2.3 SHEET METALWORKING

Classification of Sheet Metalworking Processes

Basic sheet metalworking operations: (a) bending, (b) drawing, and (c) shearing; (1) as punch first contacts sheet and (2) after cutting. Force and relative motion are indicated by F and v.

Cutting Operations

Shearing

Shearing is a sheet metal cutting operation along a straight line between two cutting edges by means of a power shear.
Blanking and punching

Blanking and punching are similar sheet metal cutting operations that involve cutting the sheet metal along a closed outline. If the part that is cut out is the desired product, the operation is called *blanking* and the product is called *blank*. If the remaining stock is the desired part, the operation is called *punching*. Both operations are illustrated on the example of producing a washer:

![Steps in production of washer](image)

**Engineering analysis**

Cutting of sheet metal is accomplished by a shearing action between two sharp edges. The shearing action is illustrated in the figure:

![Shearing of sheet metal between two cutting edges](image)

Shearing of sheet metal between two cutting edges: (1) just before the punch contacts work; (2) punch begins to push into work, causing plastic deformation; (3) punch compresses and penetrates into work, causing a smooth cut surface; and (4) fracture is initiated at the opposing cutting edges that separate the sheet. Symbols $v$ and $F$ indicate motion and applied force, respectively.
Clearance

Clearance $c$ is the distance between the punch and die. The correct clearance depends on sheet-metal type and thickness $t$:

$$c = at$$

where $a$ is the allowance ($a = 0.075$ for steels and 0.060 for aluminum alloys).

If the clearance is not set correctly, either an excessive force or an oversized burr can occur:

![Effect of clearance: (Left) clearance too small causes less than optimal fracture and excessive forces, and (Right) clearance too large causes oversized burr](image)

The calculated clearance value must be subtracted from the die punch diameter for blanking operations or must be added to die hole diameter for punching:

![Die diameter is enlarged with clearance $c$ in punching. In blanking, the punch diameter is decreased to account for clearance. $D$ is the nominal size of the final product.](image)

An angular clearance must be provided for the die hole to allow parts to drop through it:

![Angular clearance for the die opening in punching and blanking.](image)

Cutting forces

Cutting force in all shearing operations is determined by

$$F = StL$$

where $S$ is the shear strength of material, $L$ is the length of the cut edge. For approximate solutions,

$$S = 0.7UTS$$
Tools and dies for cutting operations

Simple dies

When the die is designed to perform a single operation (for example, cutting, blanking, or punching) with each stroke of the press, it is referred to as a simple die.

Multi-operational dies

More complicated pressworking dies include:

- compound die to perform two or more operations at a single position of the metal strip
- progressive die to perform two or more operations at two or more positions of the metal strip

[Diagrams of simple and multi-operational dies]
Bending operations

Processes

Bending is defined as the straining of the sheet metal around a straight edge:

Bending operations involve the processes of \textit{V-bending} and \textit{edge bending}:

\begin{itemize}
  \item \textit{V-bending}—sheet metal is bent along a straight line between a V-shape punch and die.
  \item \textit{Edge bending}—bending of the cantilever part of the sheet around the die edge.
\end{itemize}

Bend allowance

This is the stretching length that occurs during bending. It must be accounted to determine the length of the blank,

\[ L_b = \sum L + \sum BA \]

where \( L_b \) is the length of the blank, \( L \) are the lengths of the straight parts of the blank, \( BA \) is the bend allowance,

\[ BA = 2\pi \frac{A}{360} (R + K_{ba} t) \]

where \( A \) is the bend angle; \( t \) is the sheet thickness; \( R \) is the bend radius; \( K_{ba} \) is a factor to estimate stretching, defined as follows:

\[ \begin{align*}
  & \text{for } R < 2t & K_{ba} = 0.33 \\
  & \text{for } R \geq 2t & K_{ba} = 0.50
\end{align*} \]
Springback

Springback is the elastic recovery leading to the increase of the included angle when the bending pressure is removed.

To compensate for springback two methods are commonly used:

1. **Overbending**—the punch angle and radius are smaller than the final ones.
2. **Bottoming**—squeezing the part at the end of the stroke.

Bending forces

The maximum bending force is estimated as

\[ F = \frac{K_{bf} \cdot \text{UTS} \cdot w^2}{D} \]

where \( K_{bf} \) is the constant that depends on the process, \( K_{bf} = 1.33 \) for V-bending and \( K_{bf} = 0.33 \) for edge bending; \( w \) is the width of bending; \( D \) is the die opening dimension as shown in the figure:

Equipment for bending operations
**Deep drawing**

**Definition**

Deep drawing is a sheet-metal operation to make hollow-shaped parts from a sheet blank:

![Diagram of deep drawing process](image)

- **Clearance**
  
  Clearance $c$ is the distance between the punch and die and is about 10% greater than the stock thickness:
  
  $$c = 1.1t$$

- **Holding force**
  
  The improper application of the holding force can cause severe defects in the drawn parts such as (a) flange wrinkling or (b) wall wrinkling if the holding force is too small, and (c) tearing if the folding force is overestimated.

- **Measures of drawing**

  Two measures of the severity of a deep drawing operation are used,

  1. **Drawing ratio** $DR$ defined as
     
     $$DR = \frac{D_b}{D_p}$$
     
     Here $D_b$ is the blank diameter and $D_p$ is the punch diameter. $DR$ must be less than 2.0 for a feasible operation. If it is more than 2.0, the progressive deep drawing is applied (left).

  2. **Thickness-to-diameter ratio** $t/D_b$

     It is desirable to be greater than 1% to avoid wrinkling.

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Blanked and drawn parts showing progression of drawing operation
Drawing forces

The drawing force $F$ required to perform a deep drawing operation is estimated roughly by the formula

$$F = \pi t D_p UTS (DR - 0.7)$$

The holding force $F_h$ is defined as

$$F_h = 0.015 Y \pi [D_b^2 - (D_p + 2.2t + 2R_d)^2]$$

where $Y$ is the yield strength of the material.

Blank size determination

The blank diameter can be calculated by setting the initial blank volume equal to the final volume of the part and solving for diameter $D_b$.

**Other sheet-metal forming operations**

The Guerin process

The Guerin process involves the use of a thick rubber pad to form sheet metal over a positive form block:

Examples of equipment and products manufactured by the Guerin process:

*Advantages:* small cost of tooling

*Limitations:* for relatively shallow shapes

*Area of application:* small-quantity production
Hydroforming

It is similar to Guerin process but instead of rubber pad a rubber diaphragm filled with fluid is used:

Advantages:  
- small cost of tooling

Limitations:  
- simple shapes

Area of application:  
- small-quantity production

Stretch forming

In stretch forming the sheet metal is stretched and bent to achieve the desired shape:

Advantages:  
- small cost of tooling, large parts

Limitations:  
- simple shapes

Area of application:  
- small-quantity production

Spinning

Spinning is a metal forming process in which an axially symmetric part is gradually shaped over a mandrel by means of a rounded tool or roller:

Advantages:  
- small cost of tooling, large parts (up to 5 m or more)

Limitations:  
- only axially symmetric parts

Area of application:  
- small-quantity production
**High-energy-rate Forming (HERF)**

These are metal forming processes in which a large amount of energy is applied in a very short time. Some of the most important HERF operations include:

**Explosive forming**

It involves the use of an explosive charge placed in water to form sheet into the die cavity.

1. **Explosive forming:** (1) set-up, (2) explosive is detonated, and (3) shock wave forms part

Explosively formed elliptical dome 3-m in diameter being removed from the forming die

**Advantages:**
- small cost of tooling, large parts

**Limitations:**
- skilled and experienced labor

**Area of application:**
- large parts typical of the aerospace industry

**Electrohydraulic forming**

This is a HERF process in which a shock wave to deform the work into a die cavity is generated by the discharge of electrical energy between two electrodes submerged in water. Similar to explosive forming, but applied only to small part sizes.

Setup of electrohydraulic forming
Electromagnetic forming

The sheet metal is deformed by the mechanical force of an electromagnetic field induced in the workpiece by a coil:

![Diagram](image)

Electromagnetic forming: (1) set-up in which coil is inserted into tubular workpiece surrounded by die, (2) formed part

**Advantages:** can produce shapes, which cannot be produced easily by the other processes

**Limitations:** suitable for magnetic materials

**Area of application:** most widely used HERF process to form tubular parts