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TIGHT TOLERANCE PEEN FORMING WITH ON-LINE SHAPE CONTROL

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ABSTRACT

To achieve exactly shaped peen formed parts one must know and control all essential peening parameters. Variations in geometry and material characteristics can be compensated if the actual shape and contour of the peened part is measured on-line and the peening parameters (mass flow, shot velocity, mass per unit area etc.) are adapted accordingly.

A newly constructed measuring / peen forming tool and its control system that calculates the actual peen forming parameters will be presented together with results of first applications. When peening convex curved component parts tolerances down to 0.2 mm are possible.

KEYWORDS

Shot Peen Forming, Online Shape Control, Shot Velocity Control

INTRODUCTION

Shot peen forming is a partially effective forming process derived from the shot peen surface treatment. The overall forming of the component is reached through a great number of statistically distributed shot impacts. The shot is usually made up of steel balls which are accelerated with compressed air in a nozzle. During impact of the shot a certain amount of its kinetic energy is transformed into plastification of the component. When shot velocity is fairly low only a thin layer of the component's material is elongated resulting in a convex curvature. If shot velocity is increased, concave curvatures are produced (1).

Based upon earlier developments all essential parameters of shot peen forming

- shot velocity v_K
- mass flow (dosing) dm/dt
- nozzle traverse rate v_D
- mass per area m_A and coverage A*

can be measured, controlled and calculated on-line when peening is in progress (2,3).

However, for measuring the actual contour the peening process had to be interrupted. The component was taken out of the machine and put onto a measuring gauge. The deviations from the final contour were used as inputs for the following peening operations.

These interruptions of the process are not economical and therefore the number of interim measurements is reduced to the absolutely necessary. It is clear that this is not a method to achieve small tolerances given the variations and fluctuations in material characteristics and the peen forming process itself.

This paper describes how it is possible to achieve exactly shaped convex curved components with an on-line measurement of the contour and computer aided adaptation of the subsequent peening operations.

PRINCIPLE OF COMBINED FIXTURE AND MEASUREMENT DEVICE

In order to measure the contour during peening a combined fixture/measuring gauge for uni-axially convex curved parts was constructed, that can be adjusted for different dimensions of the parts to be formed. The part itself is held in the middle of two edges with spicular clamping devices, preventing any rotation or sliding. At each side aluminium stops are fastened – with the aid of a template - at positions that reflect the final contour of the part. The deviation of the part from its final contour is registered with integrated distance measurement devices whose signals are processed with a computer, s. Fig. 1. The situation for a not yet peened component is shown in Fig. 2. Because of the distance measuring devices already arranged on a curve identical to the final contour there is only a relative measurement of the deviation of the part's contour. Thus it is possible to have lower demands on the accuracy as would be necessary if an absolute x/y/z-measurement with coordinate transformation is implemented.

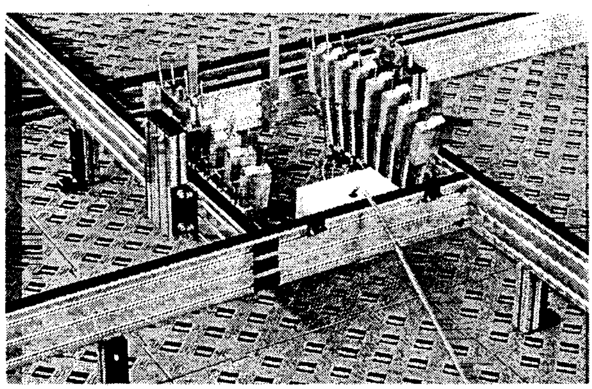

Fig. 1: Combined fixture and measurement device

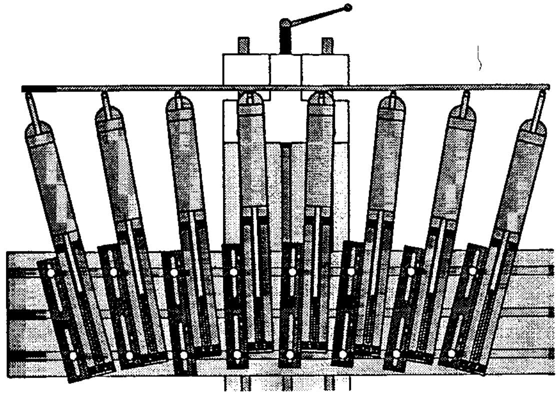

Fig. 2: **Flat component part before peen forming (schematic)**

EXPERIMENTAL SET-UP

For the shot peening experiments the injector-gravitation shot peening unit installed at the Institute for Metal Forming was used. Steel balls with a diameter of 6.35 mm were used as peening tools.

A supplement to the basic control software of the peening machine allows the computer aided pre-selection of certain values for the shot velocity for the actual peening trace. During peening action the shot velocity and the mass flow are kept constant with a newly developed control algorithm. This is quite important if mass flow changes from one peening trace to another. If no control of the shot velocity is used and only the peening pressure is controlled the variation of the mass flow would lead to different shot velocities, see Fig. 3. The above mentioned control algorithm compensates this effect by adapting the peening pressure accordingly.

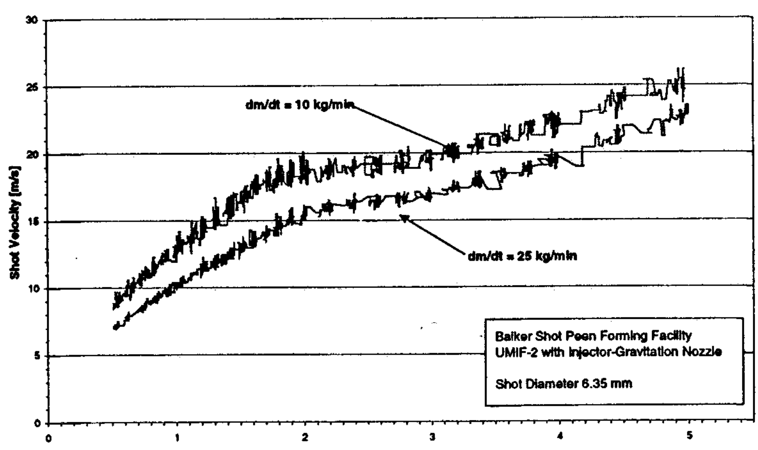

Fig. 3: **Shot velocity as function of the peening pressure and two distinct mass flows if only peening pressure is controlled**

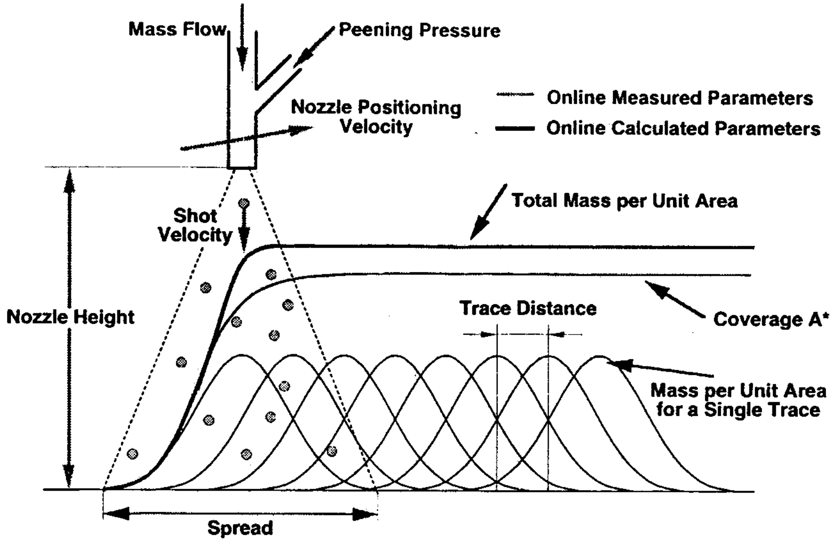

Fig. 4: Online measured and calculated peening parameters

Fig. 4 shows all on-line measured and calculated peening parameters during peen forming. The shot velocity was measured opto-electronically at the nozzle outlet, the mass flow was registered with an inductive measuring device.

Sheets from FeP01 (DC01, deep drawing quality) with a thickness of 2.99 mm served as material for the experiments.

The sheets were cut into quadratic pieces with edge lengths of 500 mm in order to achieve a difficult case in terms of peen forming.

The above presented fixture was adjusted accordingly. The actual contour was measured with 8 distance measuring devices on each side. In two test series flat sheets would be peened to curved components with a radius of 1,000 or 2,500 mm respectively.

In order to estimate which peening parameters would have the optimum forming effect some smaller test samples were peened before the actual test series with different combinations of mass flow, shot velocity and mass per unit area. The results – curvature as function of the peening parameters - of these pre-tests were fed into the data bank for the following experiments.

ALGORITHM FOR ADAPTIVE PEEN FORMING OF CONVEX SHAPED STRUCTURES

Because of the local nature of shot peen forming with forming effect only in close proximity to the nozzle position the sheets were divided into seven separate peening areas, Fig. 5a.

The distance measuring devices were positioned exactly on the boundary of two neighbouring areas; therefore except for peening areas 6 and 7 each measuring device can be assigned two peening areas.

The deviation of the component part is used as input for the calculation of the subsequent peening step. This calculation is based upon the results of the pre-tests that are stored in the data bank. The algorithm chooses the optimal combination of shot velocity, mass flow and nozzle traverse rate for the next peening actions in order to reach the final contour of the component part in as few steps as possible.

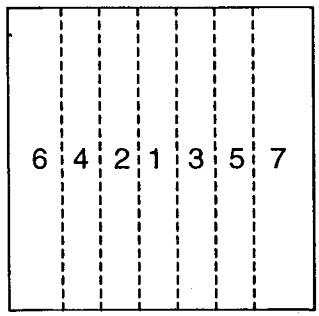

Fig. 5a: Partitioning of sheet surface into peening areas

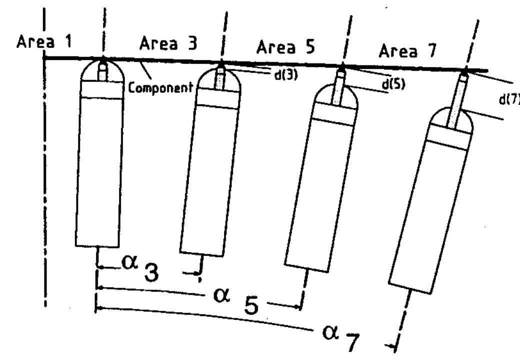

Fig. 5b: Gaps in peening areas 3, 5 and 7 if peening area 1 is already in its final contour

In a first attempt area 1 should be peened first until its contour was within the given tolerance, then the next area should be peened and so on. Only the measuring devices on the actual peening area should be taken into account.

However during the first tests it became obvious, that small measuring mistakes and inaccuracies led to problems with the calculation of the peening parameters. In the next approach not only the contour of the actual peened area was used for calculation but also that of the adjacent areas.

On the assumption that the sheet had been flat before peen forming and that area 1 has already been peened then there is a situation as shown in Fig. 5b. The gaps in the areas 3, 5, and 7 must have certain values, if area 1 is in its final contour. That is to say, that area 1 is only finished, if it is in its final contour and the gaps in the adjacent areas have certain values that can easily be calculated by some trigonometrical relations. If both criteria do not match, the calculation of the next peening step is done with the value that is less prone to over-forming.

One major drawback of the described method is that the sheet must be flat before peen forming. If the raw component has a different shape the gaps in the adjacent areas must be calculated with adapted formulas.

All peening areas are peened with this method. However the number of adjacent areas decreases and finally the areas 6 and 7 that lay at the rim of the sheet do not have any of them.

From the former peening operations it is possible to calculate secure peening parameters for these areas without danger of over-forming.

The flow chart for the peen forming of a whole component is depicted in Fig. 6.

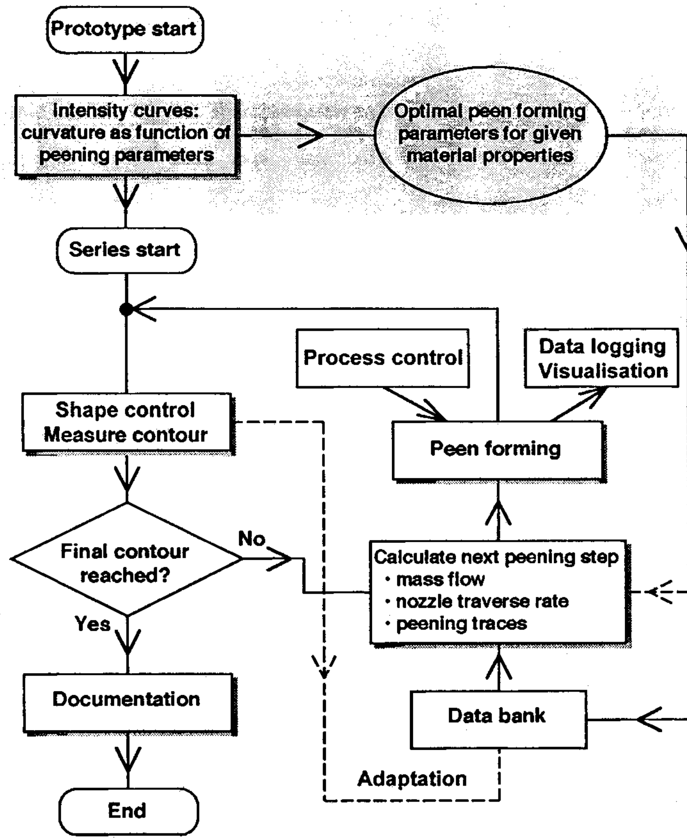

Fig. 6: Principle of peen forming with online shape control and controlled peening parameters

FIRST EXPERIMENTAL RESULTS

In several test series with different peening parameters components with radii of 1,000 mm and 2,500 mm were manufactured with different peening parameter combinations.

The maximum deviation was about 0.2 mm from the given contour. Fig. 8 and 9 show two automatically peen formed components with 1,000 and 2,500 mm radius respectively.

Especially when peening components with the 2,500 mm radius the traverse curvature could not be neglected. The measured distance values must be corrected, otherwise faulty peening parameters would be calculated. The greater the radius the more distinct is the traverse curvature because in this case after the first peening trace is applied in area 1 there is no noteworthy curvature in the required direction which would increase the inertia moment against traverse curvature.

In the first experiments the traverse curvature was measured manually and typed into the computer, which was very faulty. Additional measuring devices on the middle axis of the fixture enabled a direct measurement of the traverse curvature in the following experiments.

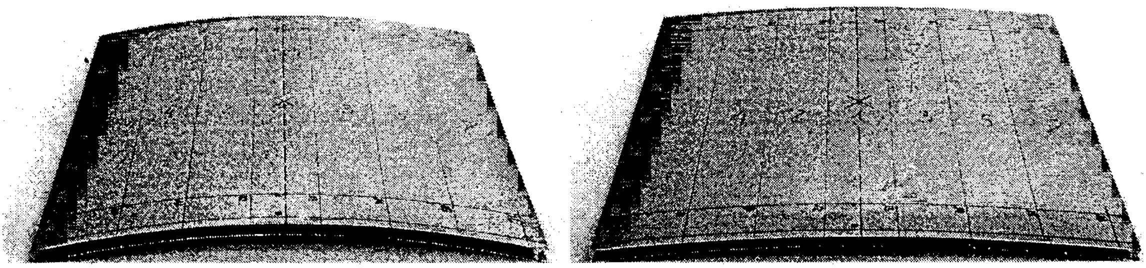

Fig. 7 **Automatically peen formed component parts (500 mm * 500 mm, 2.99 mm thick) with radii of 1,000 mm and 2,500 mm**

CONCLUSION AND OUTLOOK

The on-line shape control is the last building block of the Controlled Shot Peen Forming: Together with the measuring and control of all essential peening parameters esp. the shot velocity and the mass flow it is possible for the first time to have a fully automatic peen forming process.

There is no need to interrupt the peening process for measurement of the component. An adaptive control algorithm takes the actual contour deviation and calculates the optimised parameters for the next peening actions. Absolutely no manual intervention is necessary.

The newly constructed combined fixture and measurement device can be adjusted for different component dimensions. Together with the acquisition, calculation and documentation of all peening parameters it offers the possibility of quick and economical peen forming of small series or even individual parts.

The first experiments have shown that even the unfavorable geometry of a uni-axially curved quadratic sheet can be peen formed to a uniformly curved component.

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