HIGH PRECISION SHOT PEEN FORMING

R. Kopp, F. Wüstefeld, W. Linnemann
Rheinisch Westfälische Technische Hochschule Aachen, FRG

ABSTRACT

A flexible forming process which has been optimized at the Institute for Metal Forming of the RWTH Aachen (Institut für Bildsame Formgebung: IBF) is the shot peen forming process. Computer-aided dosing and nozzle positioning and current adaptive process models already permit production of precise, near-net-shape components on the recently installed IBF plant configuration, a seven-axis numerical controlled shot peen forming facility. This machine can be used both for forming and straightening processes and for component geometries up to 5000 x 2400 x 1000 mm^3 (length x width x height). The presentation and poster contribution will report on recent developments in the area of shot peen forming, the new numerical controlled shot peen forming facility, computer-aided planning and simulation of abrasive coverage and theoretical considerations and improved control methods for complete documentation of the shot peen forming process.

KEYWORDS

Recent developments in the area of shot peen forming
Parameters for the shot peen forming process
Computer-aided planning and simulation of abrasive coverage
Seven-Axis numerical controlled shot peen forming facility
Theoretical considerations and improved control methods
for complete documentation of the shot peen forming process

1. INTRODUCTION

Shot peen forming is a flexible forming process developed at the Institute for Metal Forming of the Aachen University of Technology (RWTH). In this process, a defined curvature is generated in large structural components for the aerospace industry by means of planned shot peening in a number of axes. Shell components of this kind are already being used for the outer skin of the Airbus A-310 and as a structural tank for the Ariane 4 European rocket [1]. More recent developments concern multicurvature geometries with differing sheet thicknesses, e.g. tank domes and parabolic antennas. Other possibilities include the levelling of previously curved component geometries or the peening of stiffening beads and other geometry elements [2,3].

The most recent application is the manufacture of spherically curved tank domes for the future Ariane 5 rocket, in whose manufacturing development the IBF was involved (Fig. 1) [4,5]. In order to ensure a high standard of manufacture for such parts and carry out development work for comparable applications, a modern 7-axis CNC-controlled shot peening plant was installed as a research and development facility at the IBF at the beginning of 1993. The following paper shows how controlled shot peen forming, employing existing models and specific control techniques, can be used to produce components with high accuracy-to-shape and high reproducibility on this compressed-air peening unit with a nozzle for shot up to 4 mm and a combined injector-gravitation compressed-air unit for shot up to 8 mm diameter.

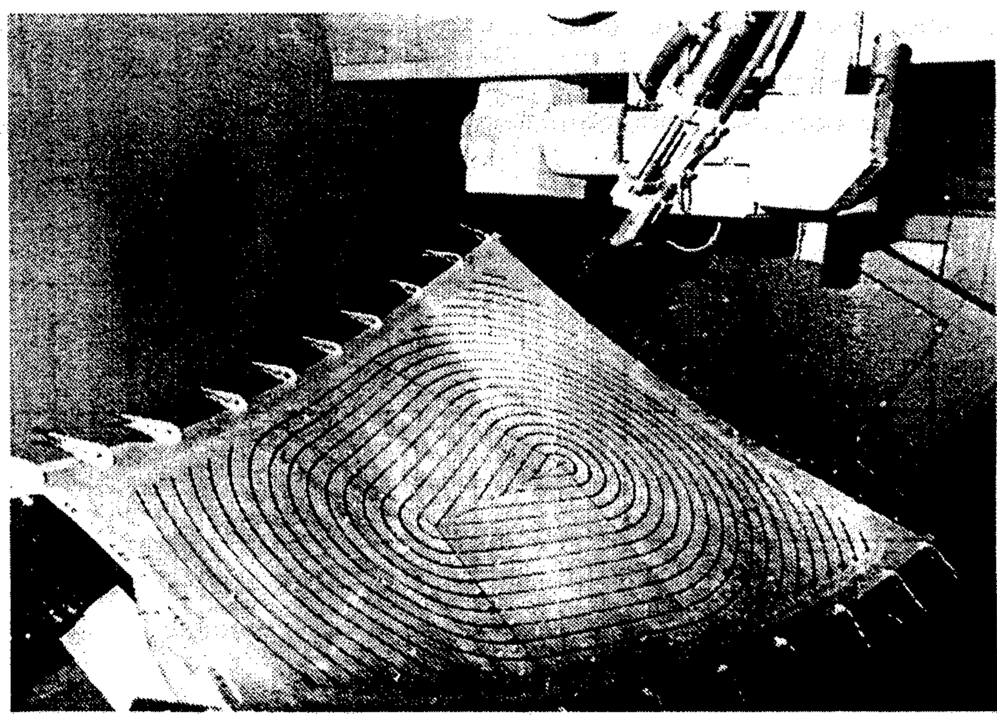

Fig. 1: Segment of a tank dome for the future Ariane 5 rocket during forming at the German Airbus GmbH shot peening plant (Source: Dornier Press Photo No. 13/146 906/11)

2. PARAMETERS FOR THE SHOT PEEN FORMING PROCESS

Changes in shape due to shot peen forming are influenced chiefly by component geometry, material properties, abrasive intensity (shot size and velocity), peening strategy, fixed clamping or preclamping and abrasive coverage [6]. The abrasive intensity of a shot peening process is a function of the abrasive jet and is determined by the size, mass and hardness of the individual balls and by their impact velocity and angle. For a given tool/workpiece combination, the chosen abrasive intensity results in a shot indentation diameter (Fig. 2a) directly on the surface of the component, which may be taken as an indicator of the depth of the plastic zone beneath the shot impression. It is known from measuring grid studies that the plastic zone forms in a spherical region beneath the shot impression (Fig. 2b). Hardness measurements and numerical simulations including FEM calculations have confirmed this assumption.

The abrasive coverage is defined as the ratio of the surface area on which shot impacts actually occur to the total peened area. Unlike abrasive intensity, abrasive coverage is a function of peening time. If the abrasive intensity of a given abrasive jet is kept constant, sheet curvature increases with abrasive coverage (Fig. 2c). Tests have shown that abrasive coverage beneath the nozzle of a compressed-air peening machine possesses a characteristic distribution, with a maximum above the line centre and a decrease in coverage towards the edges. This distribution (Fig. 2d) may be described by a normal distribution function in the form

$$N(x) = 1 / (\sigma \cdot \sqrt{(2\pi)}) \cdot \exp(-\tfrac{1}{2}\ ((x-\mu)/\sigma)^2) \qquad (1)$$

or for an area

$$N(x,y) = 1 / (2\ \pi\ \sigma_x\ \sigma_y) \cdot \exp(-\tfrac{1}{2}\ ((x-\mu_x)^2/\sigma_x^2 - (y-\mu_y)^2/\sigma_y^2)). \qquad (2)$$

On the basis of this characteristic distribution, a modular software package for the planning and simulation of abrasive coverage in the shot peen forming process has been developed and sophisticated at the IBF. Installed on a high-performance personal computer linked to the central control unit of the 7-axis CNC-controlled shot peen forming plant at the institute, this software package can be used for control and on-line monitoring and documentation of the entire peening process.

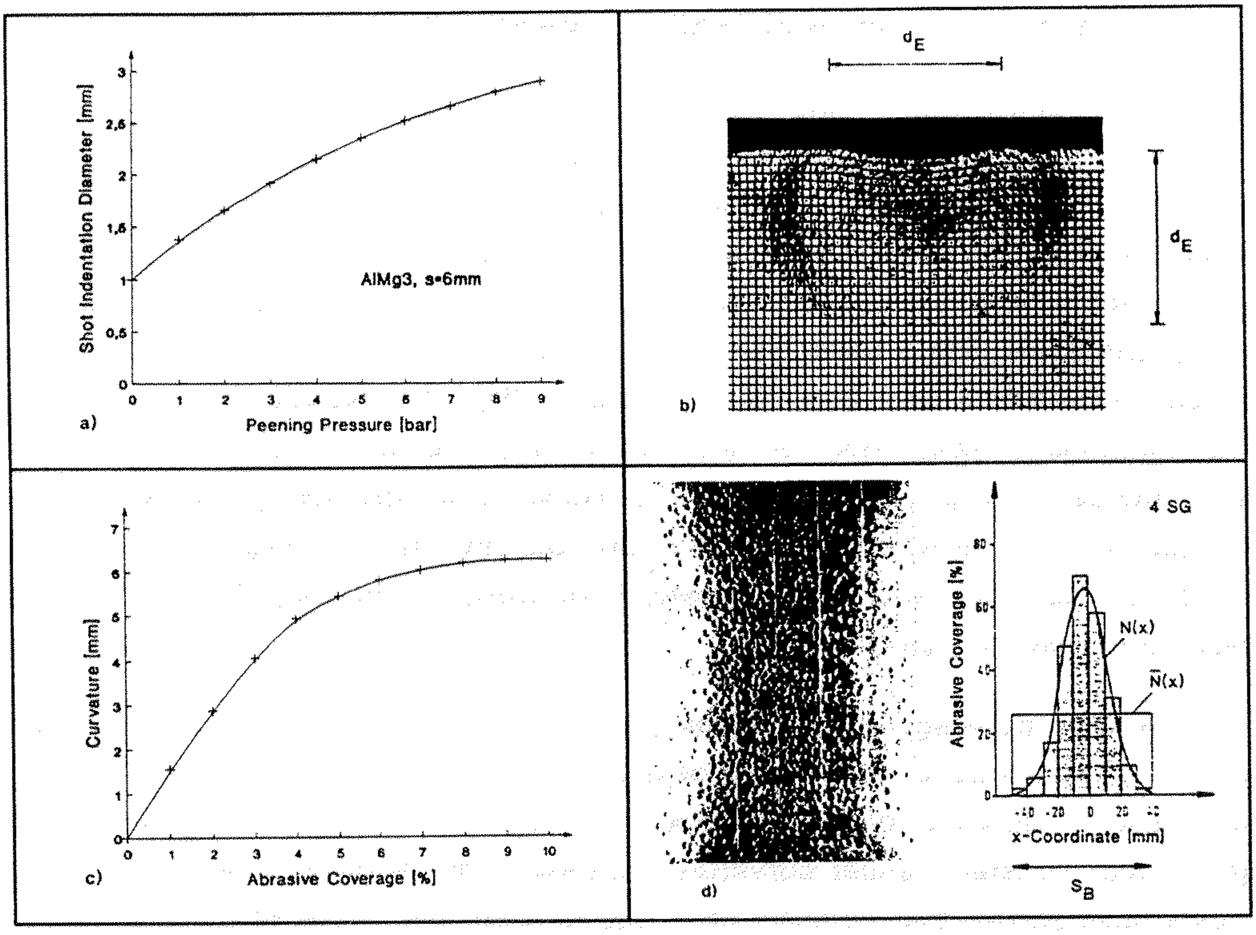

Fig. 2: Shot indentation diameter (a), characteristic forming zone (b), Almen intensity (c) and abrasive coverage beneath the nozzle (d)

3. SOFTWARE PACKAGE FOR THE PLANNING AND SIMULATION OF ABRASIVE COVERAGE

It is assumed that the abrasive coverage in a compressed-air peening plant with one nozzle exhibits a normal distribution beneath the nozzle. If this assumption is correct, the total coverage after n peening paths (planning) can be inferred from the standard deviation of a single curve or, conversely, the necessary coverage distribution per peening path (simulation) can be inferred from a desired total coverage. The mathematical modules comprise a known basic statistical equation estimating the mean (area-equivalent) abrasive coverage beneath the nozzle, the mathematics of the normal distribution according to Gauss and, to allow for overlapping of a number of normal distributions, the addition statement for random events. A corresponding simulation algorithm was prepared and validated by means of practical tests [6].

The input variables are the shot diameter d_K, the shot indentation diameter d_E and the nozzle spread S_B; depending on the peening strategy, other required input variables are the peening pressure p, the nozzle height h_D, the shot per unit time m_t (dosing), the rate of travel of the nozzle v_D and the number of peening passes per path SG. The software package first uses a basic equation already described in [7] and [8] and modified in [6] to calculate from these input variables the mean value of the normally-distributed coverage

$$\bar{A}^* = 1 - \exp(-A_{dE} \cdot m_A / m_K) \qquad (3)$$

where

$$m_K = 1/6 \cdot \rho_K \cdot \pi \cdot d_K^3 \qquad \text{(shot mass)}$$

$$A_{dE} = \pi \cdot d_E^2 / 4 \qquad \text{(shot indentation area)}$$

together with the mean value of the impinging abrasive volume per unit area

$$m_A = m_t \cdot t / (\pi/4 \cdot S_B^2) \qquad \text{(for point peening)}$$

$$m_A = SG \cdot m_t / (S_B \cdot v_D) \qquad \text{(for line peening)}$$

$$m_A = SG \cdot m_t / (S_B \cdot 2 \cdot \pi \cdot R \cdot U) \qquad \text{(for circle peening).}$$

From this are inferred the standard deviation of the normal distribution ($\sigma = S_B / 6$) and the nozzle-position-dependent local abrasive coverage beneath the nozzle

$$A^*(x) = \bar{A}^*_M \cdot 6/\sqrt{(2\pi)} \cdot \exp(-½((x-\mu)/\sigma)^2). \qquad (4)$$

Graphics can be generated for a single curve or for a number of peening paths offset by a line interval z_A (modelling module) (Fig. 3a).

In order to ensure a uniform total coverage, a line interval

$$z_{A,opt.} = 1/2 \cdot \sqrt{3} \cdot \sigma \qquad (5)$$

should be selected [6]. The resulting total coverage will then be

$$A^*_{ges}(x) = 1 - [\prod_{i=1}^{n} (1 - A^*_i(x))]. \qquad (6)$$

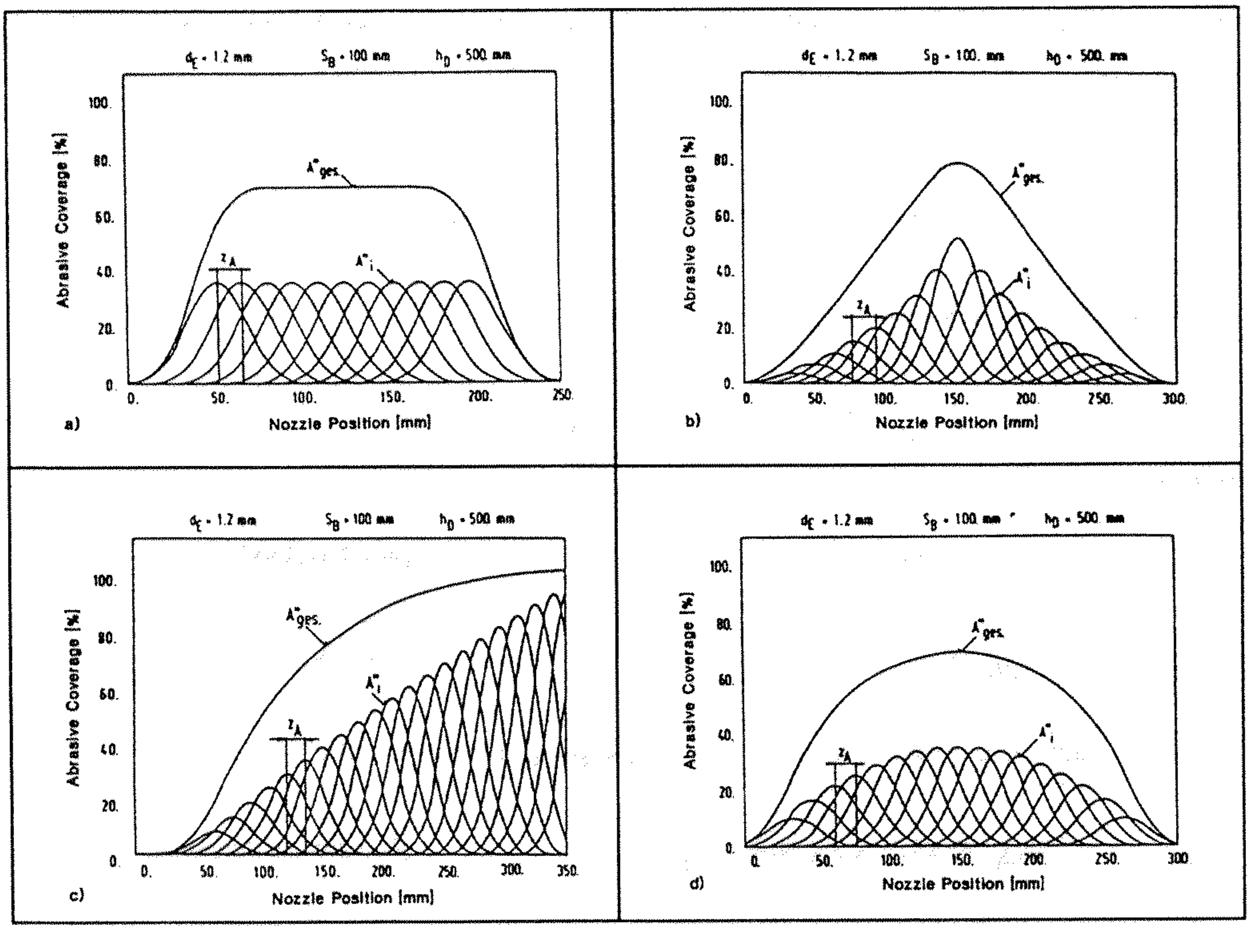

Fig. 3: Calculation of a) a constant, b) a linear, c) a degressive and d) a semicircular total coverage curve (examples)

Conversely, a desired overlapping curve for the total coverage can be specified and the necessary abrasive coverage per peening path and the necessary machine settings can be inferred from it (simulation module). The desired function curve is treated as sectionally constant, i.e. a rising curve is for example converted into a step function with an increment $z_{A,opt}$. If points at these intervals are selected, any desired function values for the required mean abrasive coverages of the individual curves which overlap to produce the specified total coverage can be calculated (Fig. 3 b - d).

Free specification of the peening conditions, independent of model concepts, for example identical peening parameters for n peening paths or a constant line interval, is also possible (planning module). This module can be used to develop forming strategies for integral components where widely differing local parameters for abrasive intensity and abrasive coverage are required depending on the component thickness and/or the position of the component stringers. Results are shown in tables and/or graphics, allowing the user to estimate peening parameters beneath the nozzle precisely.

All necessary input variables are available as geometrical or plant-related tool and machine variables. The only parameter which has to be determined in a short preliminary test is the shot indentation diameter (Fig. 2a). The nozzle spread S_B for the plant configuration at the IBF is known from a method developed for optical abrasive fan measurement as a plant manipulated variable; it is expressed as a function of the nozzle geometry employed, the peening pressure and the nozzle height. With this method, the abrasive fan itself is observed and its spread or cone angle measured photo-optically [6].

4. 7-AXIS CNC-CONTROLLED SHOT PEEN FORMING PLANT

At the beginning of 1993, a modern 7-axis CNC-controlled shot peen forming plant suitable for forming sheet metal and integral components with maximum dimensions of 5000 x 2400 x 1000 mm^3 (L x W x H) came into operation at the IBF. This plant has continuous pressure peening system with a nozzle for shot with a maximum diameter of 4.0 mm and a combined injector-gravitation-peening system for shot up to 8 mm diameter. The positioning accuracy of the plant is +/- 0.1 mm for the x, y and z axes and +/- 0.1 degrees for possible rotary and slewing motions of the nozzle (v and w axes). Workpiece feed and removal are by means of a rail transporter carrying a rotary table (C axis); software is provided for a retrofittable grill or slewing device (A axis) (Fig. 4).

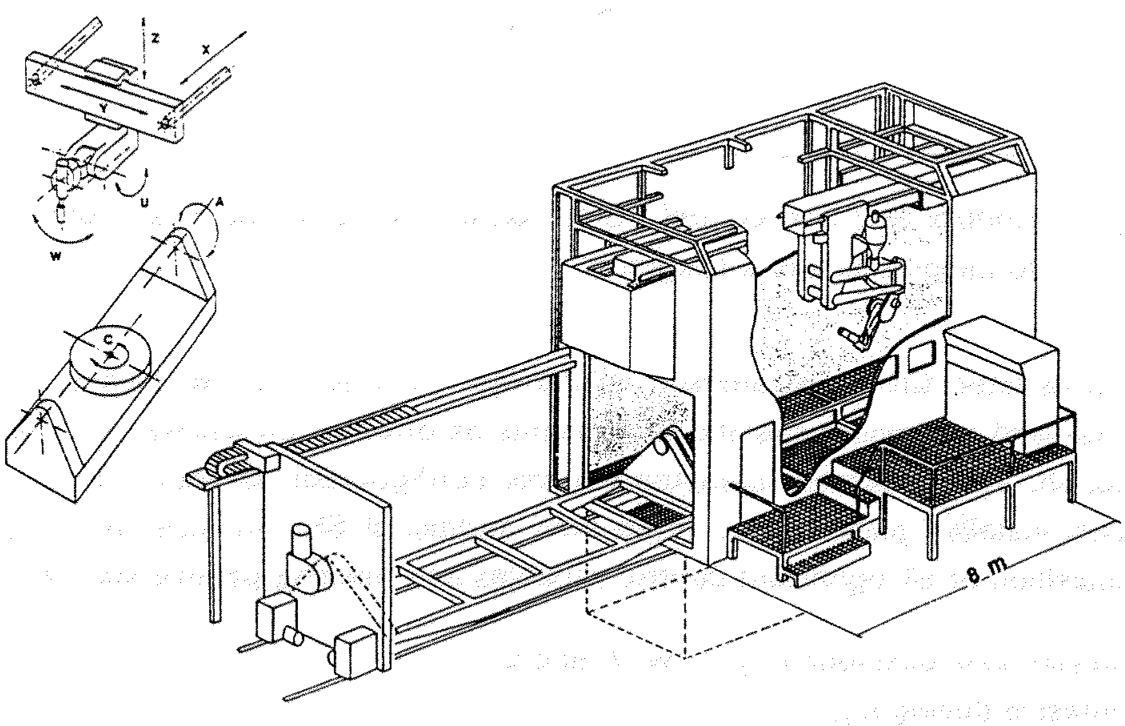

Fig. 4: 7-axis CNC-controlled shot peen forming plant at the IBF (RWTH Aachen) (diagram)

The Baiker plant is fully compatible with the manufacturing plant which German Airbus GmbH installed in Munich in 1990 (cf. Fig. 1). It is supplied from a 10 bar compressed-air network and fitted with a Schleicher stored-programme control. Shot flow can be controlled within narrow ranges, using nozzles provided for different peening systems (Nozzle 1: pressure peening system, ϕ_i = 15 mm; Nozzle 2: injector-gravitation-compressed-air peening system, ϕ_i = 20 mm) as an acceleration system. Critical zones, like the stringers in a skin section, can be protected by masking or by appropriate positioning of the nozzle.

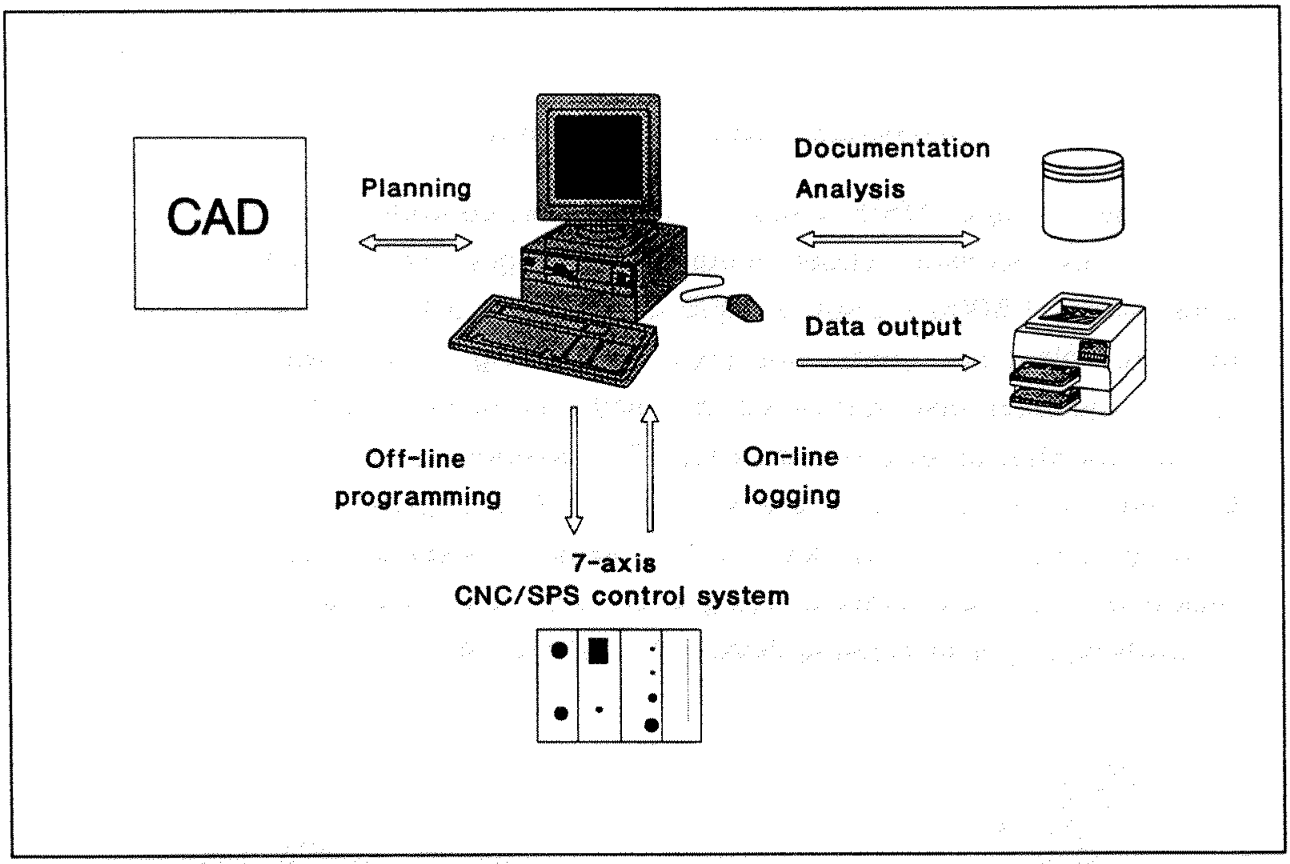

Fig. 5: Control unit and control PC for on-line documentation and control of the forming parameters (diagram)

CAD-assisted CNC programming allows fast generation of NC blocks, which can be re-used to process specific components as often as necessary, as in series production. The necessary computer/control configuration is shown in Fig. 5. The newly-installed plant is also fitted with additional SPC modules allowing on-line acquisition of all significant control variables and peening parameters, i.e.

- current axis positions x, y, z, w, A and C,
- abrasive dosing m_t,
- peening pressure p,
- rate of nozzle travel v_D,

- abrasive volume per unit area m_A,
- local abrasive coverage A*,
- etc.,

as a function of peening location and peening time.

Figures 6 and 7 show, for example, the abrasive masses impinging on a 600 x 600 m^2 section of a component with meander jet guidance and line intervals of z_A = 50 mm (Fig. 6) and z_A = 28 mm (Fig. 7). These examples indicate the significant effect of incorrectly-selected peening parameters on real peening conditions and material influencing. In the case shown in Fig. 6, a polygonal shot peening result is to be anticipated, whereas guidance by the optimum line interval (Fig. 7) quantified in (5) leads to a homogeneous overall curvature.

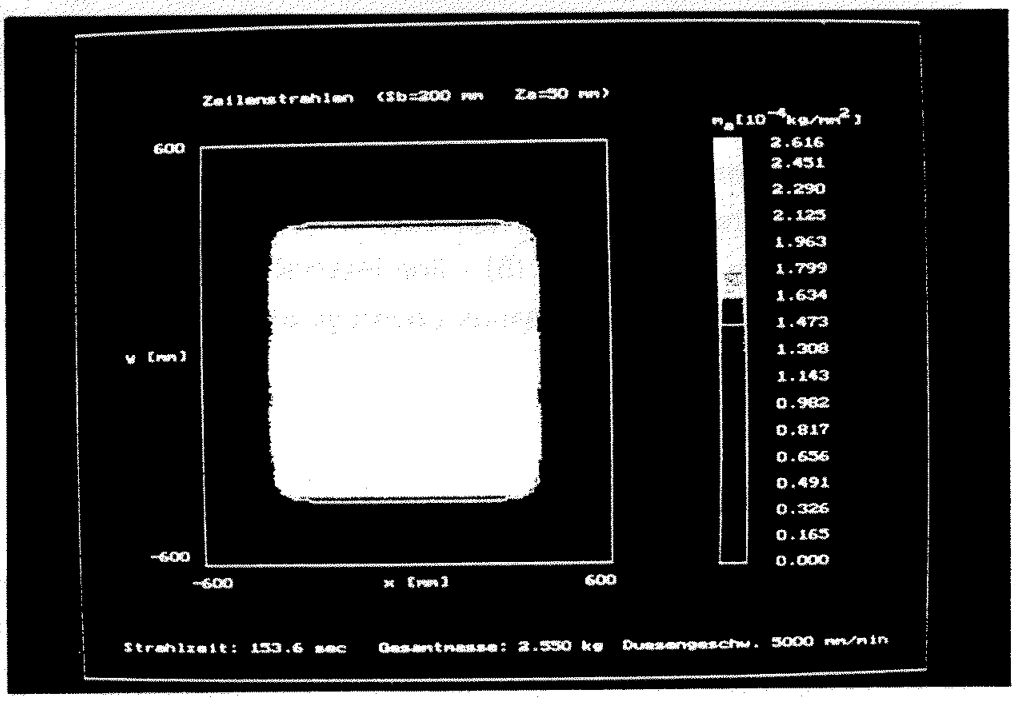

Fig. 6: On-line documentation and control of the abrasive volume per unit area impinging on the component surface; the case shown, with meander guidance at a line interval of 50 mm and a nozzle spread of 200 mm, results in differing coverages on different areas of the component surface

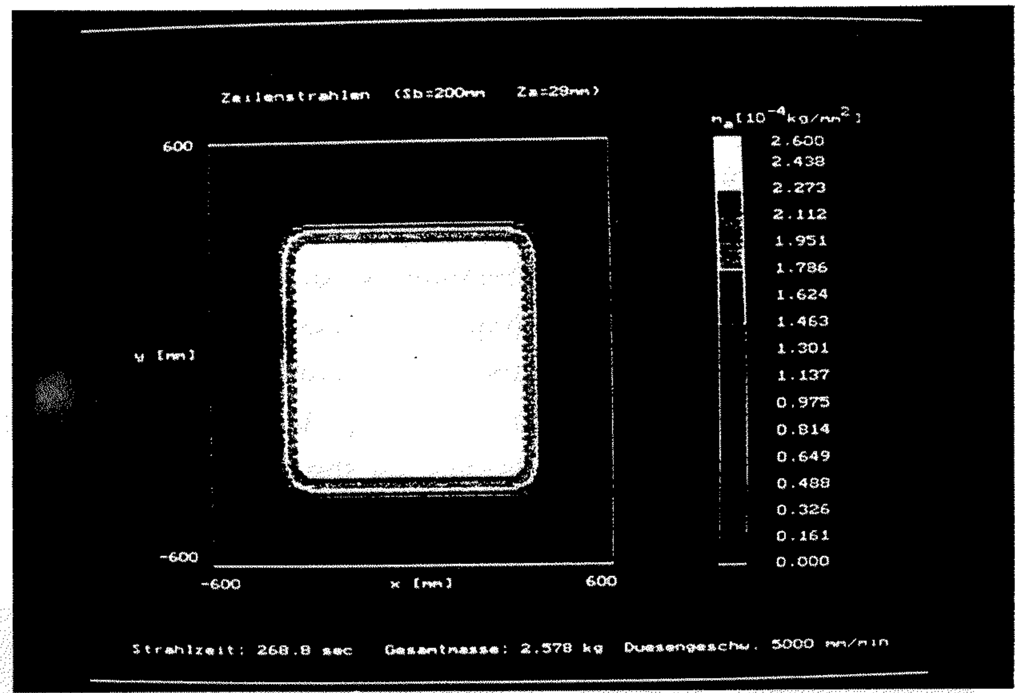

Fig. 7: On-line documentation and control of the abrasive volume per unit area impinging on the component surface; a correct choice of peening path offset according to Equation (5) - line interval 28.8 mm and nozzle spread 200 mm - results in homogeneous coverage of the component surface

5. CONCLUSIONS

The IBF has been active in the field of shot peen forming since the beginning of the nineteen-seventies. During this period, various components, especially for the aerospace industry, have been developed to the series production stage on the institute plant. A number of publications [9-12] at international conferences have presented models for

- the manufacture of cylindrical component geometries,
- the manufacture of shell components,
- adaptive process monitoring using force decay curves,
- the planning and simulation of abrasive coverage,
- the estimation of impact probabilities and
- numerical simulation using the finite element method.

The system presented in the paper, for the planning and simulation of abrasive coverage in shot peen forming operations, together with the associated model equations and the new 7-axis CNC-controlled peening plant, now permits precisely-quantifiable control and documentation of this forming process on the institute plant. This represents a significant advance towards a reproducible process cycle and towards clear documentation of material influences in the shot peen forming process.

In the author's view, the available models are also applicable to other peening processes, e.g. surface finishing or hardening using a nozzle. The new peening plant installed at the institute was funded by the Ministerium für Wirtschaft, Mittelstand und Technologie of North-Rhine Westphalia, partly with the aim of initiating extensive research activity in the Aachen Region as a result of this newly-created potential.

7. REFERENCES

[1] Kopp, R.; Hornauer, K.-P.:
Kugelstrahl-Umformen und -Richten; Metall, 34. Jahrgang, Heft 4, April 1980

[2] Kopp, R.; Ball, H.-W.; Wüstefeld, F.:
Kugeln als Werkzeug - Komplizierte Bauteile umformen mit dem Kugelstrahlverfahren verringert den Fertigungsaufwand; Maschinenmarkt 94, Nr. 24 (1988)

[3] Kopp, R.; Wüstefeld, F.:
Die Kugelstrahlanlage, eine flexible Fertigungseinrichtung für die Blechumformung; FGU-Seminar: Neuere Entwicklungen in der Blechbearbeitung, Stuttgart, 31.05. - 01.06.1988

[4] Sauerwein, H.-P.; Behle, E.:
Ariane 5 - Europas Raumtransportsystem der nächsten Generation; Dornier Post 2/89

[5] Sauerwein, H.-P.; Kühnle, E.:
Erste Großbauteile von Dornier für Ariane 5 fertiggestellt; Dornier Post 4/89-1/90

[6] Wüstefeld, F.:
Modelle zur quantitativen Abschätzung der Strahlmittelwirkung beim Kugelstrahlumformen; Dr.-Ing. Dissertation, DGM-Informationsgesellschaft, 1993

[7] Hornauer, K.-P.:
Untersuchungen zur Umformung von Bauteilen durch Kugelstrahlen; Dr.-Ing. Dissertation, RWTH-Aachen 1982

[8] Ternes, P.-T.:
Der Überdeckungsgrad beim Kugelstrahlen; Fachberichte Hüttenpraxis Metallweiterverarbeitung 1976

[9] Kopp, R.; Hornauer K.-P.:
Kugelstrahl-Umformen, ein flexibeles Umformverfahren; erste internationale Kugelstrahlkonferenz (ICSP 1), Paris, 01.-07. Sept. 1981, Pergamon Press

[10] Kopp, R.:
Kugelstrahlumformen, neuere technologische und theoretische Entwicklungen; zweite internationale Kugelstrahlkonferenz (ICSP 2), Chicago, 14.-17. Mai 1984

[11] Kopp, R.; Ball, H.-W.:
Neuere Entwicklungen beim Kugelstrahlumformen; dritte internationale Kugelstrahlkonferenz (ICSP3), Garmisch Partenkirchen, 12.-16. Okt. 1987

[12] Kopp, R.; Wüstefeld, F.:
Neue Simulations- und Optimierungsmöglichkeiten für Kugelstrahlumformprozesse; vierte internationale Kugelstrahlkonferenz (ICSP4), Tokio, 02.-05. Okt. 1990