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Analysis of Machine Influence on Process Stability in Sheet Bulk Metal Forming

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Abstract

This contribution deals with the process-machine interaction while forming parts by sheet-bulk metal forming. The goal of this process is to form complex functional elements, such as gearing and carrier elements, by means of controlled thickening of the metal sheet. The high process forces in vertical as well as in horizontal direction to form these elements, cause displacements of the tool and press components, which lead to parts defects retroactively. This work demonstrates these challenges with regard to manufacturing of asymmetrical parts and introduces a suitable approach to represent the process-machine interaction by modelling.

Keywords: asymmetrical parts; horizontal loads; process-machine interaction; simulation

1. Introduction

In sheet metal forming as well as in bulk metal forming, the geometrical accuracy and the final mechanical properties of a finished part depend on many factors such as material, lubrication, machine and tool properties [1]. Their interaction and the resulting influences on parts quality are not easy to predict. Therefore, in the start-up phase of production the manufactured workpieces frequently don't meet the expectations in terms of quality.

One impact which influences the parts quality degradation significantly is the interaction of the forming machine and the forming process [2]. Nevertheless, dynamic effects as well as displacements of the tool and press components resulting from the forming forces are usually neglected in the process layout [3, 4].

The process of sheet-bulk metal forming (SBMF) is characterized by high forming forces in vertical as well as in horizontal direction. It represents a combination of sheet metal forming and bulk metal forming by inducing a three-dimensional material flow in metal sheets in order to form complex functional elements, such as gearing and carrier elements [6]. Exemplary parts (e.g. synchronizer rings, adjustable fittings etc.) as the potential products of application of SBMF are depicted in Fig. 1.

Fig. 1. Exemplary parts as potential products of application of SBMF

The functional applications such as fixation, motion and load transmission of the depicted elements require compliance with high geometrical accuracy as well as high precision regarding the final mechanical properties

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of the part. The realization of these elements nowadays requires additional processes such as machining. Therefore, the vision of the Transregional Collaborative Research Centre 73 funded by the German Research Foundation is to reduce the production stages by forming the functional elements by means of controlled flow of the material. The long-term goal can be clarified by the functional elements to be realized using the SBMF. Examples of these elements are combined in a symmetrical demonstrator (Fig. 2).

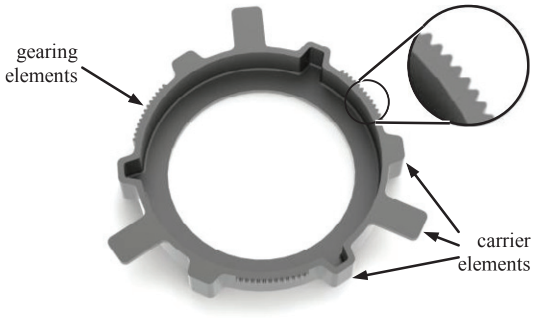

Fig. 2. Demonstrator with functional elements

The forming of asymmetrical parts requires higher horizontal forces compared to the production of symmetrical parts. Furthermore, forming of modern high-strength steels with a reduced number of forming stages raises the demand on higher computational accuracy of the process and its faster practical implementation [7]. Due to the parts quality deviation caused by the high forming forces, the process-machine interaction becomes more and more the center of attention in practice and modelling [8,9].

The challenges mentioned are demonstrated by forming an asymmetrical part by means of SBMF. Moreover, a suitable approach to represent the process-machine interaction in order to improve the computational accuracy of SBMF process simulation is presented.

2. Forming Process

The investigated one-stage forming process comprises a deep drawing of a blank (Ø100mm) without a blank holder and a subsequent extrusion of the gearing elements. The forming tool and the finished part are shown in Fig. 3.

The asymmetrical part contains gearing elements on the parts bevel as well as three carrier elements arranged next to each other. The thickness of the finished gearing elements is higher than the initial blank thickness of 3mm. The experimental setup to realize this part by means of a mechanical press is summarized in Table 1.

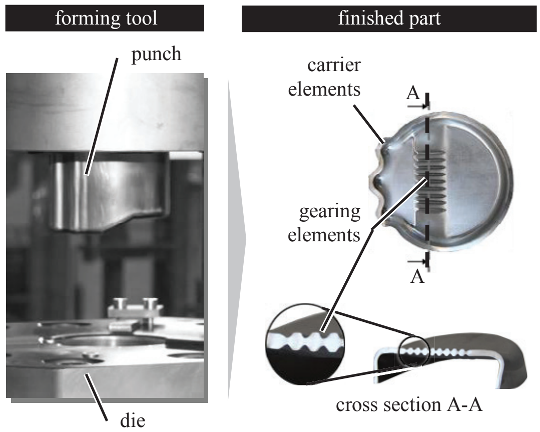

Fig. 3. Forming tool and finished part

The analysis of the parts geometry in [10] has shown that the ideal mould filling of the gearing elements couldn’t be achieved by using the process parameters resulting from the process simulation. One reason is the lateral offset between the punch and the die due to high horizontal forming forces caused by the extrusion of the gearing elements. The high die load in the area of the gearing elements due to the acting forming forces at the bottom dead centre is confirmed in Fig. 4. Due to the asymmetrical geometry of the part the vertical forming forces are superimposed with horizontal forces. The vertical forces are absorbed by the press drive and the horizontal forces are absorbed by the guidance of the press. The tool guidance is not capable to counteract the high loads due to its limited stiffness. Therefore, high horizontal displacements of the ram and upper tool components are expected.

Table 1. Experimental setup

machine type	mechanical press
stroke rate	40 1/min
stroke height	109mm
forming stages	one
process	deep drawing + extrusion
blankholder	no
workpiece material	DC04
initial sheet thickness	3mm
blank diameter	100mm
tool material	AISI D2 (1.2379)
hardness (HRC)	58

The horizontal displacement of the ram due to the process-machine interaction can be visualized by means of optical measurements and is subject of investigations discussed in following.

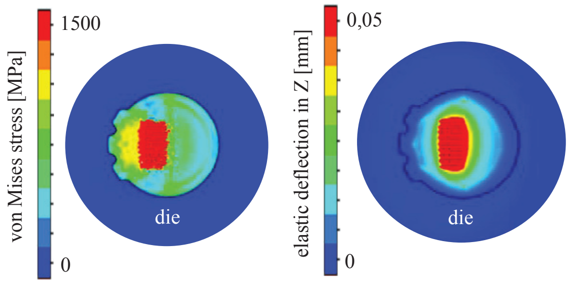

Fig. 4. Tool load and displacement at the bottom dead centre

3. Characterization of process-machine interaction

3.1. Influence of the forming forces on the machine components displacement

To analyze the influence of the acting forming forces on the displacement of machine components the optical measuring system PontosHS© has been used. The position of the bottom plate has been as reference. The determined lateral offset between the upper plate (fixed to the ram) and the bottom plate of the forming tool is shown in Fig. 5. The displacements are presented by means of scaled vectors overlaid with camera images. Additionally, the offset is represented by the diagramm that indicates the rams horizontal displacement in relation to the rams stroke. During the extrusion of the gearing elements, a ram displacement up to 0.3mm in X-direction has been determined (Fig. 5b). This is not acceptable regarding the targeted dimensions of the gearing elements (tooth height is approx. 1mm) shown in Fig.2.

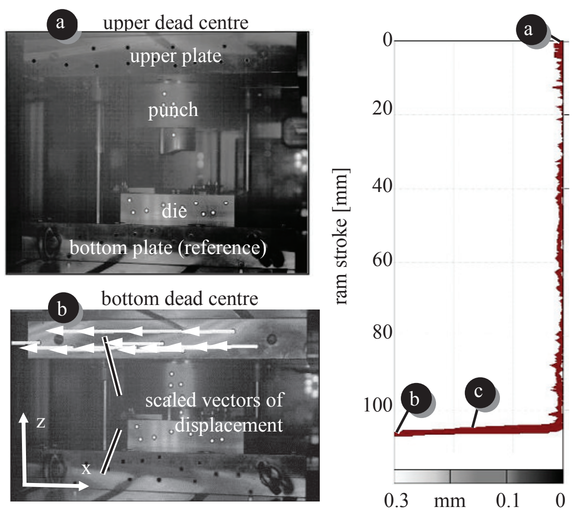

Fig. 5. Displacement of the upper plate (fixed to ram) in X-direction due to the acting forming process

In order to improve the computational accuracy of the process simulation the lateral offset needs to be taken into account. To do this the characteristics of the experimental press have been analyzed.

3.2. Analysis of machine chracteristics

In order to investigate the machines` characteristics under load, a new hydraulic three-axial load device has been developed (Fig. 6). It enables a simultaneous and defined application of vertical and horizontal forces between the ram and the bolster plate [11,12]. The load device consists of a mechanical part, a hydraulic aggregate and a control PC. The installed triple radial piston pump allows the pressure in each cylinder to be set independently from each other. That means a wide variety of load profiles can be applied. The regulation and monitoring of the acting forces is provided by means of the control PC.

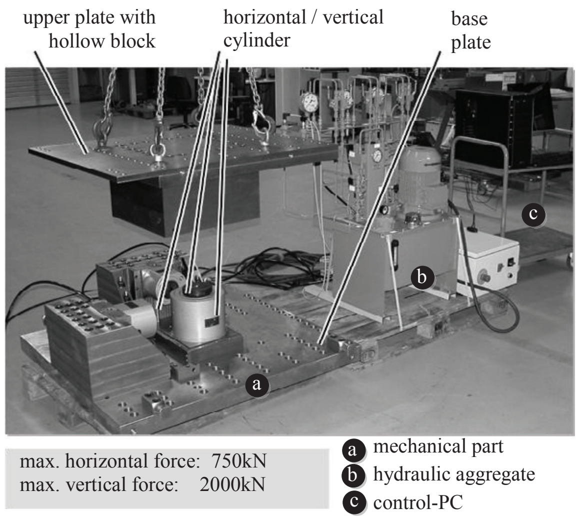

Fig. 6. Three-axial load device [11]

For the analysis of machine characteristics the mechanical part of the load device has been installed in the die space of the experimental press. The displacements of the press components have been determined by means of the optical measuring system PontosHS© in dependence of acting forces applied by means of the load device. The experimental setup is shown in Fig. 7. The benefit of a static load is the exact knowledge of the acting forces and the resulting displacements of the press components. So the results of these measurements have been used to analyse the static press characteristics and the validation of the machine model, which is discussed in the following chapter.

Fig. 7. Experimental setup

4. Modelling of machine characteristics

4.1. Machine model

Due to the high requirements on the process accuracy, a multi-body simulation model (MBS) of the experimental press has been developed in order to represent the machines characteristics. To do this the software tools LMS Virtual.Motion-LAB© and ANSYS© have been used. In this MBS, the rigid press components such as eccentric shafts, connecting rods, ram and press frame have been replaced by finite element (FE) components. The FE-components have been modally reduced by means of the Craig-Bampton-Method in order to reduce the computational time. By means of this method the degrees of freedom of the FE-components have been reduced to a set of static and dynamic modes for each body. This way the developed hybrid multi-body model takes into account the machine kinematics, dynamics as well as the elasticity of press components and allows simulations of high precision and acceptable computing time.

In order to validate this model, the static and dynamic characteristics of the virtual press have been compared with the results from experiments.

4.2. Validation of the machine model (static)

A vertical force has been applied between the ram and the bolster plate in order to determine the vertical displacement of the ram in relation to the bolster plate. The results of the measurement and simulation are compared in Fig. 8. The simulation with rigid machine components (Fig. 8b) doesn't match the reality (Fig. 8a) due to the infinite stiffness ($c_Z = \infty$ kN/mm). By taking the design data of the bearings into account, more computational accuracy has been achieved (Fig. 8c). Higher computational accuracy is expected by replacing the rigid bodies of the press components with elastic FE-models. This expectation is confirmed by modeling the elasticity of the press frame (Fig. 8d), ram (Fig. 8e), conrods (Fig. 8f) and finally of the eccentric shafts (Fig. 8c). The remaining divergence of the stiffness between the simulation and measurement results from the fact, that not all press components were elastically modelled. Therefore, the stiffness of the virtual press is higher than of the real press. Nevertheless, the correlation between simulation and the measurement is more than acceptable because the press model is based on the design data given by the manufacturer and has not been adjusted.

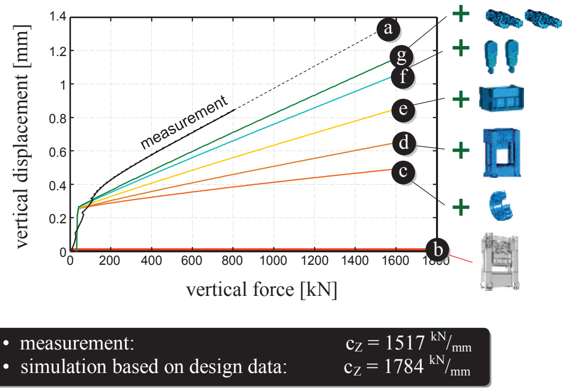

Fig. 8. Comparison of the vertical displacement between the measurement and simulation

4.3. Validation of the machine model (dynamic)

The forming process described in chapter 2 (Fig.3) has been used to validate the virtual ram displacement due to the acting forming forces. The recorded process forces obtained from experiment (in vertical and horizontal direction) in dependence of the recorded ram position have been used as input data for the multi body simulation of the press. The horizontal displacement of the ram has been used as a validation criterion.

Two types of machine modelling have been analyzed and compared to each other and to experiment. Besides the elastic model (Fig. 8) a spring model has been tested in order to reduce the computational time. In this model, the FE-components have been replaced by spring elements in the contact areas of the ram (guide rails and conrods). The setup of the spring elements applied to the contact areas of the ram is presented in Fig.9. By comparison to the elastic model, the advantage of the spring elements is the adjustability of their stiffness. The stiffness of the wagons c_h has been set using the design data of the manufacturer by means of spline curves applied to the multi-body model. The stiffness of the springs c_v is based on the measurement results (Fig. 8a).

The results of simulation with both models and from experiment are compared in Fig. 10. The diagramm shows the horizontal displacement of the ram in relation to the ram position by forming an aluminium alloy blank.

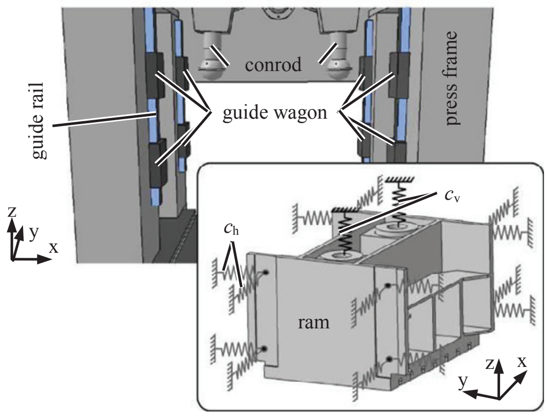

Fig. 9. Spring model

The results show that the elastic model matches with the reality (Fig.10a-b). Using this model the process-machine interaction can be represented realistically. Modelling with the spring elements based on design data leads to higher deviation between the simulation and experiment (Fig.10a-c) due to the used horizontal spring characteristic c_h. It considers the design data of the wagons but not of the other press components. This kind of model can be used in case the stiffness of the press is already known and the stiffness of each spring can be adjusted according to the measurements.

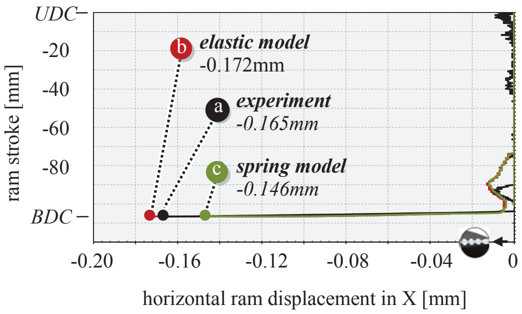

Fig. 10. Results of validation

5. Summary and outlook

The machine influence has an impact on workpiece quality. This impact is significant for in the sheet-bulk metal forming due to high forming forces and resulting ram displacements. A hybrid multi-body simulation is a suitable approach to represent the machine characteristics. Next step of the presented research is to combine the machine and process simulation in order to improve the computational accuracy of the process simulation by taking into account the machine characteristics. In order to counteract the horizontal displacements of the ram new techniques will be developed in future.

Acknowledgements

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