# DEVELOPMENTS IN INTERACTIVE CONTROL OF SHOT PEENING INTENSITY

Kirk D
Coventry University, UK

## ABSTRACT

Interactive control of shot peening is based on continuous monitoring of peening intensity changes. The latest development in monitoring presented here involves the use of an elastically-strained arm carrying a strain gauge that is in contact with a disposable steel disc. As the disc deforms, due to peening, the arm relaxes with consequent strain gauge signal changes being continuously chart-recorded. The device has been used to study the effects of peening distance, air pressure and peened area on peening intensity/peening time changes. The very high sensitivity of the strain gauge device allows very small changes in intensity to be detected.

## KEYWORDS

Interactive control, strain gauge, shot peening, monitoring, peening intensity.

## INTRODUCTION

The intensity of shot peening is conventionally described in terms of the 'Almen Arc Height'. There are problems of accuracy and repeatability as described by Champaigne (1). These problems are compounded when a peening intensity/peening time curve is required since several individual Almen strips are required. A further problem arises because the measurement is retrospective. The strip deflection is only measured after peening has been completed. Monitoring of a wide range of peening intensities requires three different thicknesses of Almen gauge.

Continuous monitoring of peening intensity has been described by the author (2) based on employing a linear variable differential transformer (L.V.D.T.), see Fig.1.

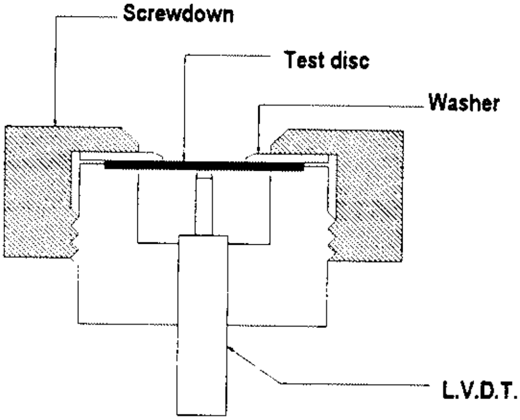

Fig.1 Continuous monitoring device based on an L.V.D.T. as sensor

This technique is in regular use for research and development purposes but the L.V.D.T. itself is relatively bulky and has to be carefully protected from high-velocity shot. Because of that a new type of sensor has been developed, using strain gauge technology, and is described in the following section.

## STRAIN GAUGE SENSOR DISC AND TEST ASSEMBLY

The displacement of a clamped disc during shot peening can be monitored continuously using a sensor disc as shown in Fig.2. This was fabricated from a 0.60 mm thick spring steel disc, 41.0 mm in diameter, cut out to leave an arm, A, 3.0 mm wide. The underside of this arm carries a single strain gauge, SG, which senses the elastic distortion of the arm. Test discs are held against the sensor disc by means of bolts, a clamping ring, clamping washer and a clamping block, see Fig.3. The strain gauge is connected to a strain bridge and thence to a chart recorder. Appropriate adjustments are made for the specific strain gauge factor and the strain bridge is zeroed when the test disc is held flat against the sensor. At this stage the sensor point is depressed below the level of the sensor disc. The hardened steel contactor point, P, is welded onto the sensor disc arm and is 1.0 mm in height. Different sensor discs can have different point heights but larger points require the use of thinner spring steel in order that plastic deformation of the arm does not occur during compression by the test disc.

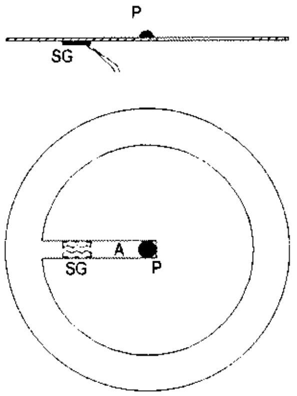

Fig.2 Sensor disc showing strain gauge, SG, mounted on arm, A, with contactor point, P.

The test assembly shown schematically in Fig.3 is mounted, using two studs on the clamping block, normal to the plane of the drawing. These studs fit into a rack inside a shot peening cabinet. This rack contains pairs of locating holes at different distances from a shot peening gun. The gun is mounted in a fixed position at one end of the rack. Hence the test disc is held at $90^0$ to the axis of the gun.

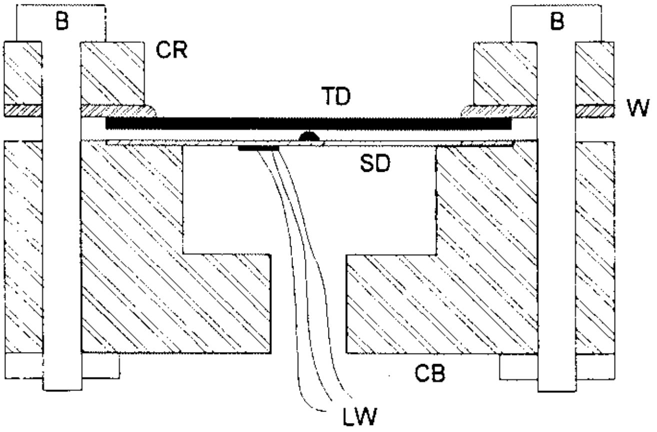

Fig.3 Schematic representation of test assembly showing bolts, B, compression ring, CR, washer, W, test disc, TD, sensor disc, SD, compression block, CB and strain gauge lead wires, LW.

## CALIBRATION OF SENSOR DEVICE

Calibration of the sensor device was effected using a bench-mounted, flat-ended, depth gauge micrometer pressing onto the sensor point. The strain gauge output was zeroed when the sensor point was fully depressed by the micrometer. As the micrometer was wound back in steps of 0.05 mm the strain gauge digital output and the micrometer reading were recorded. After the maximum displacement of 1.00 mm the micrometer was wound back to its zero position to confirm that the strain gauge output was still zero. Fig.4 shows the corresponding calibration graph for a sensor disc with a 1.0 mm point. The actual data points have been plotted with a spline fit curve to the points. The strain gauge output/displacement relationship is almost linear. Fig.4 also includes a calibration curve for the multi-point chart recorder connected to the scope socket of the strain bridge. Again the relationship is almost linear.

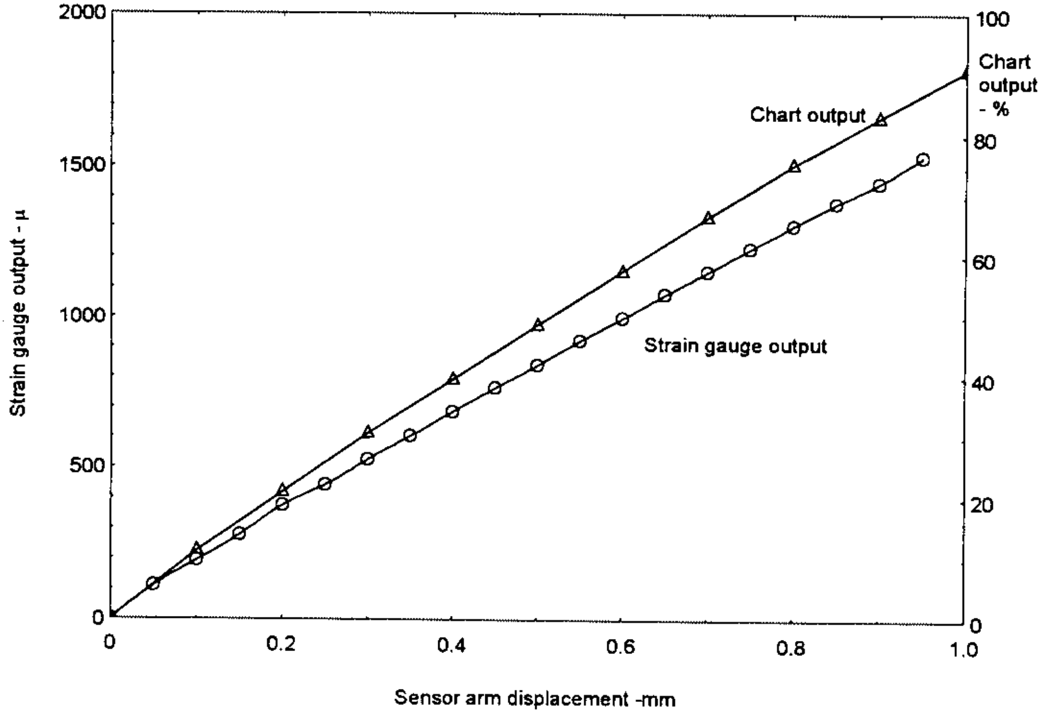

Fig.4 Calibration curves for strain gauge sensor device

Fig.5 shows a chart record produced using the strain gauge sensor device for peening a 1.60 mm thick test disc manufactured from gauge plate steel. Peening was carried out with 1.1 kg/minute of S170 cast steel shot at 4.0 bar pressure and a stand-off distance of 250 mm. The shape of the curve is one of continuously decreasing slope but with a significant slope even at long peening times. At the maximum peening time of 400 seconds the chart calibration curve indicates that the disc displacement is 400 μm. The smooth nature of the curve, whose shape agrees with theoretical predictions, indicates that the device is capable of sensing changes of disc displacement of the order of 1 μm.

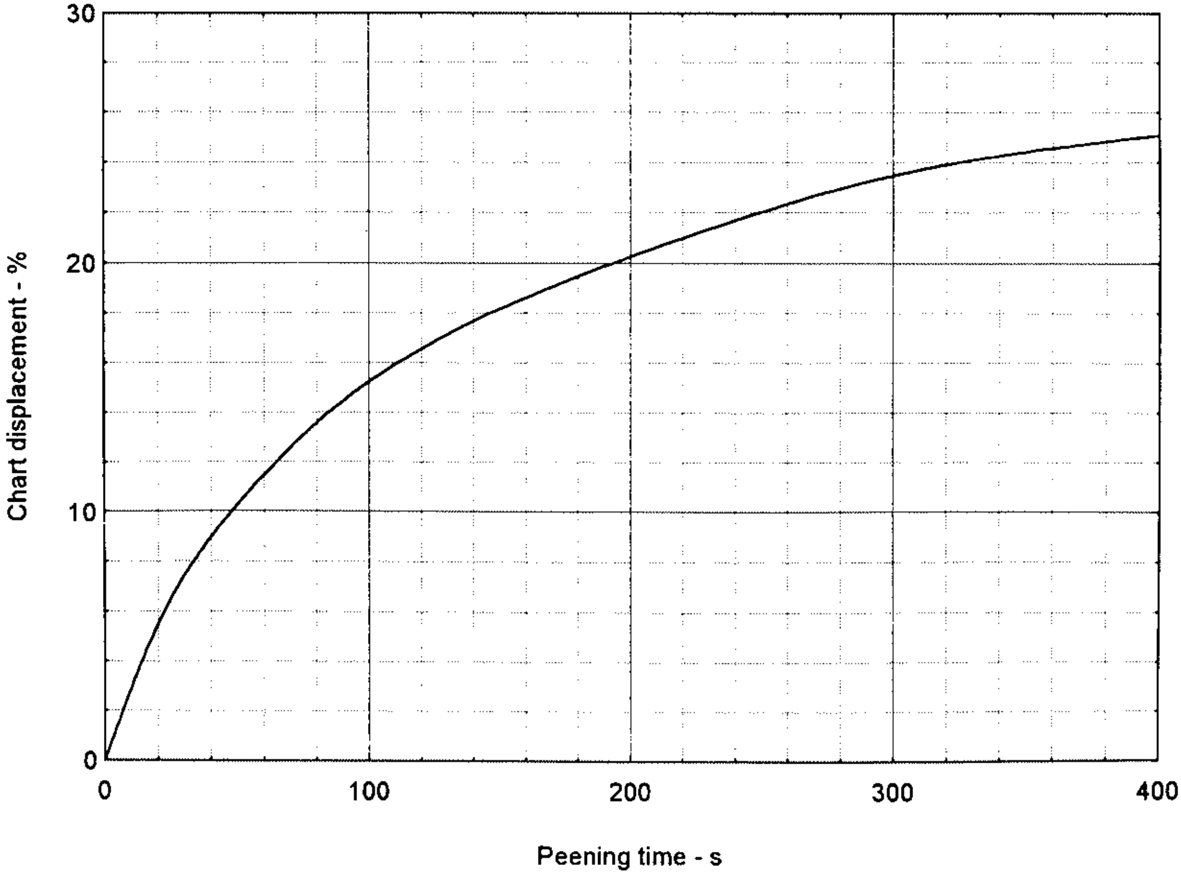

Fig.5 Peening intensity variation with peening time at 4.0 bar pressure

For the remainder of this research the test discs used were manufactured from 850 µm thick mild steel sheet. The discs were blanked using an Erichsen blanking press and de-burred by polishing on a metallographic rotary polisher.

## EFFECT OF PEENING DISTANCE FOR 2.0 BAR PEENING PRESSURE

The effect of varying the distance from the exit nozzle of the peening gun was examined using a blast pressure of 2.0 bar and a feed rate of 1.0 kg/min. This distance was varied between 125 mm and 325 mm. Six different mild steel discs were used and the change in peening intensity was monitored continuously. For each disc the area peened was some 962 $mm^2$ corresponding to a 35 mm diameter. Fig.6 shows the different peening intensity/peening time curves.

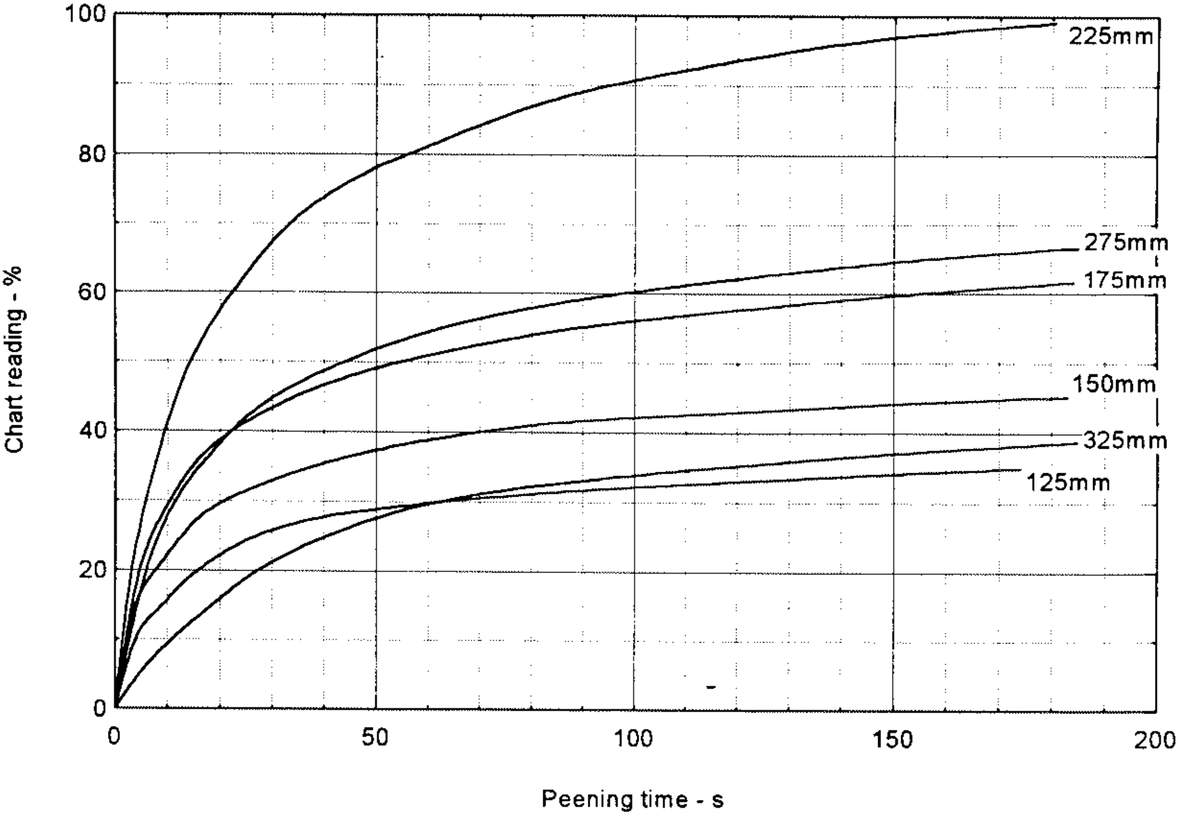

Fig.6 Effect of peening distance for 2.0 bar peening pressure and 35 mm diameter peening area.

It can be seen from Fig.6 that as the distance increases from 125 mm the peening rate increases until a maximum is reached at 225 mm. Thereafter the peening rate decreases progressively with further increase in distance. A comparison of the two extreme distances, 125 and 325 mm, shows that the early stages of intensity increase are greater for the short distance. This is probably because the disc is being bombarded with a higher proportion of the highest velocity shot which is known to occur in the centre of the shot stream (3).

## EFFECT OF PEENING PRESSURE

The effect of peening pressure was examined using three discs all peened at 325 mm with 1.0 kg/min. of cast steel shot but at air pressures of 2.0, 3.0 and 4.0 bar respectively. The corresponding peening intensity/time curves are shown as Fig.7.

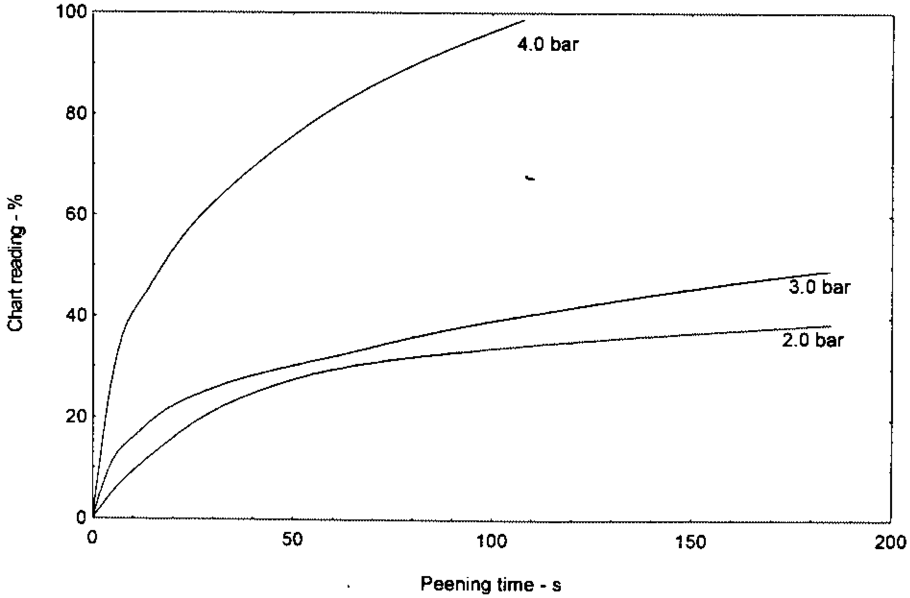

Fig.7 Effect of varying peening pressure at 325 mm gun-to-sample distance.

The curves shown in Fig.7 indicate that the rate of increase of peening intensity is strongly dependent on the air pressure used. It may be assumed that the velocity of the shot is roughly proportional to the air pressure and therefore the kinetic energy of the shot particles increases as the square of the air pressure. It is clear that higher air pressures or shorter distances would be outside the range of the set-up used for these curves. For such higher intensities we can adopt one or other of several strategies. These include reducing the area being peened by incorporating a smaller diameter blanking washer, increasing the thickness of the discs used and using much harder test disc material. The first of these strategies has been examined.

## EFFECT OF AREA BEING PEENED

Three different diameters of blanking washer were used - 35, 30 and 20 mm diameter respectively - to expose test discs at 325 mm to 1.0 kg/min. of shot propelled with 4.0 bar pressure air. These washers exposed test disc areas of 962, 707 and 314 mm$^2$ to the shot steam. The corresponding peening intensity/peening time curves are shown in Fig.8. These curves show a surprisingly small reduction in peening rate for the decrease from 962 mm$^2$ to 707 mm$^2$. The reduction in peening rate for 314 mm$^2$ is much more substantial. This is clear evidence that the central region of the shot stream being used is much more intense than the outer regions. It does indicate, however, the effectiveness of the smallest diameter washer in allowing higher peening intensities to be monitored.

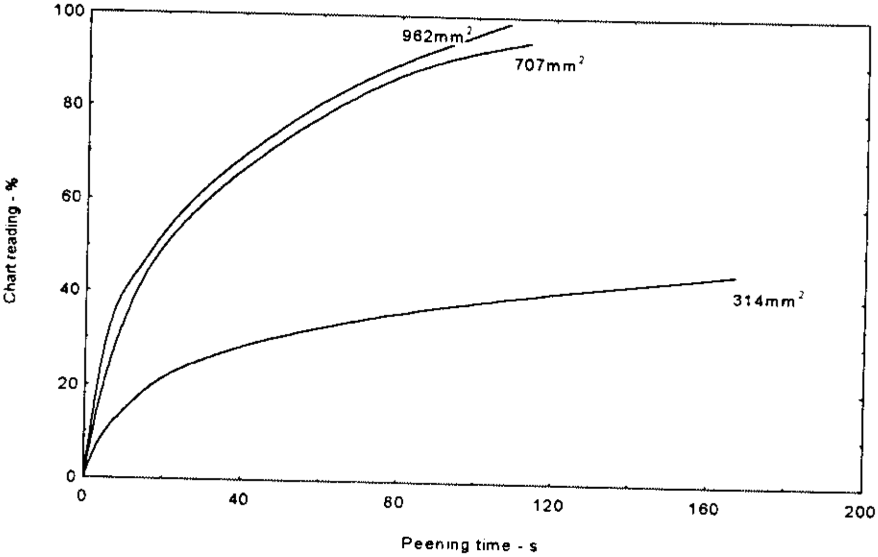

Fig.8 Effect of exposing different areas of test disc to the same shot stream.

## EFFECT OF PEENING DISTANCE FOR 4.0 BAR PEENING PRESSURE

Given the successful use of the 20 mm diameter blanking washer the effect of peening distance was examined for a peening pressure of 4.0 bar. The corresponding peening intensity/peening time curves are presented as Fig.9.

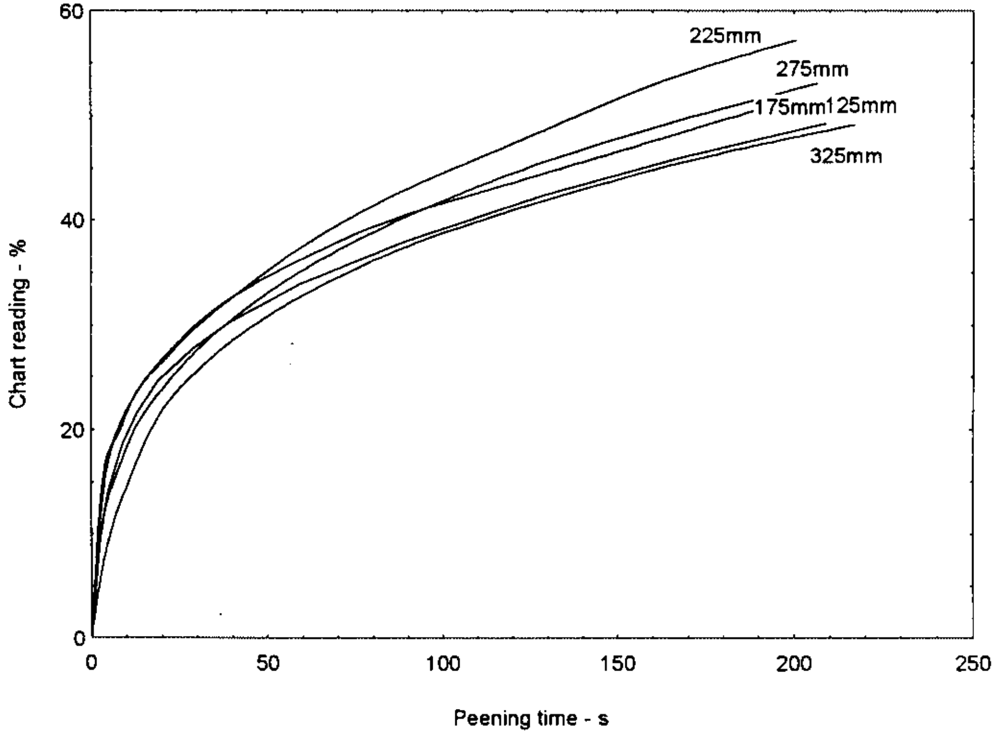

Fig.9 Effect of peening distance for 4.0 bar peening pressure and 20 mm diameter peening area.

The intensity/time curves given in Fig.9 show that peening intensity rates increase from 125 mm to reach a maximum at 225 mm and thereafter decrease.

## DISCUSSION

The interactive device based on using a strain gauge has proved to be successful as a method of continuously monitoring the change of peening intensity with time for a variety of peening conditions. As with the L.V.T.D. device a complete intensity curve is obtained very quickly and needs only a single test specimen. This is in direct contrast with the Almen method which requires a series of strips for each curve. The use of a single specimen and the continuous nature of the monitoring ensures that the peening conditions can be maintained relatively constant as compared with the 'stop-and-start' requirement for loading a series of Almen strips into the same shot stream. The curves shown in this paper were transferred manually from chart records to a computer. Current developments include incorporating an analogue/digital converter into the recording systems. This will allow data to be recorded directly by computer. The calibration data given in Fig.4 will be used to allow automatic correction of strain gauge data to give precise displacement values.

The strain gauge device described here has proved to be extremely robust as compared to the L.V.D.T. device. Current developments include miniaturisation of strain gauge based devices. This is feasible because of the observation that blanking washers had to be used in order to be able to monitor high peening intensities. Overall dimensions of 30 mm diameter by 20 mm thickness are being used. An added advantage of miniaturisation is that the device can then be utilised in smaller areas adjacent to components being peened. A comprehensive interactive control system is being developed to continuously monitor peening intensity and to provide automatic cut-off when an equivalent Almen intensity has been reached.

The use of simple mild steel discs rather than the very hard steel of Almen strips has been advantageous in that virtually identical discs can be produced quickly and cheaply. Different disc materials can, however, readily be used in order to study the effect of varying material composition on induced peening intensity. The same can, of course, be said for the Almen strip method.

There is a fundamental difference in the origin of the curvatures observed with Almen strips and the test discs used for this research. The curvature observed with an Almen strip is due to the imbalance of bending moment when the strip is released from the four retaining screws. Prior to release, peening builds up a bending moment due largely to the plastic deformation of the peened surface and, to a lesser extent, to the induced surface compressive residual stress distribution. The minor contribution of the latter factor has been proved by the fact that on stress-relieving peened Almen strips only recover a small part of their curvature (4). With the test discs used here the curvature is developed continuously.

When the shot stream is turned off the disc remains with its final curvature. No measurable change is observed when the disc is released from its clamping block.

The tests carried out on the effects of peening gun-to-disc distance, peening air pressure and peened area show several significant features. Fig.10 uses the data from Figs. 6 and 9 to highlight the importance of distance from gun to disc. The intensity achieved after 100 seconds of peening at each distance has been divided by the area being peened to obtain the specific intensity.

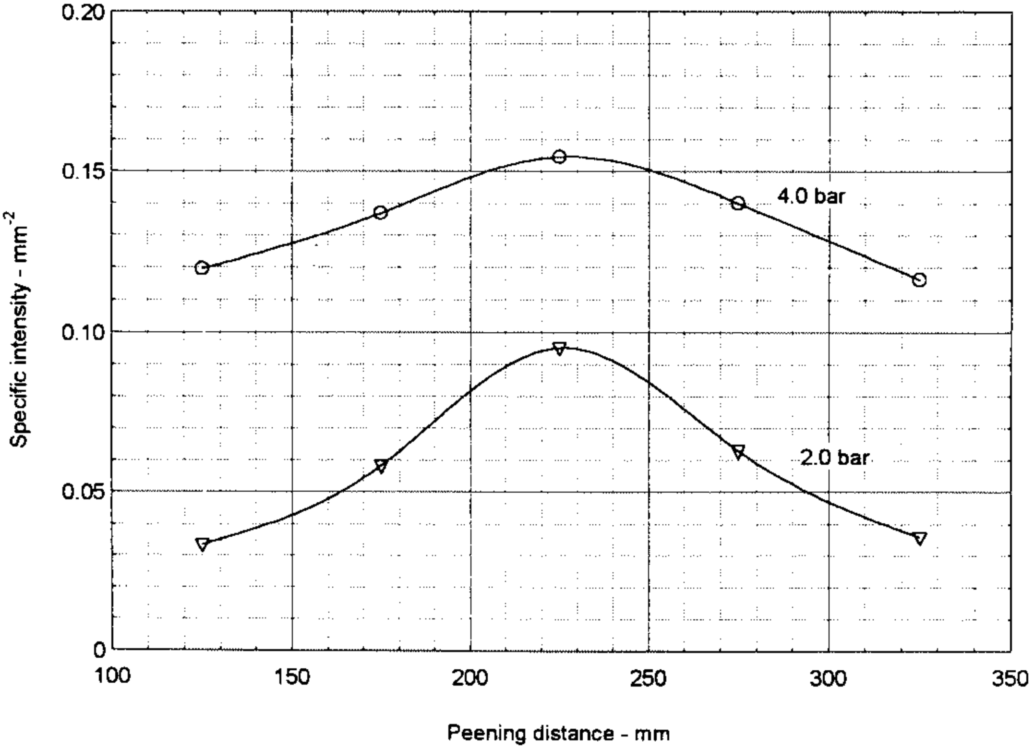

Fig.10 Variation of specific peening intensity woth peening distance and pressure.

The observed optimum distance effect is due to the fact that the shot velocity continues to increase with distance from the nozzle as the air is flowing past the shot particles. This increases the kinetic energy of each shot particle. At a greater distance from the gun the shot particles are travelling faster than the air stream and start to slow down. On the other hand the number of particles striking the fixed area of disc per unit time decreases with distance from the nozzle. The optimum combination of kinetic energy and impact rate occurs near to 225 mm for the specific peening facility being used. It is of practical importance to maintain constant gun-to-component distances in order to achieve uniform peening intensities. In commercial practice, however, the gun is not normally static relative to the component surface. The dependence of specific peening intensity on gun air pressure is also very important. With the equipment used for this research air pressure is continuously monitored from a sensor at the gun head. The curves obtained for different areas being peened confirm that a standard shot stream has an intensity varying from high values at the centre to much lower values at the extremes.

## REFERENCES

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