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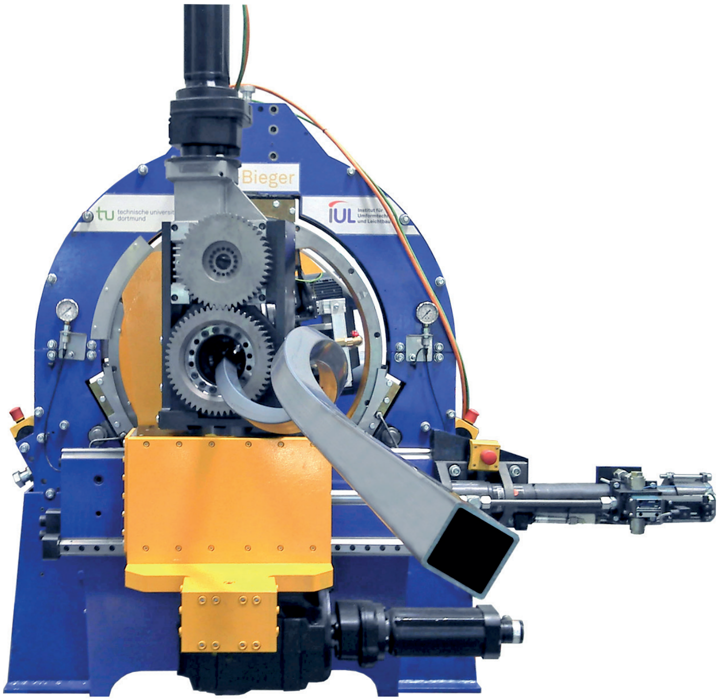
Daniel Staupendahl

3D Profile Bending with Five Controlled Degrees of Freedom



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Berichter:	Prof. Dr.-Ing. Dr.-Ing. E.h. A. Erman Tekkaya
Mitberichter:	Prof. Dr.-Ing. Bernd Engel
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For Katrin, Luisa, and Marie

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Abstract

In the recent decades, several processes for kinematic bending of tubes and profiles to three-dimensional (3D) contours have been developed. Although these processes offer the potential to cope with current demands for natural aesthetic design and high flexibility, they are not yet widely used in the industry. One reason has been, until now, the lack of fundamental knowledge about the forming process itself – specifically the forces and torques acting on the profile during 3D bending and the resulting stresses and strains in the cross-section.

In order to build up comprehensive process understanding, first, a general geometric description of 3D profile shapes is given. Using this geometric description, fundamental 3D-bending kinematics are derived. It is found that three controlled degrees of freedom (cDOF) are necessary to produce a 3D bending line – here, the rotation of the cross-section cannot be controlled – while at least four cDOFs are needed in order to produce profile shapes with a 3D bending line and a specified rotation, or twist, of the cross-section. Any additional cDOFs are not necessarily needed but might extend the process limits of a specific bending process. Using this knowledge, the 3-cDOF TSS bending process is extended by two additional actuators and torque measurement equipment. In order to time-efficiently analyze 3D profile shapes a new kind of 3D contour measurement device is developed and set up. To allow a thorough investigation of 3D bending with the least amount of abstraction of the material data, cold-drawn and heat-treated steel profiles are used, which can be regarded as isotropic. In addition to simple tensile tests for the generation of flow curves, cyclic tensile tests are used to measure the apparent Young's modulus degradation. In order to analyze the elastic behavior of the profile during 3D bending, a curved beam model is set up. The model can be used to represent a beam held by up to three roller/hinged supports, a single full-moment support, or a combination of a single hinged support and a single full-moment support. The model allows the accurate calculation of profile deflection as well as the calculation of the reaction forces and moments caused by an applied bending force and torque. Through thorough analyses of the stresses and strains in a profile segment during simultaneous application of a bending moment and a torque it is shown that a stress state with uniaxial stress and additional shear stress suffices to accurately model real-life profile behavior. An interesting observation is the linear decrease of shear strains from the intrados and extrados to the neutral axis of the profile.

The geometric relation of profile shape and bending kinematics is finally used together with the elastic and plastic analyses to set up a comprehensive process model, which can accurately simulate the profile behavior during 3D-profile bending and can be used to generate springback compensated NC-data for bending processes with 3-6 cDOFs.

Publications

The following articles have been published with permission of the chairman of the doctoral committee prior to the publication of this dissertation:

Staupendahl, D., Becker, C., Hermes, M., Tekkaya, A.E., Kleiner, M., 2011. New methods for manufacturing 3D-bent lightweight structures. In: Wieland, H.J., TEMA Technologie Marketing AG (Eds.), SCT 2011. 3rd Intern. Conf. on Steels in Cars and Trucks, Future Trends in Steel Development, Processing Technologies and Applications, Verlag Stahleisen, Düsseldorf, pp. 120-129.

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Staupendahl, D., Tekkaya, A.E., 2017b. The reciprocal effects of bending and torsion on springback during 3D bending of profiles. Procedia Eng., 207, 2322-2327.

Staupendahl, D., Schultz, D., Tekkaya, A.E., 2018a. Device for Tactile Detection and Analysis of the Geometry of Bent Profiles or Tubes. European patent EP 3 315 221 B1, priority date: 31.10.2016.

Staupendahl, D., Tekkaya, A.E., 2018b. Mechanics of the reciprocal effects of bending and torsion during 3D bending of profiles. Journal of Materials Processing Tech., 262, pp. 650–659

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