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Reduction of tool wear by systematic design of the tool clamping situation☆

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ABSTRACT

As a result of the cutting impact, shear cutting processes initiate intensive vibrations in cutting presses and tools. With the aim to improve the press accuracy and tool lifetime, damping systems for reducing the press vibration are state of the art. However, only small attention is given to the tool vibration. Due to its mounting condition in a high-speed press, the lower tool can vibrate like a bending plate. The amplitude of the tool displacement depends on the clamping situation of the plate edges. Moreover, the displacement amplitude correlates with the tool wear. Against this background, it is possible to reduce the wear of a shear cutting tool by systematic design of its clamping situation. In this paper, a methodology for modelling the dynamic behavior of the tool is given. This approach allows a systematic design of the tool clamping situation with the objective to minimize the vibration and thereby the tool wear. Furthermore, the effect of the clamping situation on different process and tool parameters is given by experimental investigations.

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1. Introduction

The shear cutting process is characterized by an extensive tool vibration due to the impact of the cutting punch and the subsequent cutting impact. The first impact arises when the cutting punch hits the sheet metal with high speed. The cutting impact is caused by the sudden drop of the process force [1]. The resulting tool vibration has a high importance for the tool wear and the part quality [2]. Vertical tool vibration results in an additional relative movement between punch and sheet, which causes a higher wear of the punch [3]. The horizontal vibration changes the cutting gap and thus increases the tool wear on the one hand and reduces the part quality on the other hand [4]. Hoffmann and Hirsch [5] show that an asymmetrical cutting gap can even lead to a premature tool failure. Furthermore, Xia et al. show in [6] that reducing vibrations during sheet metal blanking reduces the sound pressure level. As a high tool wear increases maintenance costs and leads to a decreasing part quality, current research focuses on the tool wear mitigation. To lower vibrations in shear cutting processes, different approaches are adopted. For damping the press vibration, active damping systems can be used. In [7], a system based on a magneto-rheological fluid is used to control the shear surface. An auto-adaptive mass balancing system is introduced in [1] to reduce the vibration of the press body. In most scientific works that focus on reducing vibration in shear cutting processes, the aim is to reduce the press vibration or the ram vibration, whereas the vibration of the cutting tool itself is not regarded. Groche and Schneider show in [8] the influence of the dynamic press behavior on its horizontal accuracy by the example of a high speed linear motor press. They introduce a methodology to predict the vibration behavior of the press to optimize, or to minimize the vibrations by an appropriate press design. Looking at the typical installation conditions of a shear cutting tool in a high-speed press, the importance of the elastic tool behavior becomes more significant. Due to the opening of the press table, being necessary to discharge the stamping parts, especially the lower tool is afflicted by vibrations and tool displacement. Whereas the tool edges are fixed by the clamping devices, most of the surface of the lower faceplate is not supported by the press table. Aggravating this situation, the tool is generally loaded by the process force in this area. Thus, the tool behaves approximately like a bending plate.

One example to reduce vibration of the tool is to set the tool stiffness specifically. To investigate the effect of lightweight materials, e.g. carbon fiber reinforced plastics, magnesium, or aluminum on the tool vibration, a comparison of these materials and steel is performed by investigating a shear cutting tool [4]. It is found that the tool stiffness influences the tool vibration depending on the Young's modulus. By using steel with a high Young's modulus for

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the head plate, the measured acceleration is at the lowest level. Kraus et al. show in [9] that the vibration behavior of the cutting tool can be influenced by the design of the tool fixation. Using a lower number of clamping bolts leads to a reduction of the acceleration amplitude at the cutting impact. As a reason for this behavior, a damping squeeze film between tool and press table was found. A lower number of clamping points results in a higher vertical movement of the tool relative to the press table, whereby the effect of the damping squeeze film on the tool acceleration was increased.

For the fixation of a cutting tool to the press, an extensive product range of clamping devices is provided by industrial suppliers. For transmitting forces and torques between tool and press, the tool position is to be ensured by clamping. The process forces must neither result in a tool displacement, nor set the tool into vibration or deform it in an unintentional way [10]. The tool is fixed by means of an interlocking or a frictional connection. The tool fixation during a process is defined as tool clamping [11]. According to the operating principle, clamping systems can be divided into:

- mechanical clamping devices (bolts, quick-release systems),
- magnetic clamping plates,
- hydraulic clamping devices, and
- pneumatic clamping devices [12].

The clamping situation describes the fixation method of the tool. It comprises the number of clamping elements, their arrangement, the amount of the clamping force, as well as the type of clamping system and the operating principle. Whereas most clamping devices transmit the process forces locally, magnetic clamping plates have an effect on the whole surface of the tool faceplate. Brecher et al. [13] describe the importance of the interaction between machine and tool relating to cutting and sheet metal forming processes. He notices that process effects such as vibration and deflection can only be explained by these interaction phenomena. Nevertheless, the determination of the clamping situation is mostly based on personal experience. Scientific investigations regarding the influence of the clamping situation on the tool behavior and the process performance in shear cutting processes are rare. With reference to the different clamping devices and especially their differing ways of force transmission, it seems to be evident that the clamping situation influences the tool behavior during the forming process. In the numerical and experimental investigations described below, the effect of the clamping situation on the dynamic tool behavior is examined.

2. Numerical simulation of the tool vibration

The Finite Element Analysis (FEA) allows the preliminary design of the tool clamping situation as well as a deeper analysis of the tool behavior. In the following, the approach for building the simulation model and the results of the simulation are presented.

2.1. Modeling the cutting tool

For the numerical simulation of the shear cutting tool, the FEA software ABAQUS with an implicit solver static / general is used. The below described approach for building the numerical model is visualized in Fig. 1.

The tool components are imported from the CAD software SOLIDWORKS to ABAQUS. In a first step, the complete upper and lower tool models are both simulated as deformable bodies. A direct and stiff connection between upper and lower tool is given by the four column guidances. To reduce computing time, the upper tool is replaced by springs, representing the column guidance. The stiffness of the springs is determined by a numerical bending test of the

guidance. The used test load and test torque as well as the determined stiffness in x- and y-direction and in direction of rotation around the two axes, is given in Table 1.

The press is represented by the press table, which is modeled as an encastré rigid body. The required element size of the mesh depends on the interesting vibration frequency and is determined as follows. To simulate the eigenform of the tool, the maximum size of the elements must be half the wavelength λ. The velocity of propagation is calculated as

$$c = \sqrt{E/\rho}. \tag{1}$$

Here, $E = 210,000 \, \text{N/mm}^2$ is the elastic Young's modulus and $\rho = 7.85\text{E-}6 \, \text{kg/mm}^3$ is the density of steel. Furthermore, f_n is the frequency, $\omega_n = 2^*\pi^*f_n$ is the angular frequency and $\beta = \omega/c$ is the wave number. With $\lambda = 2^*\pi/\beta$, the equation to calculate the element size according to [14] is

$$l_e = \lambda/2 = \pi/\beta = (\pi * c)/\omega = \sqrt{E/\rho}/(2 * f_n). \tag{2}$$

For the highest interesting frequency of 50,000 Hz and a safety factor of 2, the maximum element size is $l_e = 26 \, \text{mm}$. Due to the poor mesh quality when using a size of 25 mm, the element size of the press table is set to 15 mm. To mesh the geometry of the lower faceplate with an adequate mesh quality, an element size of 10 mm is chosen. The element size of the tool plate and the stripper plate is 5 mm. For the discretization of all elastic parts, linear hexahedral elements of the type C3D8R are used. The rigid press table is discretized by the linear quadrilateral elements of type R3D4 and the cutting bush consists of the linear triangular elements of type R3D3. The complete model consists of 61504 elements. In the first step of the simulation, the preload forces of all bolt connections are initiated. The tool plate and the lower face plate are connected with four bolts of the size M12. The bolts are simulated using the Abaqus feature "bolt load" with a preload force of 45,335 N. This load results from a preload torque of 70 Nm, that was chosen according to [15]. The clamping bolts of the size M16, fixing the lower faceplate to the press table, are simulated as rigid circular plates. The surfaces of these plates comply with the surface of the washers which are used in the experimental investigations. The clamping force of these bolts is 80,000 N and results from a preload torque of 180 Nm. As a result of the pretension load, the bolts are lengthened. In the next step, the length of the bolts, connecting tool plate and faceplate, is fixed to their current length after reaching the preload force. This approach leads to a realistic simulation of the bolt behavior. In the subsequent step "frequency", the eigenfrequencies and eigenmodes are calculated for the frequency range of 100 Hz–15,000 Hz. A modal analysis follows in the step "modal dynamics". Here, the measured force course of the shear cutting process is initiated at the cutting bush. In this step, the vibration response of the tool is determined in the time domain. All contacts between the tool parts are defined as "hard contact" with a tangential friction coefficient of $\mu = 0.14$ and a contact damping with a damping coefficient of $d = 30$. In the step "modal dynamics" the structure damping is specified by the Rayleigh damping. In contrast to the contact damping coefficient, this damping value describes the damping behavior of the whole system. Thus, it is possible to simulate the behavior of the complex vibration system, consisting of the press and the tool, by modeling entirely the lower tool and the press table. The proportional damping matrix consists of a linear combination of the mass matrix and the stiffness matrix. According to [16], the modal damping matrix of the Rayleigh damping is defined as

$$B = \alpha M + \beta K \tag{3}$$