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A knowledge-based control system for the robust manufacturing of deep drawn parts

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Abstract

Throughout a single batch of deep drawing parts the settings of the press have to be adjusted to account for several influences. These can be divided in influences originating through the process, like heating of the tools or aggregation of the lubricant in the tool, and influences originating in the manufacturing of the blanks, like scattering material properties within a coil or between different coils. In the present paper, a method is shown to minimize the effects of both types of influences. The first step in building up a knowledge based control is the quantification of the influences. This is done by running a virtual process tryout based on FEM simulations in order to predict the influence of the scattering material and process properties on the process outcome. For an effective feed forward control based on the variant system, the blank properties are measured during the cutting stage and every part is labeled with a unique identification. The yield strength and ultimate tensile strength are measured by an eddy-current system, while the blank thickness is measured via laser triangulation. As the knowledge of the blank properties alone is not sufficient, a feedback loop is introduced to compensate for the non-blank related influences. For the feedback control, an optical measurement system is proposed, which is able to calculate the draw-in at pre-defined points. The relevant measuring points are defined by evaluation of the correlation between draw-in and changing properties in the virtual process tryout. Both control mechanisms are solely using the usual available and adjustable press settings. In the presented case, the position of the blank as well as the different blankholder forces were chosen. Finally the applicability of the proposed method is evaluated virtually.

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1. Introduction

In production of deep drawing parts, scattering material properties as well as process related changes like increased temperatures in the tools through the forming process, have a significant impact on the scrap rate and therefore the costs. In an automotive press shop up to 89% of the part costs are material cost [1]. To realize a zero defect production, a combination of measurement systems and knowledge based control is required. For a knowledge based control it is necessary to measure all relevant process data. In the past different approaches based on in-line measurement systems and data mining have been tested. While feedback solutions are covered well in literature, the implementation of feedforward control in deep-drawing based on material properties is only proposed by Mork, Neumann and Heingärtner [2][3][4]. In all systems for deep-drawing the state variable (draw-in) is, either measured in the forming tool as done by Bräunlich [5][2][3][6][7][8] or it is acquired after the drawing operation [9]. Also the location of the intervention to adapt the process can change. The actuators can be integrated in the forming tool [2][7][8] or the blankholder forces of the press line can be adjusted [9][3]. For strip bending a possible solution for a model based control is shown by van den Boogaard [10]. In deep-drawing, Mork [2] gathered data and trained a neural network using these data. He proposed to directly control the process through neural networks. The approach of Neumann [3] focused on data collection and evaluation, as well as proposing a possible system for process control. The success of all these approaches heavily depends on the evaluation of the acquired data. As Neumann showed in her work, not all influences on the process can be measured directly. For this reason, the proposed control system consists of two different parts. The feedforward part, which links the measurable influences to the knowledge base and a feedback loop using the draw-in to compensate non-measurable influences. The required knowledge base is derived from numerical experiments (FEA simulations). As the knowledge base can only be used for the compensation of measurable influences, the later on shown feedback loop was designed and tested in production. The control system described in this work uses the draw-in acquired after the first deep drawing operation and the blankholder forces to adapt the process. In this contribution the necessary equipment as well as the approach of designing a feedforward control based on simulation data is shown.

Nomenclature

S	Virtual draw-in sensor position
TM	Measured blank thickness
F	Force until 80mm

2. Virtual process tryout

The first step in building up a knowledge based control, is a thorough investigation of the process. As the demonstrator part is already in series production, two different methods could be used. The first method would be experiments in the press shop. As most of the influences on the part quality (e.g. material properties) cannot be changed according to a design of experiment, virtual process modelling is chosen for building up the knowledge. In detail, the kitchen sink that is chosen as demonstrator is modelled with the finite element method in AutoForm. As knowledge based control works only when the model has a good agreement with the reality, a nominal simulation is build up which corresponds to the series production part. Therefore the material is characterized with tensile tests at different temperatures as well as the bulge test. As the material is the stainless steel 1.4301, the martensitic content during tensile tests is measured as well. The Hänsel model is chosen as baseline model for the material. The baseline model is afterwards collapsed to a single yield curve at 30 degree Celsius for the calculation in AutoForm. As yield surface the BBC model is chosen [9]. The forces in the nominal model are chosen according to the press settings in series production, which means that the blank holder forces are changing after a drawing depth of 80mm while the complete