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Three-Dimensional Bending of Profiles with Stress Superposition

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ABSTRACT: The paper shows a new method for three-dimensional bending especially of profiles. The bending process only works in one plane according to the machine geometry. To leave the two-dimensional bending plane, the profile cross-section is turned by an overlaid torsional moment. By this process very long symmetrical and asymmetrical profiles can be bent three-dimensionally without surface damage and the unwanted torsion of asymmetrical profiles can be prevented by means of a similar compensation moment. The paper focuses on the bending method which is realized in the new experimental setup. The device consists of a hybrid machine design of hydraulic and electrical drives, both numerically controlled. The new device realizes a new roll-bending method that uses 6 transportation rolls and also a roll-based bending head. The bending moment is applied in the profile by a transverse force driven by the bending head and a servo-hydraulic cylinder. The turning of the cross-section during the process is realized by a special machine design, making it possible to turn the guiding rolls and the bending rolls of the machine synchronistically.

Key words: 3D-Bending of Profiles, Roll-Bending, Superposition of Stresses, Torsion Compensation

1 INTRODUCTION

In recent years, the demand for three-dimensionally bent steel and aluminum profiles as important structural and design elements in traffic systems as well as in civil engineering has increased strongly. 3D-bent profiles provide the design engineer with new degrees of freedom and allow the construction of lightweight structures with more advantages regarding e.g. space saving and aerodynamics [1].

In the field of tube and profile bending there are well known procedures offering a high potential for three-dimensionally bending of semi-finished products. The problem is that most of these procedures are specialized and optimised for tube bending; involving profiles with circular cross-section [2, 3]. There is no well working procedure available now in industry offering a high flexibility to bend profiles with arbitrary cross-sections and materials three-dimensionally. When analyzing several procedures suitable for 3D-shaping of profiles like stretch bending or curved profile extrusion it was found out that these procedures show obvious disadvantages or restrictions which justify new considerations for the realization of a new procedure variant for 3D-bending of profiles [4, 5]. Procedures using roll bending systems to deflect the profile towards the third axis to produce arbitrary space curves seem to be very suitable. Roll systems are highly flexible concerning adjustment and degrees of freedom and are capable of protecting the profile surface due to the low friction between rolls and profile. Other guiding systems like sliding guides or ceramic guides are expensive or need lubrication, otherwise they lead to a high surface damage. Furthermore, the superposition of stresses is easier when using rolls, giving the opportunity to superpose a torsion moment which prevents twisting of asymmetrical profiles during bending. For these reasons it was necessary to carry out pre-investigations in order to develop a new bending procedure for 3D-bending of profiles. It seemed to be reasonable to find and systematically investigate new opportunities for the purposeful influencing of the forming zone in the sense of stress superposition.

2 PRE-INVESTIGATIONS

To pre-investigate the potential of a stress superposition for 3D-bending of profiles, the universal and flexible three-roll-bending process was chosen. The kinematic 3D-bending of the profile running through the rolls can be carried out by means of a deflecting device influencing the forming process between the three rolls. The profile curvature, which is normally created by three-roll-bending, is probably also irrelevant so that the first process only serves the creation of the plastic zone which is used for the easier second 3D-shaping process. Irrespective of these aspects, the profile curvature is produced kinematically. Figure 1 shows the tool arrangement of the combined procedure which has been realized at the IUL.

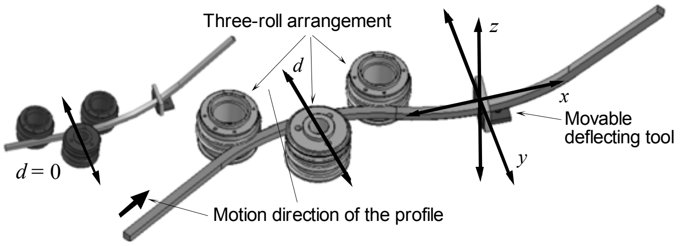

Fig. 1. Superposed three-roll-bending with subsequent profile deflection [4, 5]

The experimental set-up for this new way of profile bending consists of two essential parts: a conventional CNC-three-roll-bending-machine for the bending step in the first plane and a special device that makes it possible to deflect the profiles towards the third axis directly after the first bending process. The force for the bending in this axis is given by a position controlled hydraulic cylinder. For the first experimental phase the only automatically moving axis is the hydraulic cylinder (z-axis). Figure 2 shows a photo of the machine during an early bending experiment. The guidance of the profile after leaving the three-roll-system works with a window fixed on the hydraulic cylinder axis and furnished with PTFE plackets to reduce the friction in the contact zone [4, 5]. The objective of the procedure pre-investigations was to prove the existence of certain effects which have the potential for improvements in the field of three-dimensional bending of profiles. It was important to highlight some tendencies for solutions of classical bending problems which are not solved or only solved with extremely efforts by means of many other procedures.

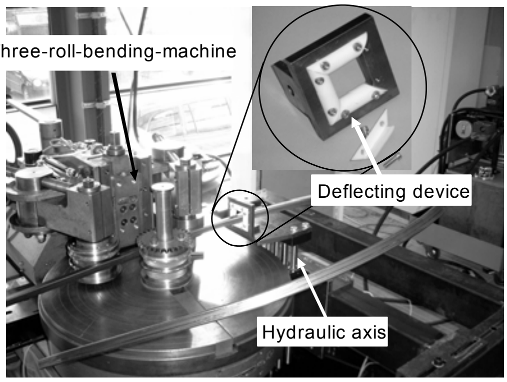

Fig. 2. Bending device for 3D-Profiles [4, 5]

First experiments carried out at the IUL included investigations to achieve 3D-bent symmetrical profiles (20x20x2 mm made of S 235 (EN 10 025)). For this purpose, both the 3-roll-bending machine (d-axis in xy-plane) and the hydraulic device (z-axis) have been adjusted and synchronized in order to produce the desired profile contour (figure 3). The first profile bending in the xy-plane step has been superposed with the second one, which is defined by the position of the hydraulic device and the leading window in the x, y, and z-axis.

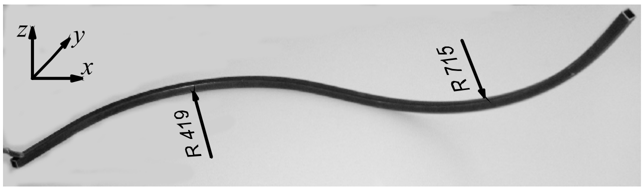

Fig. 3. 3D-bending example of a profile by superposition of bending stresses [4, 5]

To use and to make the advantage of the previous plastic deformation in the three-roll-bending zone for an easier bending in the orthogonal plane evident, different roll adjustment values (d = 0 mm, 13 mm, and 16 mm) have been selected at the middle roll and a superposed force of the hydraulic cylinder with the same adjustment value for the z-axis of 40 mm has been used. It was found out that the larger the middle roll adjustment causing a higher previous plastic deformation of the profiles is, the larger the profile curvature (smaller profile radius) in the third plane will be (figure 4).

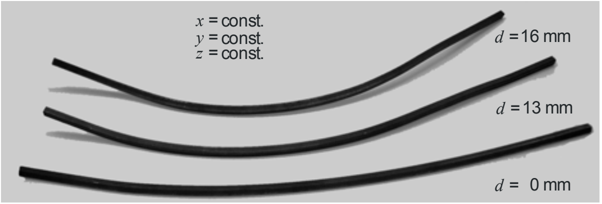

Fig. 4. Influence of previous plastification on bending radii

A reason for the curvature increase is the decrease of the profile springback due to the stress superposition. In addition to the decrease of the springback a force decrease in z-axis was measured in the deflecting tool, which is related to a smaller cross-sectional deformation [4, 5].

The concept of a machine set-up for 3D-profile bending based on a conventional 3-roll bending machine works only for relatively large profile radii. The bending of smaller radii is problematic. The transportation of the profile through the process is no longer possible because the friction between roll and profile is insufficient. To solve these problems in connection with the second demand to develop a concept for the 3D-bending of profiles, a systematic proceeding is required. To create new procedure variants a proceeding for design systematics, recommended in [6, 7], has been chosen. It is often used to design new products, but it is not common in production technology. In [7], a similar method is used, based on a morphological system, for the production process of ring rolling.

3 A NEW CONCEPT GENERATED BY SYSTEMATIC ENGINEERING DESIGN

The first step in the design analysis according to the VDI 2221 is to reduce the technical problem influencing the main function and then to make a subdivision into main functions and auxiliary functions [6]. The systematic for 3D-bending of profiles is shown in figure 5. This simple system can be subdivided into three main functions. The first is the transportation of the profiles over their longitudinal axis. The second is the plastification of the material to allow a forming process. The third is an essential function which defines the bending geometry of the workpiece. Furthermore, the realization of a suitable bending system requires a guiding system for the profile to reduce the cross-section deformation.

It is reasonable to limit the subdivision into further subfunctions to a special degree of abstraction. The following search for solutions for each subfunction has been made on the basis of the only demand of a roll-based system. The recombination of this work produces a morphological matrix of solutions for the problem. After an evaluation the best variant needs to be chosen. A useful recombination for a process, designed especially for open and closed non-circular profile cross-sections, is shown in figure 6.

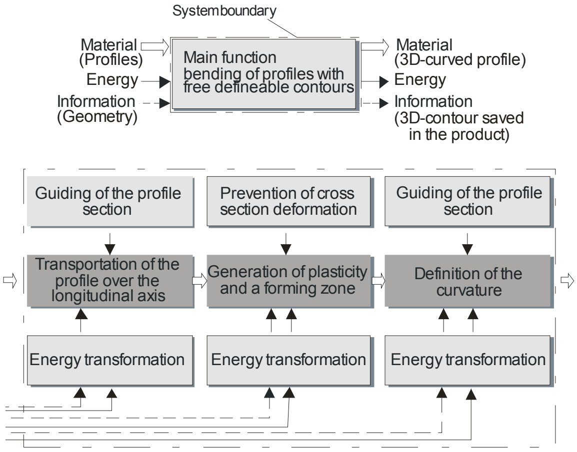

Fig. 5. Design systematics and analysis

Unlike the system analysis in figure 5, the function definition of the bending contour has been subdivided into two subfunctions according to dimensional aspects. The 2D-bending process has been realized by a plane bending system and by the positioning of the tangential position of the roll pair at the end of the process. This solution realizes the full function for bending 2D-curves. On this basis it is possible to easily create a 3D-contour system by turning the whole system over the longitudinal axis of the profile, but without changing the position of the roll system in the other axes. By this movement the bending plane of the profile cross-section changes during the process and the profile obtains a 3D-bending curve. Hence, it is a 2D-bending with a superposed 3D-bending process.

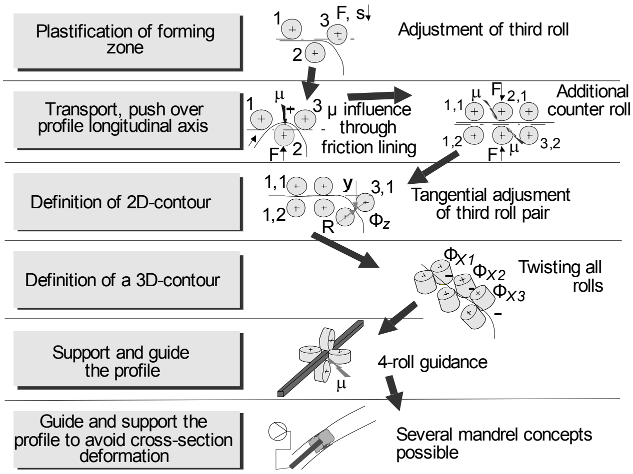

Fig. 6. Combination of possible solutions

According to the method of VDI 2221 [6], the different solutions have to be recombined to obtain a new system for 3D-bending of profiles. The result of the recombination is shown in figure 7. The new system has three pairs of rolls and a roll-based guiding system that defines the bending curve in a horizontal plane. This bending axis is realized by one horizontally mounted machine axis. The profile leaves the device during bending in any case in the horizontal plane. The turning axis for the definition of the 3D-curve is realized by a torsion bearing and a compensation axis positioned in the bending head. By this function the bending plane can be changed and a 3D-shape is produced. Furthermore, the adjustment of a difference between the angle of the roll pairs and the angle of the compensational axis enables a superposition of torsion moments with the bending process. This can be used for the prevention of the twisting of asymmetrical cross-sections.

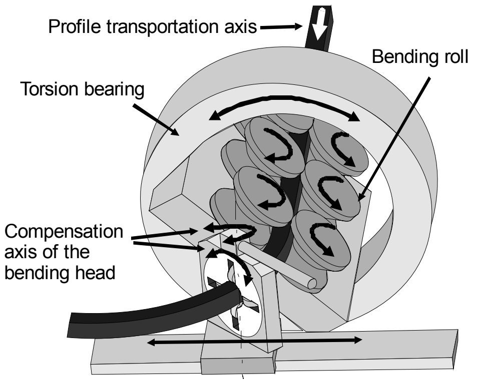

Fig. 7. Principle of the new 3D-bending process

These new aspects are not easy to investigate by experimental equipment based on a conventional 3-roll-bending-system. Thus, a new experimental set-up has been planned and designed at the IUL.

4 DESIGN CHARACTERISTICS OF THE NEW DEVICE

In Figure 8, the system and the additional drives are shown as a CAD-plot. The main 6-roll unit for the transportation of the profile over the longitudinal axis is pivot-mounted in a lunette-based bearing that allows a high stiffness. The drive system is a hybrid construction combining a servo hydraulic and electrical drives. The twisting system is realized by an electrical servo engine with a synchronous belt drive with a maximum of 2000 Nm. The profile transport is realized by an electrical six-roll-driven system with a chain gear. The four-roll-based bending head can be adapted to several profile types. It is mounted on a hydraulic axis of 60 kN. By means of this set-up it is possible to realize a maximum bending moment of approx. 21000 Nm. This provides the potential to bend typical industrial profiles.

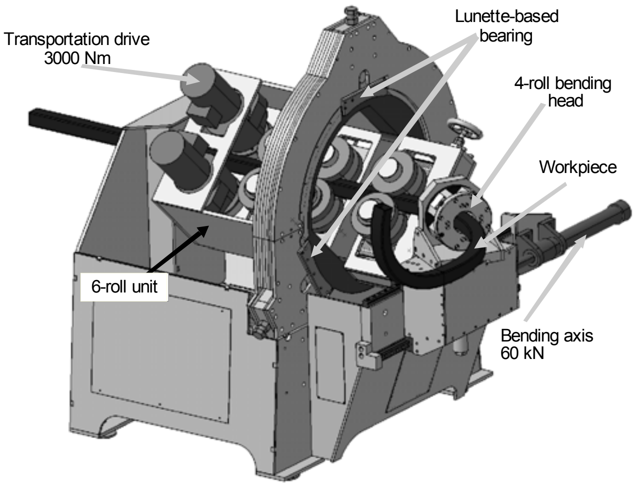

Fig. 8. New machine set-up (front view)

5 CONCLUSIONS AND OUTLOOK

A new machine set-up for the 3D-bending of profiles has been developed (kindly supported by the German Research Foundation (DFG)). The device will be available at the IUL in the beginning of 2008. Detailed experimental as well as theoretical investigations of the process using semi-analytical and FE-process simulations are planned.

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