RECENT DEVELOPMENTS AND DESIGN OF TOOLS FOR PUNCHING AND CUTTING

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ABSTRACT

Intensive utilization of computers is especially emphasized in the field of industrial production, where use of computer applications achieves significant savings in regard to the time required for manufacturing of products. Shortening of the production time decreases the production costs and new products are faster introduced to the market, thus making the company more competitive. In addition to the shorter time for production, better precision and accuracy is also accomplished, resulting with better product quality at the end.

Due to the fact that, for the reason of cost-effectiveness of manufacturing of tools, processing of sheet metal on presses is primarily performed in the course of serial production, this paper focuses on an analysis of the use of computers in the process of design of tools for punching and cutting of sheet metal on presses. The presented methodology encompasses all phases in the process of design of tools – from planning the work piece until the final design of the tool for punching and cutting, with an emphasis on the activities performed exclusively by computer applications.

The result of this research is a 3D geometrical model of a tool for punching and cutting, with an explanation of characteristics of its construction parts, calculation of its executive parts, analysis and simulation of operation of the tool, and finally the conclusion on the representation and importance of the utilization of computer applications in the process of design of such tools.

Key words: Tool design, CATIA, Modeling, Sheet metal, Presses

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1. INTRODUCTION

The possibility of modeling of solid objects in three dimensions (3D) is the most significant aspect of the CAD (Computer-Aided Design) system. Solid modeling enables engineers to create precise mathematical and graphic representation of an object. With the use of computer applications, solid models can appear as real objects. The CAD system also significantly shortens the time required for generating of two-dimensional (2D) drawing. Majority of modern CAD systems provide associative connection between 2D drawings generated on
basis of solid models, therefore all changes made on the model are automatically reflected on the drawings.

3D modeling plays an important role in numerous segments: DfM – Design for Manufacturability, CAM – Computer-Aided Manufacturing, CIM – Computer Integrated Manufacturing, CE – Concurrent Engineering, etc. In fact, everything is directed toward accelerating of the process of design, minimizing of used materials and labor, increasing the quality of products and decreasing the price of the final product. In order for the projected goals to be realized, good communication within a company is necessary. A shared 3D database for products that are designed and manufactured enables multiple users to simultaneously work on different aspects and problems in the process of design and fabrication. The graphic nature of the database has served as evidence that 3D modeling is a superior method of communication during designing [1]. CAD methods are one of the most important topics in the processing industry, especially the automobile industry. The application of various CAE (Computer-Aided Engineering) techniques practically covers the entire cycle of product development, from conceptual design of the product, through planning of the process all the way to the manufacturing. At the same time, CAE tools are becoming more and more important, since the parts are becoming more and more complex. The necessity for a widespread application of CAE techniques, stimulated by the requirements of global competitiveness, leads to a rational Process and Die Design Engineering (PDDE) [2].

Lately, two main approaches are used for achieving of these goals. One of them is the Knowledge-Based Systems (KBS) or Expert Systems (ES) [3], which are mostly based on a simplified theory of plasticity and empiric rules. There is huge number of articles on the use of Knowledge-Based Systems, for shaping of sheet metal and metal processing [4, 5]. The other approach is numerical methods (most frequently the finite element method) for analysis of plastic deformities [6-10].

2. PROCESSING BY PUNCHING AND CUTTING
The processing by punching falls into a group of processing without deformities of materials, whereas one part of the material is removed from the other. Punching is mostly performed by special tools and machines. Punching equipment is designed in the form of two tools on presses, which process the material by removal, without taking off of scrap. These tools are cost-effective only when a large number of work pieces are manufactured. The reason for this is their complicated construction, especially when multiple operations are to be performed in a single turn of a machine. The process of punching is in the beginning characterized by a deformity underneath the punch, that is elastic bending which is in a certain moment transformed into plastic bending with stretching. During the plastic deformation, the edges of the punch and the cutting board destroy the outer surface of the work piece in order to punch it [11].

Cutting is a form of processing that is performed by removing of material without taking off of scrap, and falls into a group of processing by deformation of material. Different tools can be used for cutting, but usually it is performed by special devices for cutting (scissors) or tools on presses. Basically, the cutting occurs when the drive mechanism on the scissors or the press creates such a force that causes stress in the material that is higher than its strength, thus separating it [11].

2.1. Construction parts of the tool
Each tool consists of two subassemblies: upper and lower. They are completely separable from each other. The entire tool, disassembled, is shown in Figure 1.
In the process of design of the cutting tool, the most demanding part of the process is the creation of the concept of the bottom part of the tool. Its complexity enables the scrap sheet metal after cutting to pass through the bottom part, then through opening on the press table to the containers which are alternately emptied. These openings significantly weaken the load-bearing characteristics of the construction, thus special attention should be paid to critical points and additional strengthening of the construction at such points should be foreseen.

The sheet metal holder is an active (movable) component of the tool its function is to press the sheet metal to the cutting board before the puncher and/or cutters perform their function, thus providing sufficient force for holding of sheet metal during the cutting process. The force that holds the sheet metal is provided by the press and through pressure plugs transfers it directly to the sheet metal holder. The holder is mostly made out of cast iron, and its parts that are in direct contact with the work piece are treated with the finishing.

For making of smaller holes with different shapes, punchers are used, which together with the cutting board form shear stress along the scope of the hole that is being punched. Punchers and cutting board are the main parts of the punching tool, and they are made by scraping. Their bodies are standardized, and the segment that is in direct contact is processed in accordance with the shape of the hole that is to be punched.

2.2. Calculation of the punching and cutting force

In the calculations used in technical practice, the most important issue for determining the force of the punching and cutting is the shearing strength of the material ($\tau_m$). The shear stress for punching and cutting is not constant, but it varies depending on the relative depth of the punching and cutting ($\varepsilon = z/s$), type of material, etc.

For nominal and actual shear stress, analog conclusions are in force, same as for stretching. The nominal stress in the moment of separation of material equals to:

$$\sigma_m = \frac{F_m}{A_0} = \frac{d^2 \pi}{4}$$

The actual stress in the same phase of the strain equals to:

$$\tau_m = \frac{F_m}{A_0} = d \cdot \pi \cdot s$$
whereas:

– force in the moment of separation of material,

– thickness of material,

\[ \psi_m = \frac{A_0 - A_m}{A_0} \] – transversal contraction of test piece in the starting point of deformity localization, and

\[ \varepsilon_{ot} = \frac{z_{ot}}{s} \] – relative depth of punch.

Actual stress is higher than the nominal:

\[ \sigma_{mst} > \sigma_m, \tau_{mst} > \tau_m, A_m < A_0 \] (5)

The punching and cutting force for tools with parallel cutting edges is determined as follows:

\[ F = L \cdot s \cdot \tau_m \] (6)

whereas:

\[ L \] – scope of segments which are punched/cut.

Such calculated force, due to non-uniform thickness of material and bluntness of cutting edges of the tool (which is unavoidable during exploitation) is increased for 30%, therefore the actual cutting force on basis of which the press is set is:

\[ F_M = 1.3 \cdot F = 1.3 \cdot L \cdot s \cdot \tau_m \] (7)

According to (6), it is clear that the punching and cutting force is proportional to \( L \), \( s \) and \( \tau_m \). For that reason, during processing of hard metals, where a shearing strength \( (\tau_m) \) is higher, material thicker \( (s) \) or with a larger scope \( (L) \) there can be excessive increase of the force. [13, 14]

Figure 2a shows the measured lengths of the cutout, acquired with the application of the Measure tool from the software system CATIA. The lengths of cutouts are necessary for determining the value of the punching and cutting force.

![Figure 2 Cutting curves]
The total cutting length is:

\[ L = 2 \cdot 65,473 + 764,239 + 2 \cdot 687,355 + 561,362 = 2,831,257 \text{ mm} \quad (8) \]

Since it is known for the material that \( \tau_m = 300 \text{ MPa} \) and \( s = 0.8 \text{ mm} \), the total force required along the \( z \)-axis of the tool is given as:

\[ F_M = 1.3 \cdot 2,831,257 \cdot 300 \cdot 0.8 = 883,352,184 \text{ N} \approx 883 \text{ kN} \quad (9) \]

Based on the acquired value of the force along the vertical line, the force for holding of the sheet metal is determined. The force for holding of the sheet metal is approximately 10% of the total punching and cutting force. Therefore, the force for holding of the sheet metal is given as:

\[ F_D = 0.1 \cdot 883,352,184 \text{ N} \approx 88 \text{ kN} \quad (10) \]

On basis of the calculation of the force for holding of the sheet metal, the number of pressure plugs required for transfer of the force from the press to the sheet metal holder is determined. For orientation purposes, one pressure plug with a diameter of 36 mm can transfer the force of 50 kN. Pursuant to the concrete calculation in question, two pressure plugs are required, but in order to secure uniform action, 13 pressure plugs were taken, allocated to all those places where the cutting force acts. These are the critical points where the adequate holding force should be secured in order to prevent pulling out or deformities of the sheet metal (Figure 2b).

### 3. 3D GEOMETRIC MODELING AND SETTING OF PARAMETERS OF THE TOOL

The entry data for the 3D geometric modeling of the tool are the elements contained in the method, that is: borders of the work piece, cutting curves, shape of the work piece (incoming and outgoing from the tool), shape of cutting scrap, directions of cutting during the use of pusher, coordination system of the work piece which is modeled in relation to the coordination system of the tool, etc.

The 3D geometric modeling of the tool is performed in the software system CATIA. Hereinafter is a description of the course of modeling of one part of the tool, in this case the sheet metal holder (Figure 3).

The first operation during modeling of the sheet metal holder is defining the surface (Figure 3a) that is in direct contact with the work piece, that is the surface leaning on the bottom part of the tool and the work piece immediately before the cutting force comes into effect.

![Figure 3](image-url) Course of 3D geometric modeling of the sheet metal holder
After defining the bearing area of the sheet metal holder, the next step is defining its shape, which corresponds to the shape of the work piece (Figure 3b). The following step is defining of the form (bearing area) on places of cutting from direction of the z-axis, meaning places where cutting knives mounted on the upper part of the tool are to be set. After defining of the form (bearing area) on places of cutting from direction of the z-axis, the next step is defining of the form on the places of cutting from the direction of the pusher, that is from the direction of the axis that marks that direction of cutting and the cutting curve.

The next step in the modeling of the sheet metal holder is defining of ribs, 40 mm thick, used for transfer of the holding force from pressure plugs to the sheet metal holder, and in the same time alleviate the construction of the sheet metal holder as much as possible.

The last step in the process of modeling of the sheet metal holder is adding of chambers used for housing of elements for the management and securing of proper operation of the sheet metal holder, as well as adding of ribs if necessary in order to stiffen the construction.

After integration of all necessary standard elements to the sheet metal holder, its appearance changes. The final appearance of the sheet metal holder with all the standard elements is shown in Figure 3c.

After the 3D geometric modeling of the tool, setting up of its parameters took place. The setting up of parameters starts with the creation and dimensioning of a sketch (Figure 4).

Parameters are set and their values defined, as well as the formulas if there is inter-independence of one dimension in relation to other dimensions (Figure 5). [15-17]
After linking the parameters to the dimensions, a table is generated and later processed when quantities pursuant to the corresponding standard are entered.

4. ANALYSIS AND SIMULATION OF OPERATION OF THE TOOL

The simulation of operation of the tool was performed in the DMU Fitting module of the CATIA software system.

In the beginning, a 3D geometric model of the tool is prepared. That means converting the tool’s database into the .cgr format and deleting of all constrains, parameters and relations from the tool’s tree, with the goal of easier performance of a simulation in the sense of the utilization of computer resources. After that, a Part is created into which the coordinate systems relevant for simulation of movement are copied. In this case, these are the coordinate system of the tool and the coordinate system of the pusher. Together with these coordinate systems, the Part is inserted into the tree of the converted tool’s database and used for defining the direction of movement of individual components of the tool.

For simulation of movement of the upper part of the tool, the value of velocity of movement of the press of 0.5 m/s is used and the range of motion of the press of 1.2 m, that is the height of the upper part when the tool is in opened state. The simulation is defined by the selection of the Track tool from tools menu DMU Simulation, and the speed of the press of 0.5 m/s is entered in the box Speed. For Object, the subassembly of the upper part of the tool is selected with all the elements tightly connected to it. The sheet metal holder and the pusher are not selected, since they have their own movement in accordance with other norms (Figure 6).

Moving of this subassembly is performed with a compass for spatial manipulation, in a way that it is put on the xy plane of the tool’s coordinate system and the W-axis is vertical in relation to that plane. Then the value of movement for the selected subassembly of the tool is entered. When the value of the movement is entered and when the upper part of the tool has moved, option Record saves its position (Figure 7).
The movement of the sheet metal holder is simulated in the same way. The function of the sheet metal holder is to hold the sheet metal pressed against the cutting board before cutting until the cutting elements completely finishes the cutting process and is removed from the grasp. Specifically, the sheet metal is pressed until the upper part of the tool is moved 50 mm upwards (holder’s range of motion), after which the holder starts its movement (Figure 8). The difference between these two motions is reflected in that the sheet metal holder’s motion is shorter than the motion of the upper part of the tool for the value of the holder’s motion (1200 – 50 mm). Also, after the motion, it should be checked whether the sheet metal holder has occupied the correct position in the tool.

Figure 7 Moved upper part of the tool

Figure 8 Moved sheet metal holder
5. CONCLUSION

The utilization of computer applications in the process of design of tools for punching and cutting has been significantly represented in parts with simple geometrical shapes, while with parts that have complex geometrical shapes it represents an eliminatory factor for the possibility of performance of such process. The significance of the application is reflected in the fact that shape of complex surfaces cannot be fully defined dimension-wise in the technical drawings, meaning transferred from a drawing to a mould, and in the end the control of the finished shape is difficult to control.

In addition to the enabling of the very process of design of tools for parts with complex geometrical shapes, computer software for 3D visualization and design play an important role in regard to the control of proper functioning of a tool, as well as testing of tools for mechanical and other strains that may appear during the lifecycle of a tool. These tests and controls are performed during the design of tools and prevent the occurrence of defects in the phase of exploitation of tools. Possible occurrence of defects would cause incomparably higher costs for their correction than the costs for design of a tool.

The parameter modeling and linking of the structure of a 3D geometrical model with links enable quick modifications of shape of the work piece which are automatically reflected on the shape of tool and the required technical documentation. Such method of modeling simplifies the redesign of the work piece and shortens the time necessary for modifications on the construction of tool. Thus, companies are able to place their products on the market faster and become more competitive and profitable.

The utilization of computer applications in design of tools is registering constant growth, and the final goal is a fully automatic and uniform process of modeling of tools, where engineers mostly enter the data and control the shape of the construction.

REFERENCES


