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**Author:** Heinle, Ingo Matthias  
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Chapter 3
Production process of sheet metal parts

3.1 Introduction
The manufacturing of sheet metal parts for car bodies usually consists of several process steps. The original blank is transformed into the desired part shape by stamping, postforming, trimming and piercing operations. For each of these operations a part specific tool has to be designed. For the manufacturing of parts, the tools are mounted in a press line. Additional handling systems are necessary in order to transport the intermediate products from one press to the next one. The whole process runs usually fully automatic, which leads to high productivity. The design of the production process is determined by the producibility of the sheet metal part, the minimization of the sheet metal consumption, the robustness regarding scattering of the material behavior and the process conditions. Further aspects are the minimization of the investments for the tools, the required geometrical tolerances of the part and functionality demands like the mechanical strength of crash relevant parts.

3.2 The stamping operation
In the following chapter, production processes are discussed, which start with a stamping operation. The term stamping is used for describing the first shaping operation of the process and the term postforming is applied for the remaining shaping stages. The experiments of this thesis are based on stamping operations. Hence, in this thesis a detailed discussion of the design and the functionality of trimming and postforming operations is omitted. For a comprehensive description of stamping operations, a simplified example is introduced, as depicted in figure 3.1.
CHAPTER 3. PRODUCTION PROCESS OF SHEET METAL PARTS

Figure 3.1: Example; The geometry of the part.

Figures 3.2 and 3.3 show a stamping operation, which is related to the mentioned example. The following section focuses on the description of the sequence of the stamping operation.

The initial state of the press after inserting the blank into the tool is illustrated by figure 3.2 (left). During the first phase of the operation the press ram goes down. As soon as the die, the blank and the binder are in contact, the binder force begins to act against the die (figure 3.2 (right)). It has to be mentioned, that the binder force progression depends on the motion of the binder. For the built up of the desired binder force, a press specific level of binder movement is necessary. In the second phase of the operation, the drawbeads are formed, if existent, which completes the binder closing phase (figure 3.3 (left)). The functionality of drawbeads will be explained in the next section. Afterwards, the die goes down until the tool is closed and the material is formed according to the geometry of the die and the punch (figure 3.3 (right))\(^1\). During this phase, the material is plastically strained. The material flow in the binder zone strongly affects the result of the stamping operation. For controlling the material flow, there is a window of permissible levels of restraining forces. On the one hand, exceeding the upper limit of the restraining forces leads to an insufficient material flow, which causes material failure. On the other hand there is a tendency for wrinkles, if the material is not restrained enough [41].

\(^1\)An introduction in press and tooling technology can be found in [40].
3.2. THE STAMPING OPERATION

The binder is connected with a hydraulic system, which is able to induce the desired binder force. The binder force causes a restraining force resulting from the frictional response between the binder, the blank and the die. This is one way to control the material flow of the sheet metal during the stamping operation. Another method for controlling the material flow are drawbeads, which are located perpendicular to the material flow in the binder region, as depicted in figure 3.5. While the material passes through the drawbead additional mechanical work needs to be done. This causes restraining forces acting in the opposite direction of the material flow. The mentioned solution can be applied locally in the binder zone. As opposed to the binder force, the drawbeads are more robust regarding scattering process conditions. The disadvantage of using drawbeads is the additional material consumption.

The edge contour of the formed material is a function of the restraining forces and the blank geometry. Figure 3.4 (right) shows the material flow of a stamping operation without a draw bead. The minimization of the material consumption implies that the edge of the blank moves close to the die radius during the stamping operation. If the edge of the sheet metal reaches the die radius zone, a discontinuity with respect to the restraining forces is caused, because the binder cannot control the material flow anymore. Such discontinuities can lead to process instabilities, which are usually omitted. In the case the operation contains drawbeads (figure 3.4(left)), the edge of the blank should not move into the draw bead, otherwise the continuity of the restraining forces is also disturbed. Figure 3.4 also demonstrates the fact, that drawbeads can increase the material consumption of the production process. Thereby, an equivalent strain field is assumed in the zones, which do not pass through the draw bead during the stamping operation.

Subsequently, the springback effect is introduced. In the closed state of the tool the contact forces between formed material and the die face are in equilibrium. When the tool opens, the mentioned forces cannot act anymore. The stamped part enters another equilibrium state, which is accompanied with a de-
Figure 3.4: Comparison of the material flow with (left) and without (right) applying a drawbead.

Figure 3.5: Drawbead: Left: Geometry of the drawbead; Right: The drawbead induces restraining forces, which act in the opposite direction of the material flow.
formation. This physical effect is called springback. In order to deal with this effect a tool modification, called springback compensation, is computed based on the deformation caused by the springback effect. The objective is to obtain the desired part geometry after it has reached the final equilibrium state. A description of the methods needed for a springback compensation is given in [42] and [43].

For the commissioning of the stamping tools the binder has to be touched up and the radii of the punch and die are polished. The above mentioned function of the binder regarding the control of the material flow requires a constant pressure distribution between the die, the blank and the binder.

Moreover, the system, consisting of the press, the tool and the sheet metal are slightly elastically deformed during the stamping operation [44],[45] and [46]. Therefore, it is necessary to modify the binder surface slightly, in order to obtain a constant pressure distribution. This modification has to be done manually in the tool shop. Spacers (figure 3.6), adjustable in height, between the binder and the die, give the operator of the production process in the press shop the chance to modify the above discussed pressure distribution locally. Such modifications are necessary to deal with scattering process conditions.

Figure 3.6: Illustration of a spacer.

3.3 Development of production processes

Usually the part geometry is given in the coordinate system of the product (global coordinate system of the car design). The first step of the production process development is the definition of the part alignment with respect to the direction of the press ram movement. A possible approach is to introduce an additional coordinate system, as depicted in figure 3.7, for the definition of this alignment. In the example of this thesis the z-coordinate is defined to be coincident with direction of the press ram movement. Regarding the stamping operation, the minimization of the sheet metal consumption, the consideration of the undercut condition and avoidance of wrinkles have to be taken into consideration. The term undercut is defined in the next section. Furthermore, subsequent operations in the direction of the press ram movement are preferred; otherwise an additional tool investment is necessary for the redirection of the press motion within the tool.
Therefore, for finding the best part alignment, all of the production operations have to be taken into consideration.

![Figure 3.7: Definition of the drawing direction.](image)

Any straight line parallel to the direction of the press ram movement, which causes two or more intersections with the part surface, defines points belonging to a region of undercut. Obviously, the regions of undercut change, if the part alignment with respect to the stamping direction changes (figure 3.8 (middle)). Aligned parts or intermediate geometries, which are produced by stamping operations, must not have any zone of undercut. If any alignment of the part violates the undercut condition, an intermediate shape has to be designed (figure 3.8 (right)). Such a geometry enables the engineer to remove the zones of undercut by splitting the shaping of the part in different operations. In this case at least one postforming operation is needed for the production of the desired part geometry.

![Figure 3.8: Example; Left: Analysis of the undercut of the part geometry with respect to direction 1. The part geometry possesses a zone of undercut with respect to the selected direction; Middle: Analysis of the undercut of the part geometry with respect to direction 2. The shown modification of the part alignment also leads to a zone of undercut; Right: Analysis of the undercut with respect to the intermediate geometry. This geometry in combination with the selected drawing direction does not show any undercut but needs an additional forming step.](image)

As a next step the binder surface is designed. The main functionalities of the binder are the above mentioned material flow control and the avoidance of wrinkles. The second function cannot be explained by the example, depicted in figure 3.1. Especially for complex double-curved part geometries a non trivial binder geometry is necessary in order to deal with wrinkling effects. Wrinkles are caused by differences concerning the developed length of different cross sections of the same normal direction with respect to the die surface.

Finally the gap between the part geometry, respectively the intermediate shape and the binder has to be closed. This geometry is called addendum (figure 3.9 (left)). The geometry of the stamping operation is derived from the part or the
intermediate geometry and the binder and the addendum (figure 3.9 (right)). The subsequent operations are also designed at the same time.

Figure 3.9: Example; Left: Illustration of a stamping operation based on the intermediate shape; Right: Derivation of the tool surfaces.

Today, the design of the production processes is supported by CAD systems. All process relevant surfaces and contours are described by a 3D model. Based on the process design the tool design is initiated and finite element analyses are performed. Such a simulation enables the design engineer to evaluate the stamping operation with respect to material failure and the development of wrinkles. As soon as a satisfying design has been found for the stamping operation, the subsequent operations are also analyzed based on a simulation. If the process has finally reached a mature state the springback is analyzed and, if necessary, compensated. For complex parts the design of a production process is a non trivial task. Usually, several optimization loops are necessary, to find the desired optimum regarding the mentioned conditions.

3.4 Example

By looking at the example, obviously, there is no part alignment, which does not violate the undercut condition figure 3.8 (left) and 3.8 (middle). Therefore, an intermediate shape is introduced as depicted in figure 3.8 (right). This geometry, in conjunction with the addendum and the binder, leads to the design of the stamping operation with respect to the tool surfaces (figure 3.9). The tool design is shown, schematically, by figures 3.2 and 3.3. As depicted in figure 3.10 the stamped material is trimmed in another operation and finally postformed in order to obtain the desired part geometry.

Figure 3.10: Example; Illustration of the production process; Left: Stamping operation; Middle: Trimming operation; Right: Postforming operation.
3.5 Industrial production process

As a further example the production stages of a side panel are given, which are illustrated by figure A.1. The process starts with a stamping operation (OP1) and is followed by two trimming operations (OP2, OP3). The remaining process steps (OP4, OP5, OP6) contain further trimming, piercing and postforming operations. Generally, car body shell parts like the side panel have to fulfill high requirements regarding the surface quality. Wrinkles, arising during stamping usually have a negative impact on the quality of the car body shell. Consequently, the stamping operation comprises a complex double-curved binder surface in order to minimize the development of wrinkles. The trimming of the part is distributed to several operations in order to enable an automatic disposal of the trimmed material.