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Increasing the stability of the deep drawing process by simulation-based optimization

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Abstract: The paper deals with the possibilities of evaluating and increasing the stability of the deep drawing process. Not only the size of technological windows but also the stability of production processes is studied. A system for the optimization of the deep drawing processes is presented. It is capable of determining the optimal values of input parameters for the highest stability of the deep drawing process.

Keywords: Deep drawing; Finite element simulation; Stability; Optimization

1. INTRODUCTION

In metal forming, the combination of input parameters leading to a successful forming operation and acceptable products is defined as a technological window of the process. For a simplified example of the deep drawing process, where the only studied input parameter is the blank holding force, F_{bh}. the technological window is presented in Figure 1.

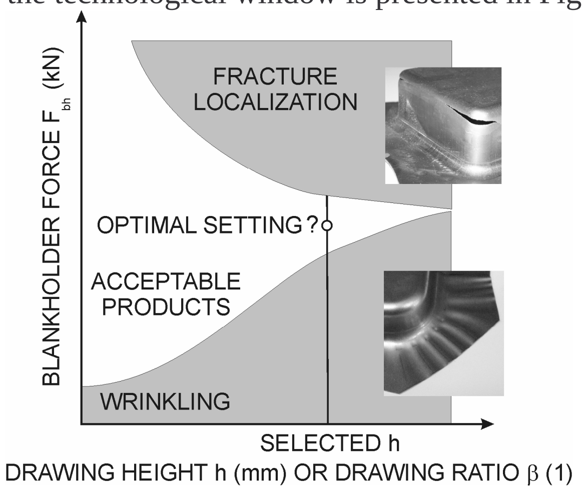

Figure 1. Technological window for the deep drawing process

In industrial practice it is extremely important to control and improve the stability of metal forming processes [1]. Let us consider the example shown in Figure 1. Let us consider the example shown in Fig. 1. Here the question is, which is the optimal setting of the blank holding force F_{bh}.

The optimization of the deep drawing processes is usually performed in advance by process planners and experts for finite element (FE) simulations. To avoid manual optimization procedure, many researchers have developed automated optimization systems. Based on the results of FE simulations, they automatically change the input setting in FE models to improve the predicted results. However, many such systems have certain disadvantages. Many take into account only a limited number of unwanted output properties, such as springback, thinning, forming forces etc. At the same time they are time consuming. In the paper a new optimization system is proposed. It uses as low as possible number of time-consuming FE simulations.

2. A SYSTEM FOR AUTOMATED OPTIMIZATION OF THE DEEP DRAWING PROCESSES

The target function, which needs to be minimized, is presented by Eq. (1). In some cases the number of input parameters and unwanted output properties to be taken into account can be different.

$$D(F_{bh}, r_m, r_p, z, F_{db}, \mu, v, F_{punch}) = \max\left(\frac{\varepsilon}{\varepsilon_{FLD}}, \frac{s_0 - s}{s_0 - s_{\min}}, \frac{h_w}{h_{w\,\max}}, \frac{d}{d_{\max}}, \frac{\sigma}{\sigma_{\max}}, \frac{\varepsilon_e}{\varepsilon_{e\,\max}} \right) \quad (1)$$

INPUT PARAMETERS

- F_{bh} - blank holding force
- r_m - die radius
- r_p - punch radius
- z - clearance
- F_{db} - drawbead restraining force
- μ - friction coefficinet
- F_{punch} - calibration force

UNWANTED OUTPUT PROPERTIES

- ε - actual strain path
- ε_{FLD} - allowed strain path
- s_0 - initial sheet thickness
- s_{min} - allowed final sheet thickness
- h_w - height of wrinkles
- $h_{w\,max}$ - allowed height of wrinkles
- d - dimensional error (springback)
- d_{max} - allowed dimensional error
- σ - equivalent residual stress
- σ_{max} - allowed equivalent residual stress
- ε_e - equivalent strain
- $\varepsilon_{e\,min}$ - allowed equivalent strain

The Response Surface Method (RSM) was selected as an appropriate optimization method for the optimization of the deep drawing process [2]. Within RSM a polynomial function (the response function) is developed which approximates the relationship between the response of a system and the input variables that effect the response. It is used instead of the actual performance function. Therefore, in our case the number of repetitions of time-consuming FE analysis can be reduced.

Second order polynomial was selected for modeling the response of the process (see Eq. (2)) according to the recommendations in the literature [3]. For determination of coefficients β_0, β_j and β_{jj} in the polynomial it is necessary to evaluate the response of the system only $1+2\cdot k$ times for the system with k input variables. The danger of every unwanted output property in Eq. (1) is evaluated with separate polynomial.

$$\eta = \sum_{j=1}^{k} \beta_{jj} \cdot x_j^2 + \sum_{j=1}^{k} \beta_j \cdot x_j + \beta_0 \tag{2}$$

The optimization system is schematically shown in Figure 2. It was developed in the MatLab environment. The properties of the deep drawing process which need to be optimized (material properties, geometry of the active tool surfaces, drawing depth, allowed values of output properties and constraints of input parameters) are provided in input file data.

The optimization procedure runs in several steps. Firstly, the system calculates the initial guess for all input parameters that can be varied. For calculation of initial blank holding force F_{bh}, drawing radius r_m, and die clearance z, the well known equations from the literature are used. For all other input parameters the initial guess is simply determined as the middle point of the allowed interval.

Based on initial guess the first FE simulation is performed. PAM-STAMP software is used. After the simulation, the results are stored and the optimization software calculates the danger of unwanted output properties presented in Eq. (1).

The predicted response expressed by polynomials used in RSM method is more accurate if the space in which they are used is as small as possible. This idea is integrated in our optimization system based on theoretical knowledge on deep drawing listed in Table 1. It reduces the search space. For example, its results for a problem with two variable input parameters blank holding force F_{bh} and die radius r_m are schematically shown in Figure 2.

Based on the size of reduced search space, additional FE simulations are performed for the setting of the variable input parameters in the middle of the reduced search space and on its borders (as shown in Figure 2). Again, the macro command writes the files with the results and optimization software calculates the danger of unwanted output parameters for all FE simulations.

Finally, the optimization software calculates the values of parameters β_0, β_j and β_{jj} in polynomials predicting the danger of unwanted output situations. The danger is then calculated within the reduced search space, and the minimal value D and the optimal settings of input parameters are recorded.

Table 1.
List of failures and measures to eliminate them

Failure	Measures to eliminate the failure
Localization	$F_{bh}\downarrow$ $F_{db}\downarrow$ $r_m\uparrow$ $r_p\uparrow$ $z\uparrow$ $\mu\downarrow$ $v\downarrow$
Thinning	$F_{bh}\downarrow$ $F_{db}\downarrow$ $r_m\uparrow$ $r_p\uparrow$ $z\uparrow$ $\mu\downarrow$ $v\downarrow$
Wrinkling	$F_{bh}\uparrow$ $F_{db}\uparrow$ $r_m\downarrow$ $z\downarrow$ $\mu\uparrow$
Dimens. error	$F_{punch}\uparrow$
Low strains	$F_{bh}\uparrow$ $F_{db}\uparrow$ $\mu\uparrow$

$\uparrow$= increase the parameter value, $\downarrow$= reduce the parameter value

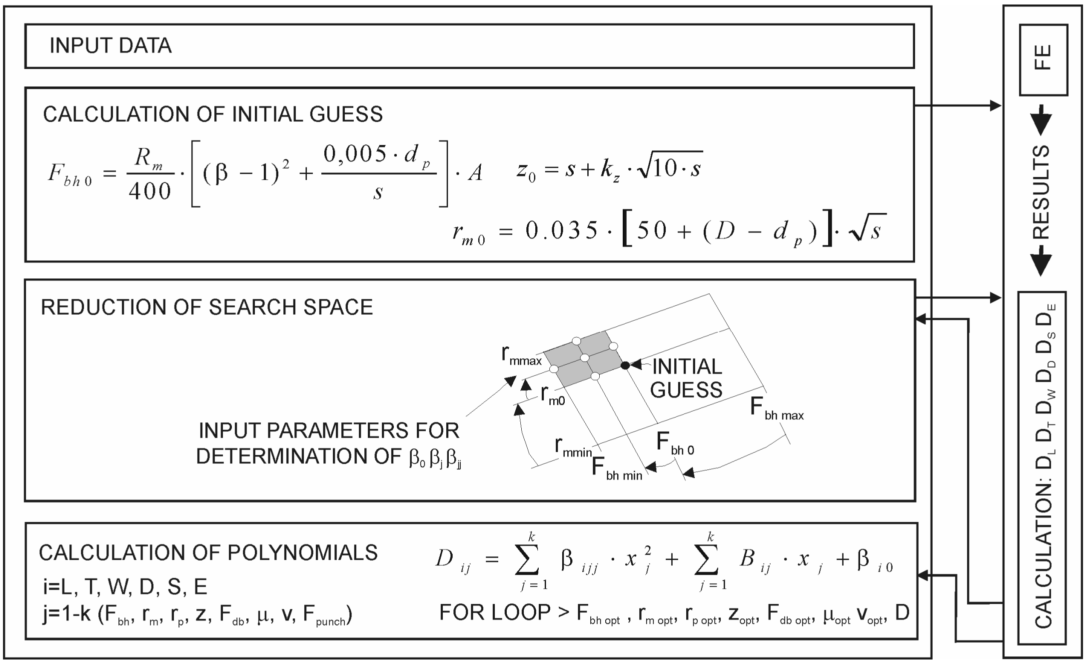

Figure 2. Structure of the optimization system

3. CONCLUSION

In the paper the newly developed optimization system for optimization of the deep drawing processes is described. It takes into account most important input parameters and unwanted output properties of the product. It is aimed at improved the stability of the deep drawing processes.

The optimization procedure is performed with minimal number of time-consuming FE simulations. The results in total and especially the joint factor effects are therefore less reliable. However, there is no need for mathematically exact solution. This is because the results of FE simulations are not completely reliable and the input parameters cannot be set exactly in practice.

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