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Original Research Article

FEA of deep drawing with dynamic interactions between die cushion and process enables realistic blank holder force predictions

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ABSTRACT

In order to efficiently compute dynamic interactions between the machine and the forming process, one approach for integrating the dynamic properties of the press, particularly of the die cushion, into the FE forming process simulation is introduced. A free-programmable-force model was used to make a condensed signal model of the die cushion's hydraulics and control available as a discrete element in an FEA Software. The user can now benefit from more realistic machine responses in FE forming simulations without the need for additional multi-body-simulation software. The authors conclude the paper by describing the successful experimental validation of the approach, including a comparison between simulated and measured blank holder force curves.

1. Introduction

FE simulations are indispensable tools for the design and calculation of today's forming processes. The extensive application of FEA allowed for tremendous time and cost savings in tool planning, design, manufacturing and test runs over the last two decades. Currently, the quasi-static computation of deep drawing processes, which employs rigid tool surfaces, an ideal press motion and merely set-value blank holder forces (BHF), is state-of-the-art technology in the industrial community. Various researchers have shown that by implementing elastostatic tool and press flexibilities into the process simulation, the accuracy of the analysis can be improved significantly [5]. At present, press developers and operators are facing the challenges of increasing process forces due to the demand for forming high strength steels and of increasing process velocities due to higher quantities and new press technologies. Therefore, it is becoming increasingly necessary to be able to predict and evaluate the dynamic interactions between the process and the press before production begins. The purpose of this study was to develop a computation method for predicting these dynamic interactions within only one software environment.

1.1. *Dynamic behavior of die cushions*

The dynamic behavior of the die cushion is particularly important for the quality of the forming operation. According to [2] the most important dynamic influences of the die cushion on the acting BHF are the pressure built-up distance, the rate of change

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in pressure, the pressure over shoot and time to constant pressure. These characteristic pressure trajectories cannot be calculated by today's industrial FE process simulation used to predict the quality of the forming process. In order to address this issue the coupling of different simulation software was investigated in various research projects. In [1] the authors describe the coupled simulation for a hydraulic press used for sheet metal forming; [9] explains the coupled simulation for a mechanical press and a bulk forming process.

The prerequisite for correctly modeling the dynamic behavior of the die cushion is a process simulation with real velocities, real accelerations and no added masses. Therefore, common methods such as mass scaling and/or time scaling that are used to speed-up explicit FE simulations are invalid. This causes significantly longer computation times. Currently a selective mass scaling method introduced by [8] is under investigation; if successful, it will reduce CPU time without affecting the system's dynamic response.

1.2. *Free-programmable-force model within FEA environment*

Along with other software, the commercial FE Software LS-DYNA enables the customer to implement user-defined subroutines into the actual FE code [4]. This code was used for all FE simulations described in this paper. The software package contains a selection of FORTRAN subroutines for programming user-defined material models. If the material model is assigned to a discrete beam element, arbitrary force–displacement or force-velocity relations between two nodes can be defined.

In the following, models created by means of this method are labeled *f*ree-*p*rogrammable-*f*orce *m*odels (FPFM). The FPFM and the original FE code are compiled into one executable FE code. Now, the programmed force–displacement–velocity relation is available as a material model within the actual FE software and can be parameterized in a pre-processor. Fig. 1 illustrates the procedure. Due to the concept of the FE code all integrals, derivatives and differential equations are required to be expressed in discrete-time form.

2. Methodology to implement the dynamic responses of the die cushion into FE process simulations

2.1. *Test machine and tooling*

The test machine is a 160 t hydraulic press with a 40 t hydraulic die cushion mounted underneath the bolster plate. The press has a slide stroke of 200 mm and bed dimensions of 800 mm × 780 mm (see Fig. 2, center). The die cushion's displacement cylinder has a maximum stroke of 100 mm which allows a maximum drawing depth of circa 90 mm.

A typical deep drawing tool was employed for experimental validation (see Fig. 1, right). The dimensions of the forming part, a rectangular tub, were 350 mm × 195 mm × 80 mm. For the experiments the aluminum alloy A6016r was used.

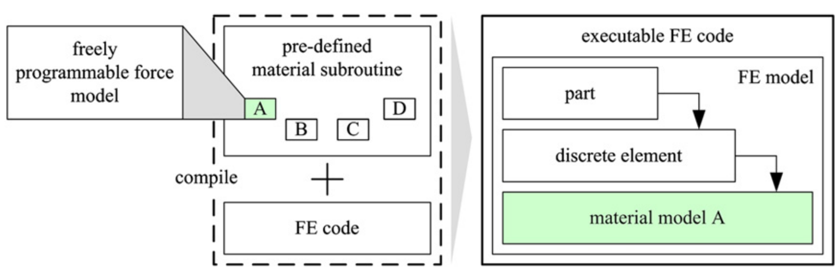

Fig. 1 – Compiling executable FE code.

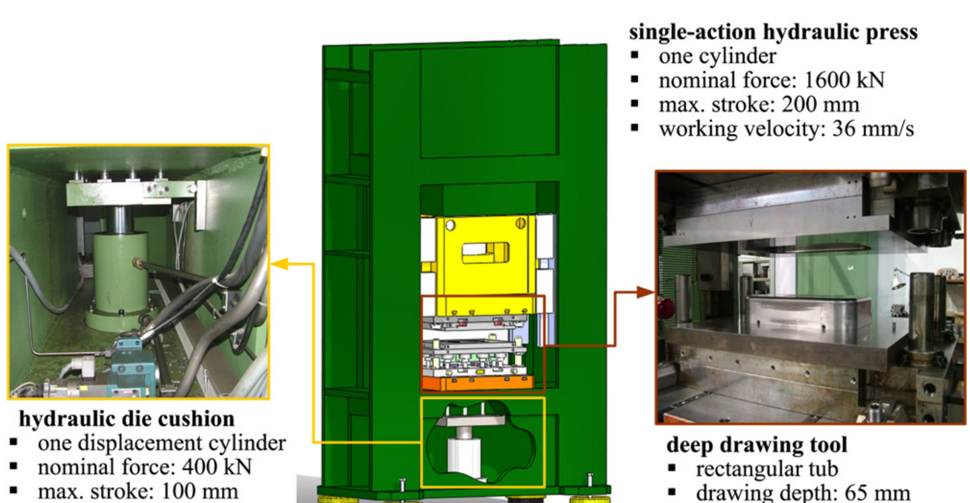

Fig. 2 – Left: Test die cushion; Middle: Test machine; Right: Deep drawing tool.