Off-center loading in sheet metal forming operations, Part I
Stamping using a single die set

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Editor’s Note: This is Part I of a two-part article. Part II will include a case study on predicting off-center loading in multiple operations in a transfer die.

Off-center loading occurs when the center of the forming load deviates from the press center, leading to a net moment that can produce elastic deflections on the press (see Figure 1) and horizontal forces on the press and tool guides. When this happens, die set tolerances might vary, which can be critical, especially in trimming, blanking, and piercing operations. Small elastic deflections of the press can go unnoticed on the shop floor during day-to-day operations, but they cause increased press and die wear and maintenance, leading to decreased part quality and more downtime.

In addition, as the center of load deviates from the press center (see Figure 2), the effective press capacity decreases, which sometimes can cause the available force to be insufficient for forming operations.

For these reasons, it’s important to predict off-center loading accurately.

Off-center Loading Compensation
Three methods used to compensate for off-center loading are (see Figure 3):

1. Shifting the die on the press bolster—If there is space available in the press to move the die, this method can cause the center of loading due to deformation to coincide with the press center, which reduces the net moment on the press.

2. Introducing an artificial load—The applied artificial load produces a moment that acts opposite to the moment produced by off-center loading. One way to apply an artificial load is to use nitrogen cylinders. Like the first method, this one requires available space in the press.

3. Stepping punches—This method is effective for a die with multiple punching operations or for a transfer or progressive die. It allows the load to be distributed over the entire stroke so that the center of the load at any ram position will coincide with the press center.

Case Study: Single Die

The aim of this case study was to develop a methodology for predicting the off-center loading in a single die using commercially available finite element (FE) software (in this case, PAMSTAMP). It used a drawn part made of 1.2-mm Al 5182-O that emulated an inner door panel.

The total forming stroke was 156 mm (assuming no fracture of material), and a constant blank holder force of 500 kN was applied throughout the stroke.

Because of the part’s asymmetry, the center of loading (location of the net forming force) shifted within the stroke. Therefore, the net moment on the press (trying to tilt the press bolster) also changed with the press stroke.

Researchers used the following methodology to predict the off-center loading:

1. Divide the die into four sections (see Figure 4a). The accuracy of off-center loading increased with an increasing number of sections, used for calculations.

2. Calculate the forming load versus stroke curve for each section of the die (see Figure 4b) For a pre-existing die, the forces could also be measured during tryouts by installing load sensors in the columns of the press (known distance

Figure 1
This schematic representation shows elastic deflection in a press due to net moment caused by off-center loading. Courtesy of AIDA Tech.

Figure 2
This diagram shows allowable off-center loading for a Komatsu press. Courtesy of D. Zhou.
from the press center). The differences (unbalances) in load at each section of the die created a net moment in the press.

3. Assume the center of load for each die section ($F_{UL}$, $F_{LR}$, $F_{UR}$, and $F_{LL}$) to be at its geometrical center. To calculate the variation of the location of off-center load with stroke, they obtained this location for each ram position (see Figure 5) using the following formulas:

Considering:

\[
\Delta_{L,\text{off}} = \frac{M_y}{F_z}, \quad \Delta_{A,\text{off}} = \frac{M_x}{F_z}
\]

Off-center load distance along transverse direction

\[
\Delta_{L,\text{off}} = \frac{1}{2}(F_{UL} + F_{LR} - F_{UR} - F_{LL})
\]

Off-center load distance along feeding direction

\[
\Delta_{A,\text{off}} = \frac{W(F_{UL} + F_{LR} - F_{UR} - F_{LL})}{2(F_{UL} + F_{LR} + F_{UL} + F_{LL})}
\]

Where:

- $\Delta_{L,\text{off}}$ = Off-center loading distance along transverse direction
- $M_y$ = Moment (caused by off-center loading) about transverse direction
- $F_z$ = Net/total load (perpendicular to the die surface or press bed)
- $\Delta_{A,\text{off}}$ = Off-center loading distance along feeding direction
- $M_x$ = Moment (caused by off-center loading) about feeding direction
- L/2 = Distance of each die section force from press center in transverse direction
- W/2 = Distance of each die section force from press center in feeding direction

As the location of off-center load changes with the stroke (see Figure 6), the net moment (due to off-center loading) on the press can be minimized but not eliminated.

4. Shift the die in the press so that the press center coincides with the coordinates of the maximum moment (see Figure 6).

In this case study, the maximum moment about the X axis decreased at least 50 percent after forming the part with the die adjusted in the press. While other methods can be used to compensate for off-center loading, the method used depends on the press restrictions, such as space availability and loading capacity.

Steps 1 through 3 of this methodology have been integrated into AutoForm R8 2019 software. This software provides variation of net force on the die and its location with respect to ram stroke, which the researchers used for the simulations to be discussed in Part II of this article.

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Reference:


Figure 3

Different methods for off-center loading compensation. Courtesy of D. Boerger.

Figure 4

Shown here are forming load versus ram stroke curve for each section of the die, where UL = upper left, UR = upper right, LL = lower left, and LR = lower right.

Figure 5

This diagram shows the off-center location with respect to press center.

Figure 6

As the location of off-center load changes with the ram stroke, the net moment on the press can be minimized but not eliminated.