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Development of an analytical 3D-simulation model of the levelling process

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ABSTRACT

Sheet metal often shows shape defects, which is not complying with the increasing requirements for the quality of the products needed to satisfy the highest demands on finer tolerances. Due to the market's high requirements on the quality of products, new high-technology levelling machines were developed. The adjustment of these levellers is very complicated and a successful adjustment depends mainly on the experience of the line operator. As the computational power has developed over the past years, simulation becomes more important in the production process and is used in analysing the effects of leveller adjustments on the unflattened sheet metal. In this study, edge- and centre waves are investigated. In order to find a suitable adjustment of the leveller to reach a flat sheet metal, an analytical 3D simulation model has been developed using the Matlab programming environment. The sheet metal will be firstly analyzed and visualized before and after deformation. A user-friendly interface has been developed to enter the required parameters before starting the simulation. Different methods have been used to investigate the effect of the levelling process on the sheet metal and to calculate the remaining shape defects after levelling. The simulation results were validated by experiments and are represented in this paper.

1. Introduction

Sheet metal often shows shape defects, which is not complying with the increasing requirements for the quality of products needing to satisfy high demands on tolerances. As the computational power has increased over the past years, simulation is playing an outstanding role in the production process and is becoming much more effective. Simulation proved to be a powerful tool for defining and developing new methods.

Sheet metal defects can be distinguished into two main types: surface-to-surface and edge-to-edge length differential shape defects. Guericke has found that the first one can be eliminated using conventional roller levellers Guericke et al. (1983), while Buchholz and Henrich said that the eliminating of edge-to-edge length differential problems requires levellers featuring an adjustable bending of the levelling rolls (Buchholz 1973; Henrich, 1994) (see Fig. 1). By means of this, the centre and the left or right edge zones of the sheet stripe can be stretched to a different extent. Bräutigam stated that a successful adjustment of these machines is complex and depends mainly on the experience of the line operator (Bräutigam, 2009; Guericke, 1994).

In this paper, wavy edges and centre waves as well as their causes and possible corrections are investigated. By means of an analytic description, a three dimensional simulation model of an adequate levelling machine was developed using the MATLAB programming environment to analyze the levelling process. Doege has compared the analytical analysis to the finite element method (FEM) and found out that the use of this model considerably reduces the calculation effort while producing satisfactory results (Doege and Zacharov, 2003). The analytic description provides a wide range of features to analyze the levelling process for different types of sheet metal and levellers. A user-friendly graphical user interface was developed to facilitate entering the required parameters for the simulation. The topography of the sheet metal to be levelled is analyzed using a measurement system and is used as input for the simulation. The optimal machine settings can be virtually determined to save time and costs and the topography of the sheet metal before and after virtual levelling can be visualized. Different methods have been tested to investigate the effect of the levelling process on the sheet metal and to calculate the remaining defects after levelling. The simulation results were validated with experimental results.

2. Levelling of sheet metal

2.1. Levellers

Levellers and straighteners consist of levelling rolls deforming the sheet metal by an alternating bending while it is passing through the machine. Behrens has obtained from his experimental results and analytical modelling that the bending strain reaches maximum values at the entry of the machine and decreases to a minimum at the exit Behrens et al. (2009a). Residual stress and geo-

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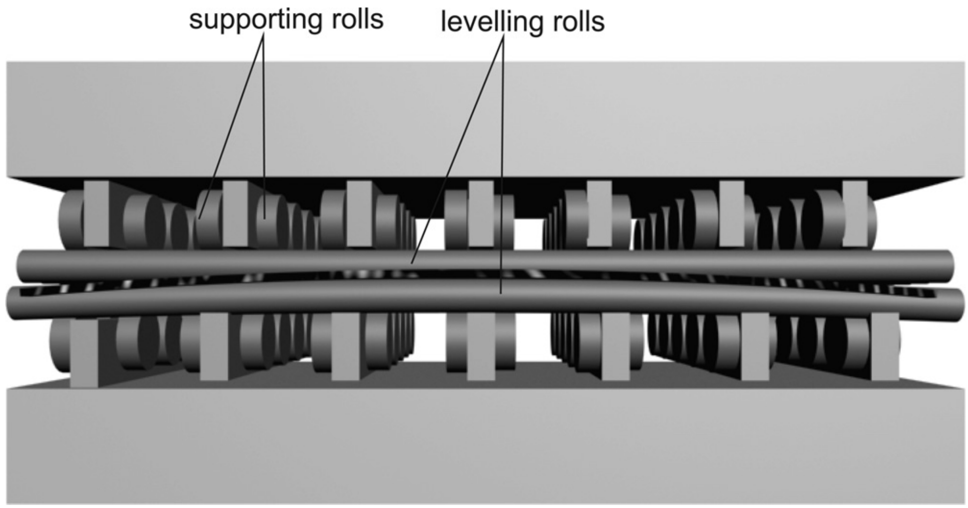

Fig. 1. Leveller with supporting rolls.

metrical defects can be reduced to a minimum. During the levelling process, the rolls are impacted by high mechanical load. To avoid an undesired and uncontrolled bending of the levelling rolls leading to unstable process conditions, Behrens and Buchholz suggest equipping the levellers with additional supporting rolls to increase both vertical and horizontal rigidity (Fig. 1) (Buchholz, 1973; Behrens and Krimm, 2008).

The type of levellers discussed here are similar with the one discussed by Bräutigam which features an adjustable bending of the lower set of levelling rolls by controlled vertical adjustment of the lower supporting rolls Bräutigam (2009).

By this, certain zones (virtual stripes) of the sheet metal as the centre and the left or right edge zones can be stretched to a different extent. Behrens calculations show that this is necessary to eliminate edge-to-edge shape defects (Behrens et al., 2009b, c).

Furthermore the upper roll set can be adjusted in vertical direction, but arranged linearly and without a bending of the rolls. This enables the machine to straighten surface-to-surface shape defects are caused by coiling the sheet metal for easier delivery.

2.2. The simulation of the levelling process

Behrens and Henrich wrote that a theoretical description of the levelling process is complex due to different sheet metal materials, the complexity of the levelling machine and the sensitive process itself (Henrich, 1994; Behrens and Krimm, 2008). The sheet metal properties, especially the residual stresses and the potential strain hardening before levelling are known only with restricted exactness due to multiple wrapping or forming of the sheet metal during its production (e.g. rolling and multiple recoiling). Guericke obtained from different experiments that the required forces on the levelling rolls respective the machine settings to obtain acceptable levelling results are accordingly variable Guericke et al. (1983).

The friction conditions within the machine vary from roll to roll in a barely predictable way and the levelling process is very sensitive. According to this, a μm of variation of the roll's adjustment can be decisively whether the sheet metal will be flat or still has shape defects after the levelling process. Furthermore, comparative data of real sheet metal as input and output parameters are difficult to gather. Behrens wrote that measured bending, wavelengths or amplitudes of waves in a sheet metal are accurate only if the sheet metal is not impacted by external forces (Behrens and Krimm, 2008). This condition is hard to achieve as in fact the self-weight of the sheet metal may influence the value of the shape defects. Due to the reasons named above as well as high computing times, the use of the finite element method for the process simulation is not suitable for a quick analysis and adjustment of a leveller Doege and Zacharov (2003). At the Institute of Metal Forming and Metal-Forming Machines of the Leibniz University in Hanover, an analytic description of a leveller was developed. The levelling process using a machine with adjustable bending of the levelling rolls was analyzed on the basis of a geometrical approach to eliminate edge-to-edge length differential shape defects (edge waves and centre waves).

2.3. Development of an analytical, three dimensional simulation model

The analytic description of the levelling machine as well as the calculation algorithms to determine the course of motion of the sheet metal through the machine were implemented and visualized in the programming environment MATLAB. The input parameters are the geometrical aspects of the machine, properties of the sheet metal material and the sheet metal's surface topography before entering the leveller.

The surface topography of the sheet metal before levelling is measured in the form of points using a commercial measurement system. A zero level is calculated for the sheet metal's surface and all points above or below this level are identified as shape defects. The obtained data is saved as ASCII-file and is used as input for the algorithm. Afterwards, the simulation of the levelling process can be started. The sheet metal and the machine are visualized, contact regions between the sheet metal and the rolls can be defined. Taking into consideration the expenditure in computing and storage capacity as well as problems of convergence, Siegert, Denkena and Guericke have virtually sectioned the sheet metal in a number of longitudinal stripes representing a two-dimensional problem (Henrich, 1994; Siegert and Dogan, 2000; Denkena et al., 2002). The length of each stripe is calculated while virtually passing the machine.

In order to obtain a flat sheet metal, the simulations carried out by Behrens shows that the length of all stripes after levelling must be the same. To give a simplified example, Behrens has virtually sectioned the sheet metal in three virtual stripes (Behrens and Krimm, 2006; Behrens et al., 2009c). For example, if the stripes at the edges are longer than the middle one, the sheet metal shows edge waves. In this case, the middle stripe must be stretched to a greater extent than the edge stripes to obtain the same length for all three stripes and accordingly a planar surface (Fig. 2).