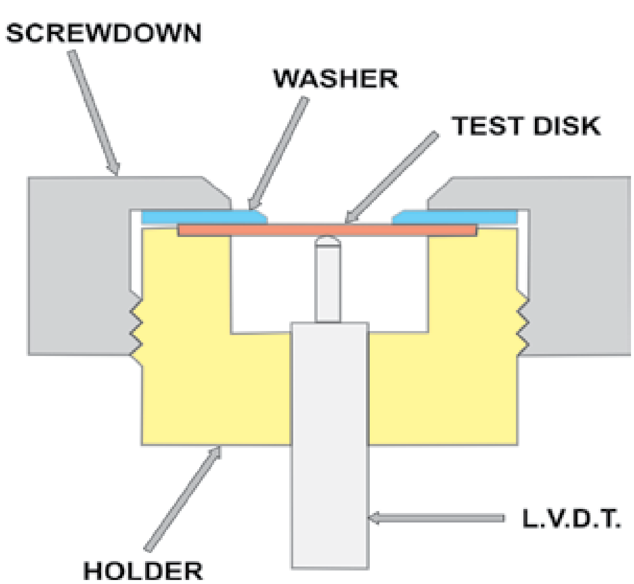


Fig.4 Schematic representation of disk device for continuous intensity monitoring.

single peened Almen strip will have reached so-called "saturation". Specifications covering this type of situation allow for a "Type 2" saturation curve to be produced (where the arc height does not increase significantly after a single pass). With continuous monitoring the approach to "saturation" for a single strip can be evidenced in one pass—without the need for more strips to be peened using multiple passes. Fig.5 illustrates the single-pass situation when a shot stream passing from Position 1 to Position 2 along a path LM aims to give "saturation" of an Almen strip.

There are three factors that affect arc height evolution as a shot stream passes over an Almen strip. Firstly, there is the proportion of the shot stream that is impacting the strip. This will initially be zero, building up to a maximum and then falling to zero as the stream's 'shadow' finally leaves the strip. Secondly, the arc height contribution falls as the coverage increases. Thirdly, the maximum contribution, other things being equal, would occur when the center of the shot stream coincides with the center of the strip. The net effect of the three factors would be reflected in the output of the L.V.D.T. shown in fig.5. Hypothetical output/time curves are shown in fig.6. The arc height is shown as having been calibrated to be the same as that which would occur after unclamping of the strip. It is assumed, just for illustration, that the shot stream takes 4 seconds to travel from Position 1 to Position 2.

If a specified arc height range of 8-10 was being targeted then Curve A would indicate that the intensity was too close to the maximum allowed value. The early leveling-out of the curve does, however, indicate that "saturation" has certainly been achieved. For Curve D the deflection achieved only just meets the minimum requirement. Additionally, the very late leveling-out indicates that

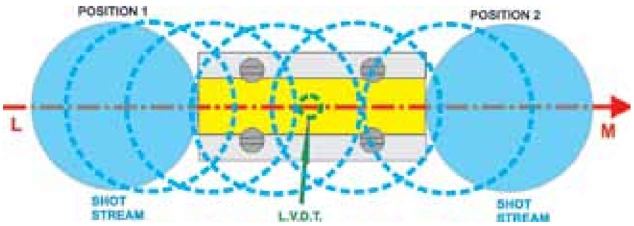


Fig.5 Schematic representation of shot stream passing across an Almen strip.

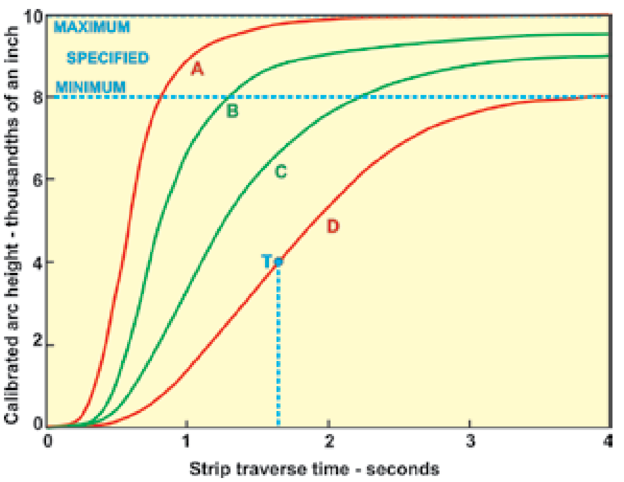


Fig.6 Examples of continuous single-pass arc height curves.

"saturation" has not been achieved. Curves B and C would be typical of peening that did achieve the stipulated single-pass requirements. The point "T" shown on Curve D is a possible defining parameter being the time required to achieve half of the exiting arc height.

3) Shot Stream Intensity Stability: Intermittent measurements of Almen strip deflection give a very unreliable indication of a given shot stream's intensity stability. Each intermittent measurement involves either multiple passes at a fixed traversing rate or single passes at different traversing rates. For each single pass the intensity may vary as the shot stream is traversing the Almen strip but such variation would not be shown up by the single deflection measurement. For multiple passes each pass contributes a fraction of the subsequently-measured deflection. The intensity may vary between passes, as well as within each pass, but again that would not be revealed by the single deflection measurement. Further discussion is included in the next section. Continuous measurement of arc height does, however, show the degree of intensity stability.

The intensity stability of a shot stream is shown by its deviation from the shape possessed by a perfectly-stable shot stream. This poses the question: "What is the shape of the intensity curve generated by a perfectly-stable shot stream?" Two approaches are available to provide an answer to this key question. The first is to analyze Wieland's data (ICSP5) where 388 Almen strips were subjected to nominally the same shot stream. Averaging out these values accommodates fluctuations in process variables. Analyzing by the author (ICSP9) indicated that an averaged-out shot stream would have a shape defined mathematically by a four-parameter equation:

$$\mathbf{h = a[1 - exp(- b{*}t^{C})] + d{*}t} \tag{2}$$

where **h** is arc height, **t** is peening time and **a**, **b**, **c** and **d** are the four parameters.

Sixteen data points were used in the analysis which is far greater than would be commercially feasible (for regular use). A second approach, favored by the author, is to use continuous monitoring of a shot stream whose stability is maintained by applying rigorous laboratory conditions. Dozens of such curves were invariably best-fitted by equation (2).

Having established the shape for a perfectly-stable shot stream the next problem is to obtain an accurate curve for a specific, intensity-variable, shot stream. This can only be done economically by applying continuous monitoring. In the author's Coventry University shot peening laboratory, intensity variability could be effected artificially e.g. by changing the air pressure during a single intensity curve production. In commercial organizations unintentional variability would easily be indicated by deviations from the proper shape of intensity curve.

INTERMITTENT PEENING INTENSITY INDICATION

Standard techniques: Intermittent peening intensity indication is the industry standard. A number of Almen strips, usually four to six, are peened for different time periods. Each strip in a set can either be peened once but for different times or peened several times but for fixed individual times. The first alternative can be effected by varying the relative speed of travel of the shot stream and the strip. The second alternative can be achieved by making different numbers of passes of the shot stream over the strip. Figs.7 and 8 illustrate the fundamental difference between the two alternative approaches. SAE Data Set No.4 has been selected as an independent example. Four strips were peened for 'time periods' of 1, 2, 3 and 4 units yielding arc heights of 3.8, 5.1, 5.2 and 5.3 respectively.

For fig.7, it has been assumed that the actual time periods were seconds. This means that a total of four passes were made involving strips being peened at progressively slower rates of travel relative to the shot stream. For each point it is not possible to ascertain the rate at which the total deflection was achieved.

For fig.8 it has been assumed that the actual time periods were multiples of a fixed time unit. Hence one pass involved a one second pass, two passes involved two one-second passes and so on. The generation of each deflection (other than the first) involves the sum of deflections induced in more than one pass. Possible contributions during each pass have been indicated. The actual contributions can only be guessed at – in the absence of continuous monitoring. There is an indication of a significant instability in either the shot stream or in the different arc height measurements.

The data set used for figs.7 and 8 would, of course, give the same peening intensity, H, using the same indicated curve.

Continuous monitoring can be employed to determine the generation of arc height during intermittent peening. Fig.9 is a schematic example of the type of reaction for four passes made over a clamped strip. During the first pass coverage is incomplete, whereas during the fourth pass coverage is almost complete. That is why the fourth pass has a relatively long period where the arc height change is very small.

Indicated Peening Intensity Curve: Intermittent measurements are used to indicate a corresponding peening intensity curve. Equation (2) shows that the 'true shape' of a peening intensity curve should be a four-parameter equation with a one-parameter linear component superimposed on a three-parameter exponential equation. This is illustrated in fig.10 where the four-parameter equation has been 'best-fitted' to the six-point SAE Data Set 10. It is worth noting that the 'extra' data point 0,0 should always be added to any data set.

Specifications require that a minimum of four data points are required in order to obtain a reasonably-reliable estimate of peening intensity. Users may require a greater number of points in order to improve on the reliability. The most effective use of a limited number of data points is to relate them to the method of interpreting the curve.

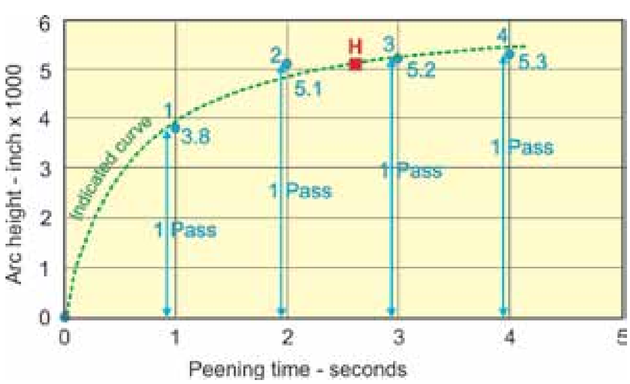


Fig.7 Intermittent indication of peening intensity using different time periods for each strip.

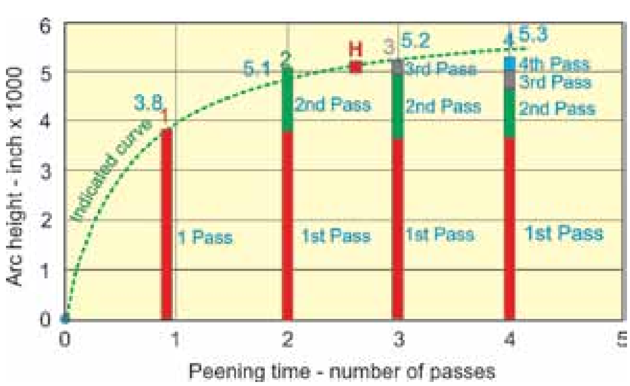


Fig.8 Intermittent indication of peening intensity using different numbers of fixed-time passes for each strip.

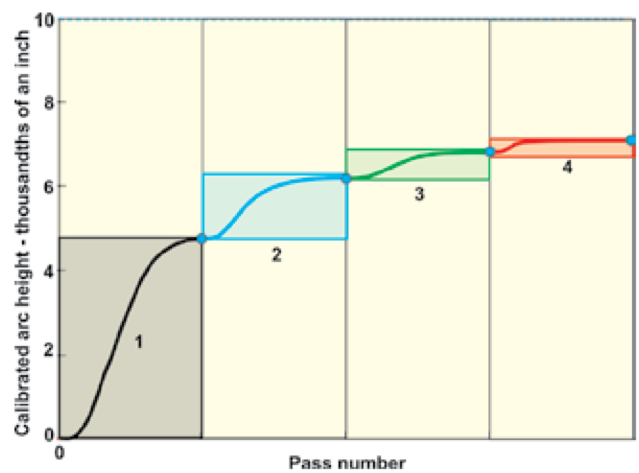


Fig.9 Individual contributions to arc height during four passes over a single Almen strip.

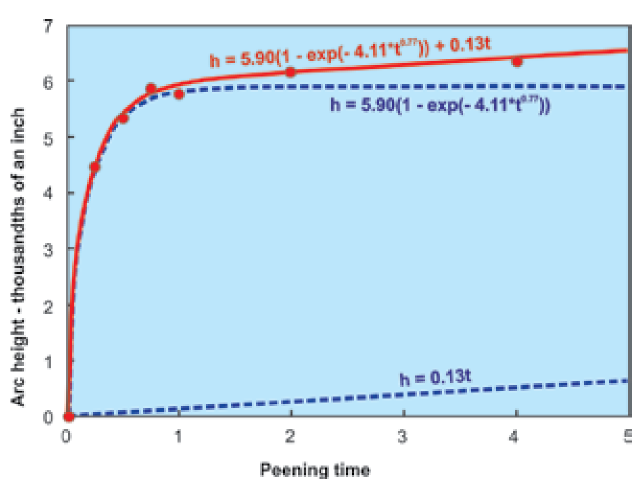


Fig.10 Four-parameter shape of curve indicated by SAE Data Set No.10.

INTERPRETATION OF PEENING INTENSITY CURVES

The main reason for producing a peening intensity curve is to be able to derive the "peening intensity" that can be associated with it. Unfortunately there is a dichotomy of opinion as to how that peening intensity should be derived. Consider the following imaginary conversation between an experienced shot peener, Joe, and a newcomer, Alec. This encapsulates the author's opinions on the subject.

Alec: "What do a set of arc heights tell me about the peening intensity?".

Joe: "If you plot them on a graph they will give you a shape something like that of a hill. The higher the hill the greater is the peening intensity."

Alec: "I've done that, but the hill doesn't have a top to it so I can't measure its height."

Joe: "The guy who invented it realized that, so he proposed that the 'knee' of the curve be used rather than the maximum height."

Alec: "That's fine but 'knee' is a bit vague isn't it?"

Joe: "I agree. What we need is to be more specific. I used to select the one point which obeyed a stated rule 'the point should be such that doubling the peening time gives less than a 10% increase in the arc height'."

Alec: "That still sounds a bit vague. The value then depends on where the points are on the peening intensity curve."

Joe: "Agreed. That is why I changed to using a computer to fit the data points to a curve of a known shape. The computer program then identifies the unique point on the knee of the curve that satisfies the more precise rule "a point on the fitted curve such that doubling the peening time gives a 10% increase in predicted arc height."

Alec: "That sounds a lot better. Why haven't you always done it that way?"

Joe: "When Almen invented the idea we didn't have computers – we had to use graph paper and pencils."

Alec: "Ugh! I suppose everybody now uses computers to find the peening intensity?"

Joe: "No. There are still people who prefer the old ways."

Alec: "Do the old ways offer any advantages?"

Joe: "There is an extra rule that requires the longest peening time point in a set to be at least double the time of the peening intensity point. With the old method that was easy to satisfy – just by always using very long peening times. With the more precise rule I have to make sure that the set of peening times satisfies this extra rule. That means being more aware of the factors that control peening time."

Alec: "You are starting to lose me. Can we have another chat tomorrow?"

Joe: "Of course. I will show you what I mean on some typical graphs."

The history and terminology used does not help to provide a clear guide as to how peening intensity curves should be interpreted. One problem is the current use of the term "Saturation curve". This implies that the curve flattens out as "saturation" is approached. In both theory and practice this does not happen for a truly-shaped curve. There is always a linear component which raises the arc height continuously with peening time. It would be better if the term "Peening intensity curve" was substituted for "Saturation curve". Another problem is that the definition of "Peening intensity" is ambiguous if both "not less than 10%" and "10%" are involved.

Determining the "Peening intensity" is straightforward for continuous monitoring – because there are hundreds of available data points. With intermittent indication of the curve we normally have only 4, 5 or 6 data points per curve (in addition to zero). The key question is "How should the data points be spread in order to determine the peening intensity curve and the peening intensity point most efficiently?" Setting vested interests aside, the answer should be based on how best to estimate the arc height at two 'peening time' points on the curve – the points at T and 2T where the arc height at 2T is 10% greater than that at T. With only four data points in a set one logical choice would be to employ peening times guessed to be at 0.5T, T, 2T and 4T. The two vital points, T and 2T, are then in the middle of the set. This maximizes the latitude (for process variation) that is available and the wide range of points helps when estimating the curve itself. On actual peening, success is then achieved if the resulting arc height data yields an acceptable peening intensity at a point anywhere between the guessed times of 0.5T and 2T. Fig.11 illustrates this approach applied to SAE Data Set No.3. The author of this data set has used four points in the peening time ratios 1:2:4:8 with the second and third points actually coinciding very closely with derived values for T and 2T. If the author had, in fact, been aiming at 0.5T, T, 2T and 4T then the aim was almost perfect.

A general rule for producing and interpreting peening intensity curves is to:

Concentrate on identifying the critical peening times T and 2T and their corresponding arc heights.

If only four data points are available then two should straddle the critical peening times. Curve-fitting should then

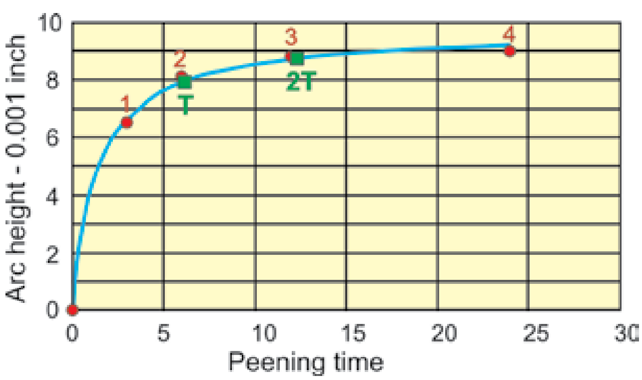


Fig.11 Interpretation of SAE Data Set No.3 with derived peening intensity time, T.

involve only two fitting parameters. More data points per set give more flexibility, but at least two should still straddle the critical peening times. With six or more data points then a three-parameter curve will give more accurate peening intensity values.

DISCUSSION

Continuous monitoring of peening intensity curves has obvious attractions in terms of speed, accurate curve definition, correct intensity location and its ability to detect process changes during actual peening (rather than post-mortem). Its major disadvantages are the absence of corresponding specifications and the more complex technology that is involved.

Intermittent peening intensity curve indication, the current industry norm, is familiar and well-specified. Inertia should not, however, preclude the introduction of continuous monitoring when it is appropriate. Misconceptions about the shape of peening intensity curves abound and can only be reduced by determined efforts on the part of the peening industry itself.

It may be concluded that continuous monitoring and intermittent indication of peening intensity curves are complementary and not exclusive. ●