

# Design Challenge

Yi-Chen Chen

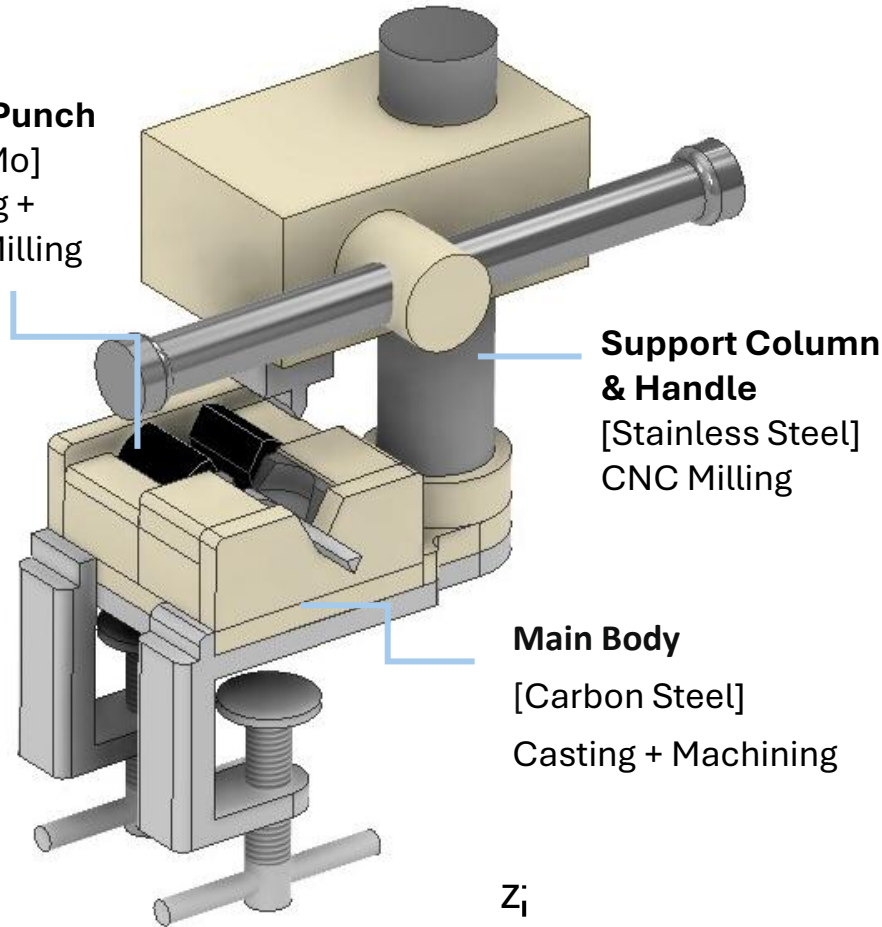
Mechanical Engineering Graduate Student  
Georgia Institute of Technology

## Outline:

- Key Components and Specifications
- Bending Process Steps
- Force Calculation
- Additional Design Considerations
- Design Risks and Potential Mitigation
- Assembly Sequence
- Conclusion

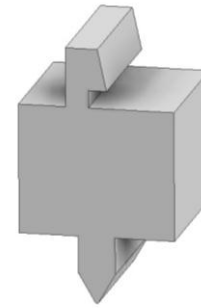
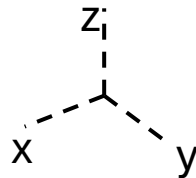
# Key Components and Specifications

**Die & Punch**  
[42CrMo]  
Forging +  
CNC Milling

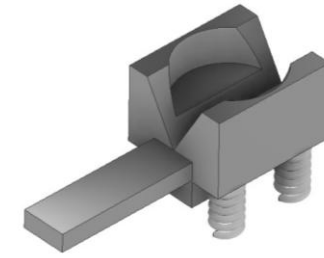


**Support Column  
& Handle**  
[Stainless Steel]  
CNC Milling

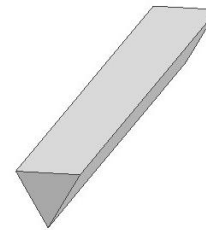
**Main Body**  
[Carbon Steel]  
Casting + Machining



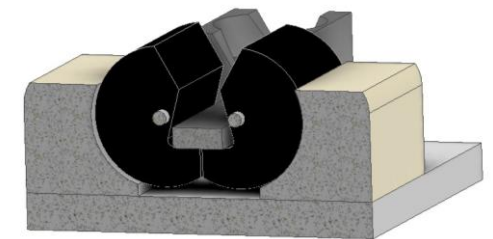
**Punch**  
24.9mm\*25mm\*41.3mm  
Tip Radius: 0.25mm  
V-Angle: 60°  
The wide rectangular structure prevents the tip from directly contacting the V-groove.



**V-Die**  
26mm\*65.4mm\*25mm  
Slot Diameter: 24.3mm  
Slot Depth: 13.8mm  
Opening Width: 10mm  
V-Groove Angle: 60°  
The extended rod applies pressure to the rotary V-die to initiate its rotation.

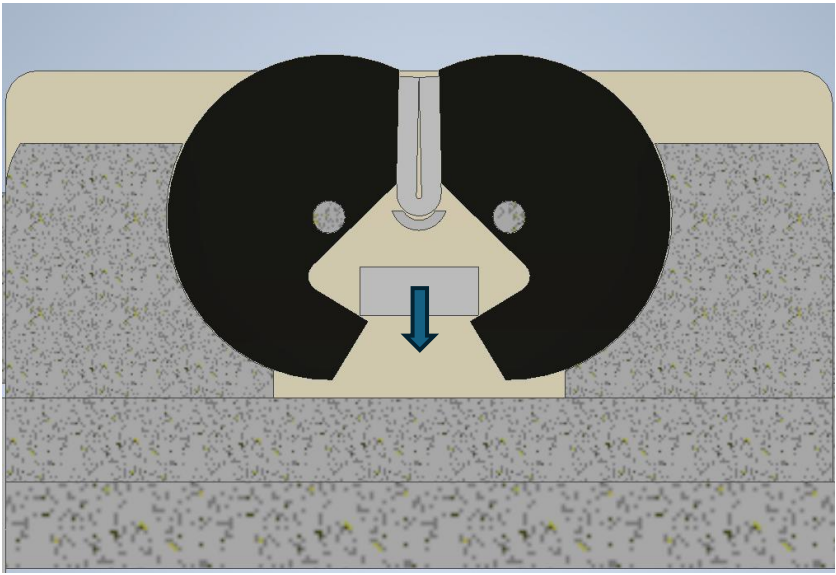
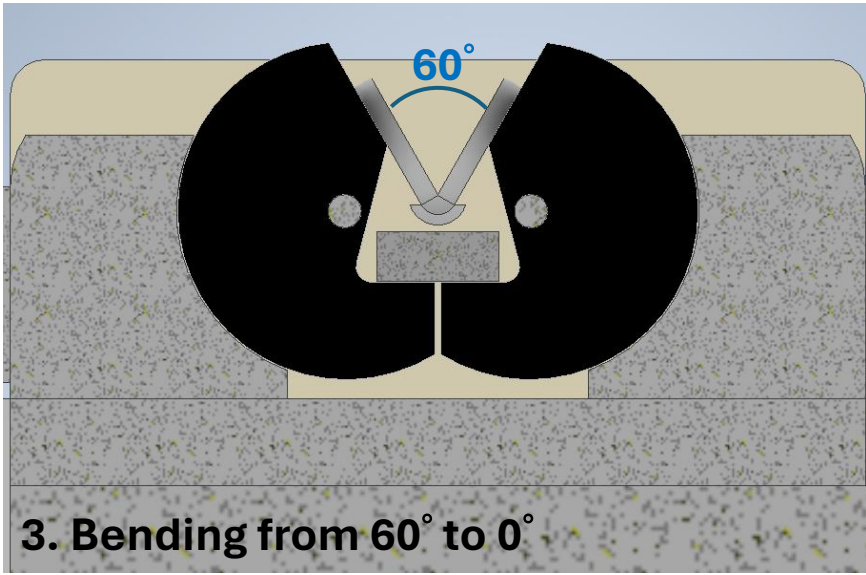
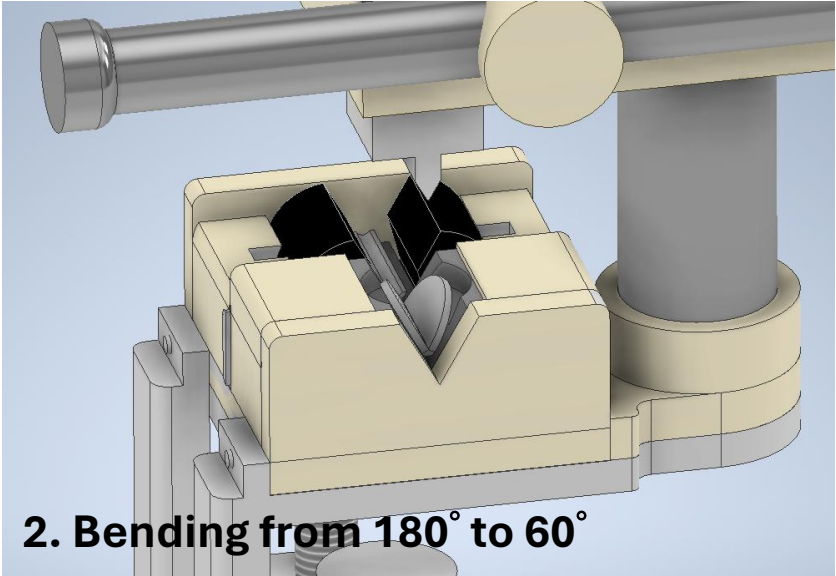
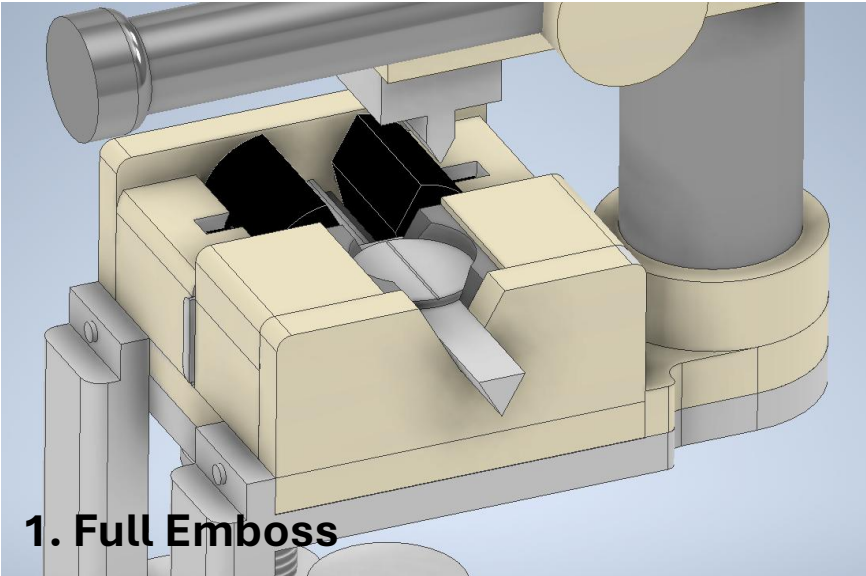


**Triangular Rod**  
10mm\*25mm\*8.7mm  
Fill up the V-groove to assist  
embossing



**Rotary V-Die**  
76.6mm\*37mm\*31.8mm  
Rotary Radius: 15mm  
V-Angle: 60°  
Fold the coin completely in half,  
ensuring proper alignment.

# Bending Process Steps



# Force Calculation

Cu-Ni 75-25 Properties	
Diameter (D)	24.26 (mm)
Initial Thickness (Th <sub>i</sub> )	1.75 (mm)
Final Thickness (Th <sub>f</sub> )	1.575 (mm)
Yield Stress (Y)	103 (MPa)
Inner Radius (r <sub>i</sub> )	0.25 (mm)
Elastic Modulus (E)	125,000 (MPa)

## Process:

- Full Emboss
- Bending from 180° to 60°
- Bending from 60° to 0°.

## Full Emboss

$$F_{emboss} = 2 * r_i * D * Y = 1249.39 (N)$$

$$F_{punch1} = F_{emboss}$$

After embossing, it will help concentrate stress.

The depth is set as 10% of the thickness.

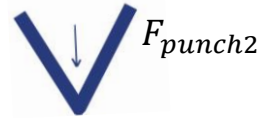


## V-Bending

$$F_V = k * Y * D * \frac{Th^2}{W} = 824.4 (N)$$

(k= 1.33 for V-die)

$$F_{punch2} = F_V$$



## Springback

$$\frac{R_i}{R_f} = 4 * \left( R_i * \frac{Y}{E * Th} \right)^3 - 3 * \left( R_i * \frac{Y}{E * Th} \right) + 1$$

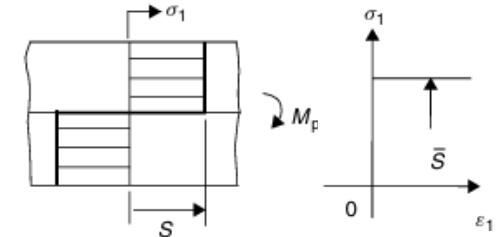
$$\alpha_f * \left( \left( \frac{2R_f}{Th} \right) + 1 \right) = \alpha_i * \left( \left( \frac{2R_i}{Th} \right) + 1 \right)$$

(Anderla, 2011)

Initial bend radius (R <sub>i</sub> )	0.249 (mm)
Final radius (R <sub>f</sub> )	0.2491 (mm)
Initial angle (α <sub>i</sub> )	180°
Final angle (α <sub>f</sub> )	179.98°

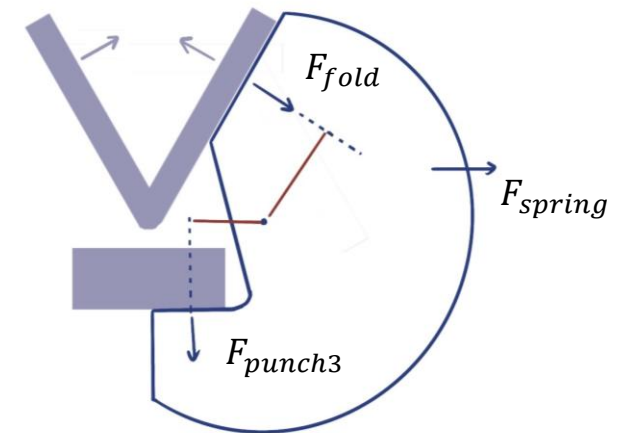
According to the requirements, the included angle can be within 5 degrees. Verified using the springback formula, the springback effect is minimal, so bending to 180° is sufficient.

## Half-Folding



(Z. Marciniak, 2002)

Ideally, if the embossed and bent area has undergone complete plastic deformation, the stress is no longer affected by strain. At this point, it is only necessary to ensure that the applied force exceeds the yield stress.



# Embossing Force Calculation

Cu-Ni 75-25 Properties	
Diameter (D)	24.26 (mm)
Initial Thickness (Th <sub>i</sub> )	1.75 (mm)
Final Thickness (Th <sub>f</sub> )	1.575 (mm)
Yield Stress (Y)	103 (MPa)
Inner Radius (ρ <sub>i</sub> )	0.25 (mm)
Elastic Modulus (E)	125,000 (MPa)

Process:

**-Full Emboss**

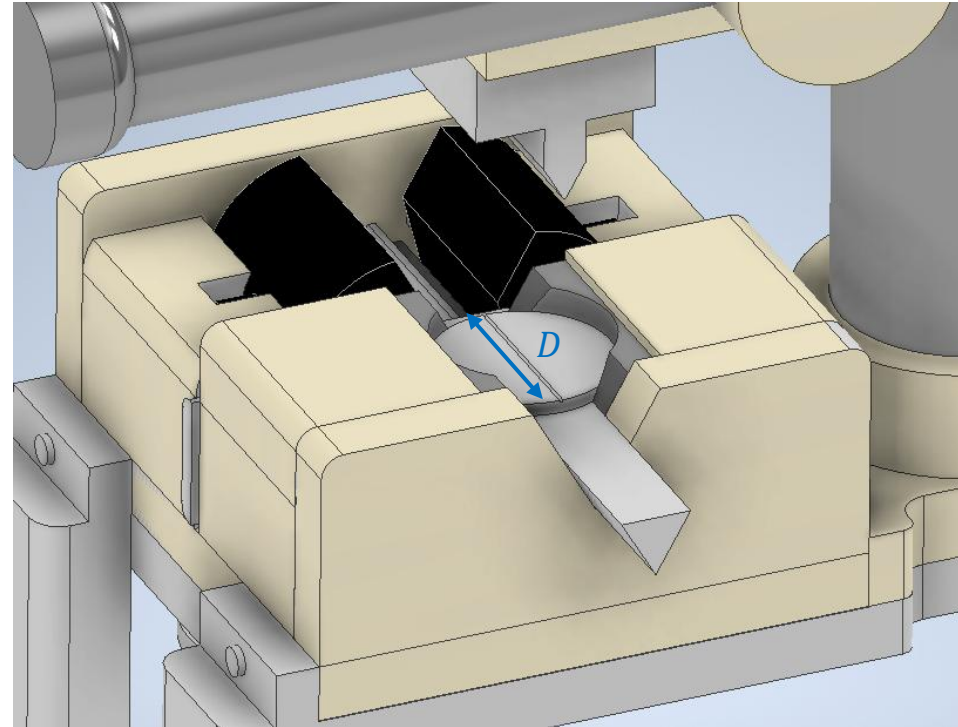
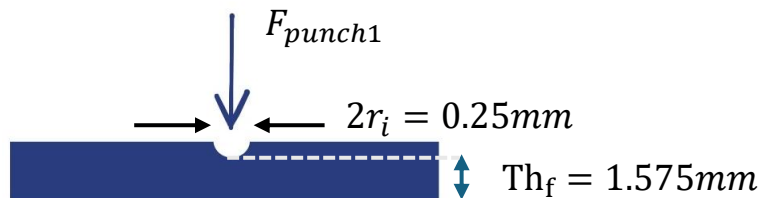
-Bending from 180° to 60°

-Bending from 60° to 0°.

$$F_{punch1} = 2 * r_i * D * Y$$

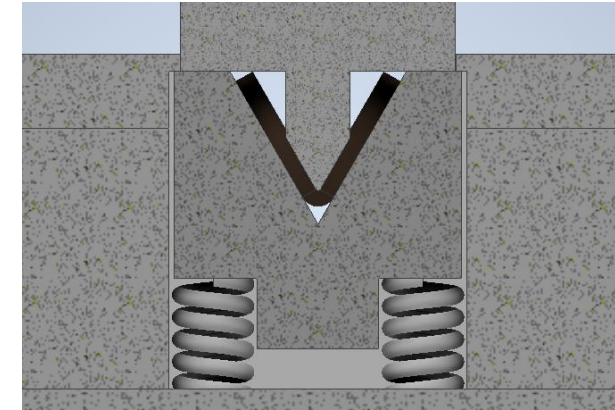
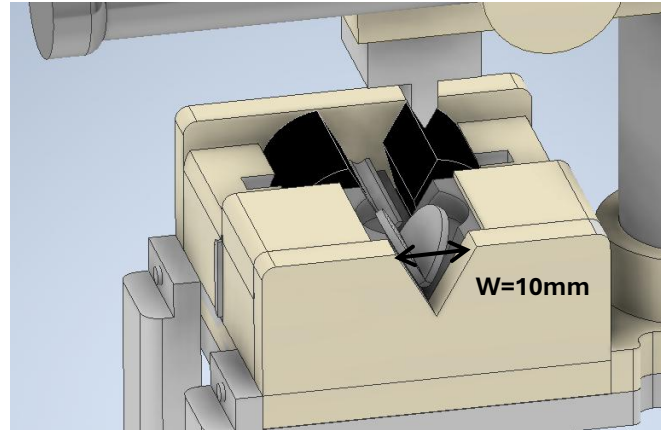
$$F_{punch1} = 1249.39 \text{ N}$$

Embossing concentrates stress.



# Bending Force Calculation

Cu-Ni 75-25 Properties	
Diameter (D)	24.26 (mm)
Initial Thickness (Th <sub>i</sub> )	1.75 (mm)
Final Thickness (Th <sub>f</sub> )	1.575 (mm)
Yield Stress (Y)	103 (MPa)
Inner Radius (ρ <sub>i</sub> )	0.25 (mm)
Elastic Modulus (E)	125,000 (MPa)



## Process:

-Full Emboss

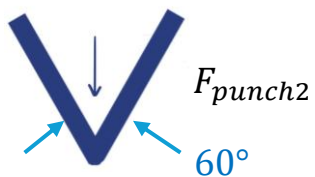
**-Bending from 180° to 60°**

-Bending from 60° to 0°.

$$F_{punch2} = k * Y * D * \frac{Th_f^2}{W}$$

(k= 1.33 for V-die)

$$F_{punch2} = 824.4N$$



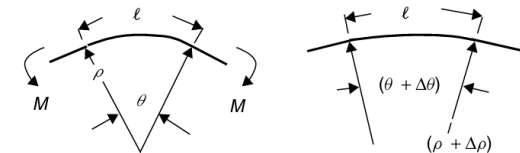
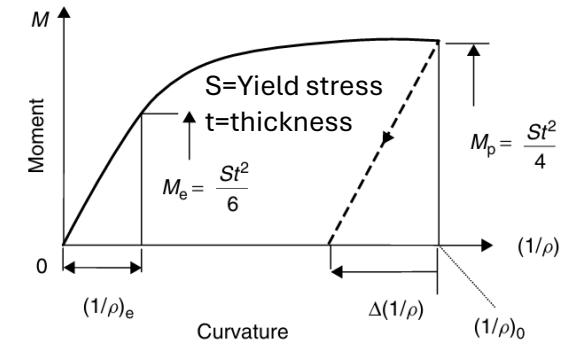
Limiting elastic radius ρ <sub>e</sub>	M <sub>e</sub> /IE
radius θ	120°
Limiting elastic moment M <sub>e</sub>	YTh <sub>f</sub> <sup>2</sup> /6
Fully plastic moment M <sub>p</sub>	YTh <sub>f</sub> <sup>2</sup> /4

$$\frac{\Delta(\frac{1}{\rho})}{(\frac{1}{\rho})_e} = \frac{-M_p}{M_e} = -\frac{3}{2}$$

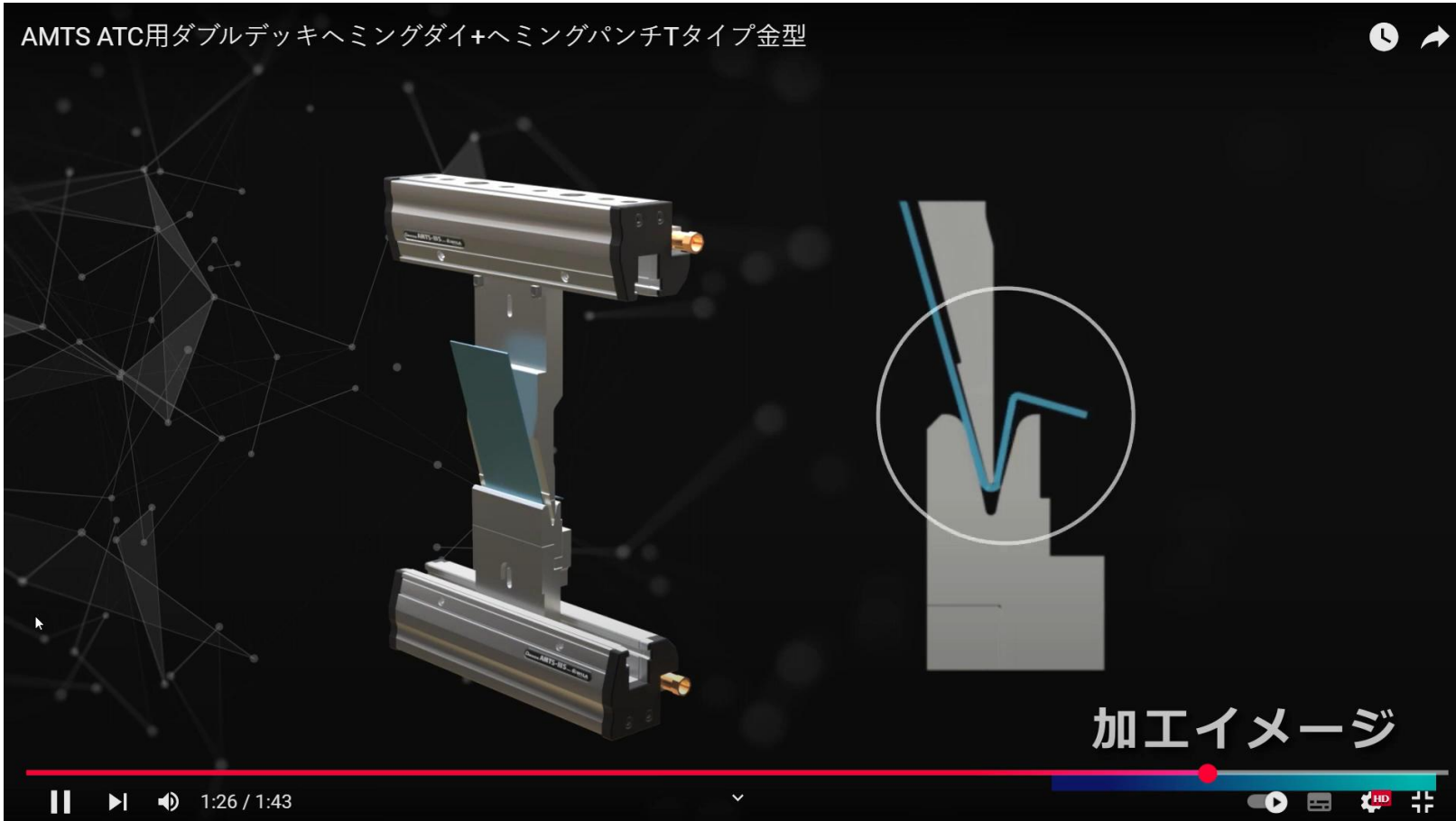
$$\Delta\left(\frac{1}{\rho}\right) = -\frac{3 M_e}{2 IE}$$

$$\rho\theta = (\rho + \Delta\rho)(\theta + \Delta\theta) = l$$

$$\Delta\theta = -1.38 * 10^{-7} \text{ rad}$$

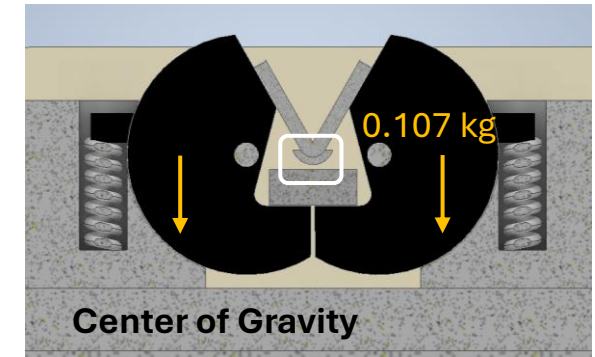
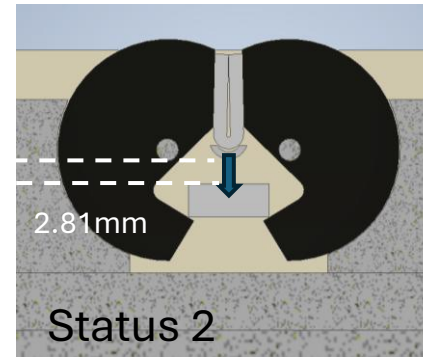
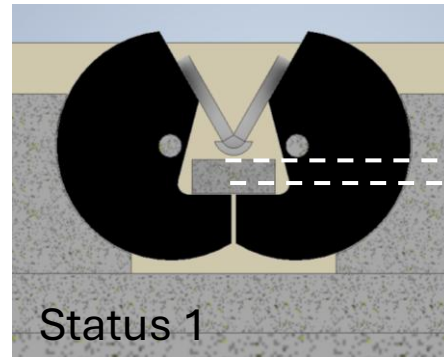


(Z. Marciniak, 2002)



# Bending Force Calculation

Cu-Ni 75-25 Properties	
Diameter (D)	24.26 (mm)
Initial Thickness (Th <sub>i</sub> )	1.75 (mm)
Final Thickness (Th <sub>f</sub> )	1.575 (mm)
Yield Stress (Y)	103 (MPa)
Inner Radius (ρ <sub>i</sub> )	0.25 (mm)
Elastic Modulus (E)	125,000 (MPa)

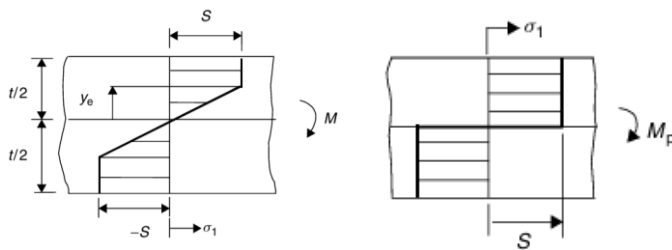


## Process:

-Full Emboss

-Bending from 180° to 60°

-Bending from 60° to 0°.



(Z. Marciniak, 2002)

$$M_p = \int \sigma y dA = \int_{-Th/2}^{Th/2} Y y D dy = Y * D * \frac{Th^2}{4}$$

$$M_p = F_{fold} * \frac{D}{4}$$

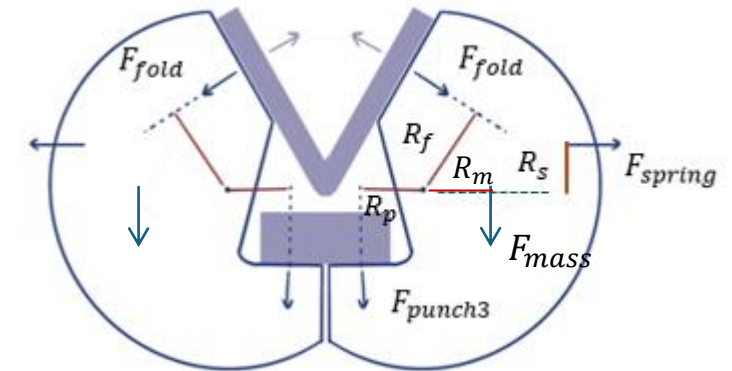
$$2 * F_{fold} = 255.5N$$

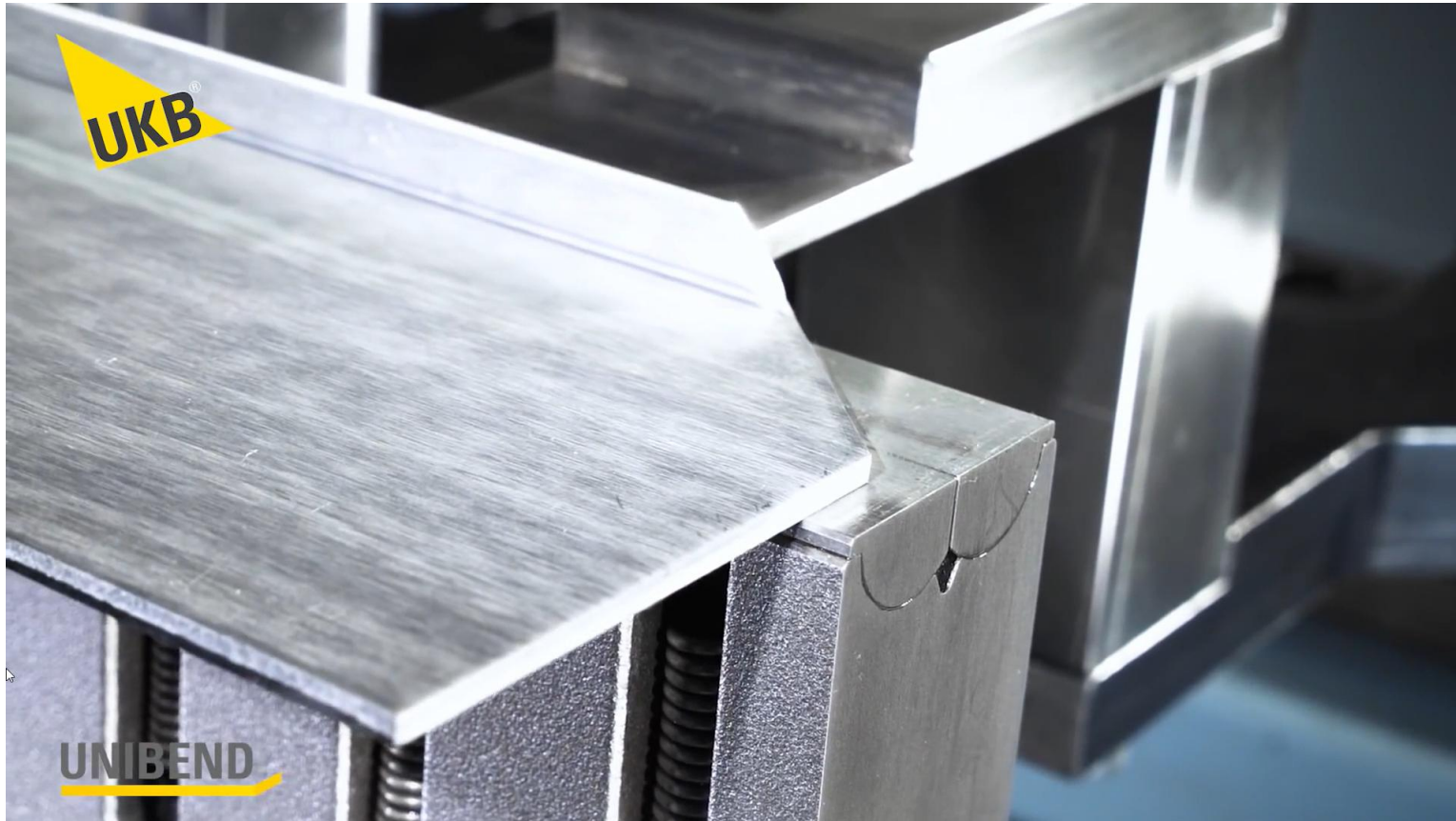
$$F_{punch3} * R_p = F_{fold} * R_f + F_{spring} * R_s + F_{mass} * R_m$$

(Assume the spring force and mass force are negligible.)

$$R_p = 5.6mm; R_f = 6.1mm$$

$$F_{punch3} = 139.2N$$

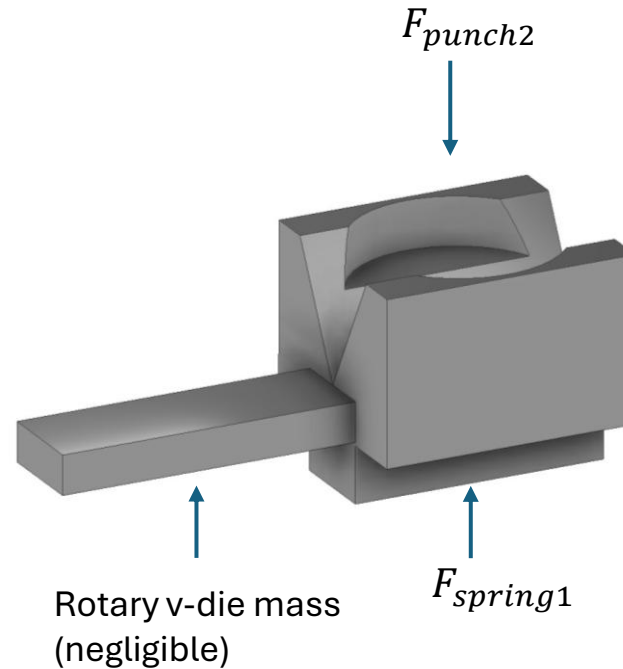




# Spring Force Calculation

- Material: spring steel
- Free length = 28.6 mm
- I.D.= 5.8 mm
- O.D. = 12.7 mm
- $K = 216 \text{ N/mm}$
- Load max = 466 N  
(reference: Farnell)

## Step 2: Bending from 180° to 60°



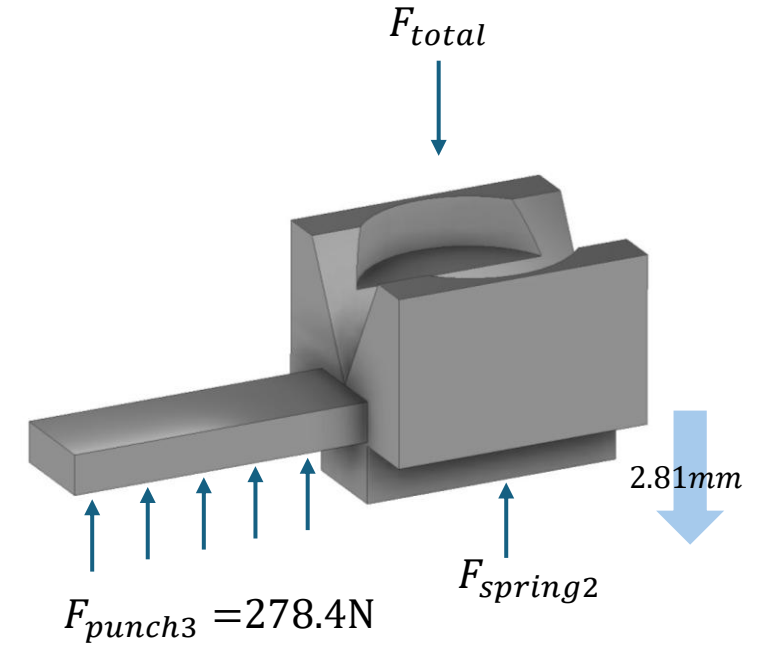
\*V-die mass = 0.112 kg (negligible)

$$F_{spring1} = F_{punch2} = 824.4 \text{ N}$$

$$F_{spring1} = 4 * k * displacement$$

$$displacement = 0.95 \text{ mm} < 2.81 \text{ mm}$$

## Step 3: Bending from 60° to 0°

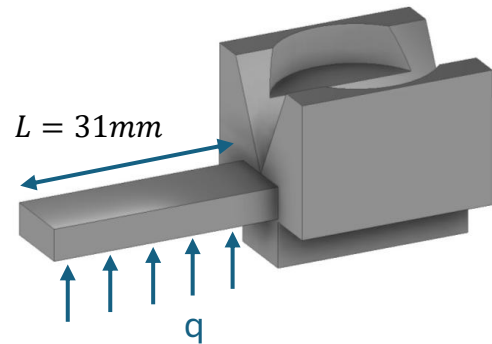


$$F_{spring2} = 4 * k * 2.81 = 2427.8 \text{ N}$$

$$F_{total} = F_{punch3} + F_{spring2} = 2706.2 \text{ N}$$

# Fatigue Life Calculation

42CrMo Properties	
Length (L)	31 (mm)
Thickness (t)	4.5 (mm)
Width (w)	11 (mm)
Yield Stress (Y)	1000 (MPa)
Elastic Modulus (E)	210,000 (MPa)

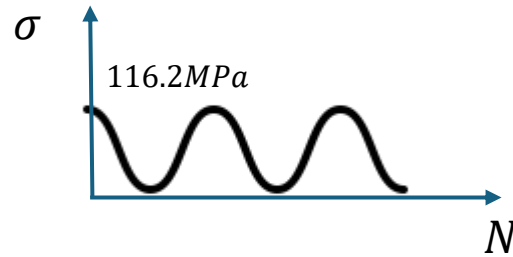


$$y = \frac{q \cdot L^4}{8 \cdot EI} = 0.059 \text{ mm}$$

$$q = 2F_{punch3} / L$$

$$2F_{punch3} \cdot \left(\frac{L}{2}\right) = M = \sigma \cdot \frac{I}{y}$$

$$\sigma \left(y = \frac{t}{2}\right) = 116.2 \text{ MPa}$$



Ultimate tensile strength  $S_{ut} = 1000 \text{ MPa}$

Estimated fatigue limit  $S_e' = 500 \text{ MPa}$

Surface condition modification factor

$$k_a = a \cdot S_{ut}^b = 0.28 \text{ (assume as-forged)}$$

$$S_e = k_a \cdot S_e' = 140.78 \text{ MPa}$$

(assume other modified factors = 1)

$$\sigma_a = 58.1 \text{ MPa}$$

$$\sigma_m = 58.1 \text{ MPa}$$

$$\sigma_{rev} = \frac{\sigma_a}{1 - \frac{\sigma_a}{S_{ut}}} = 61.68 \text{ MPa}$$

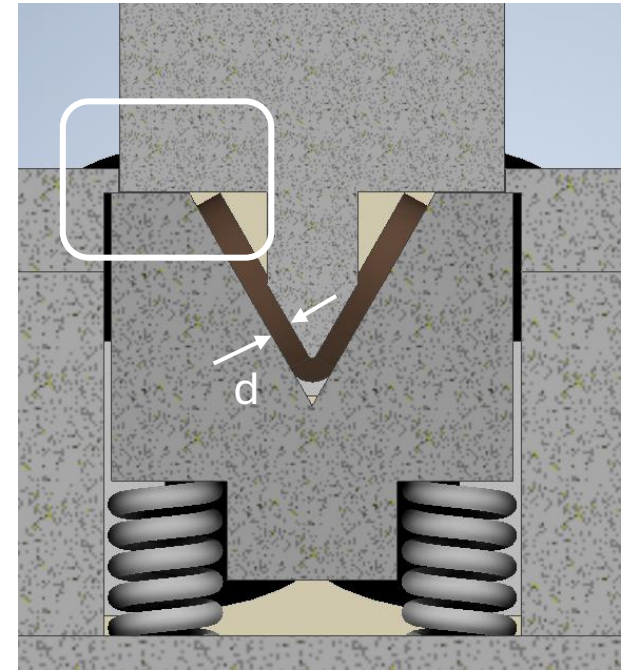
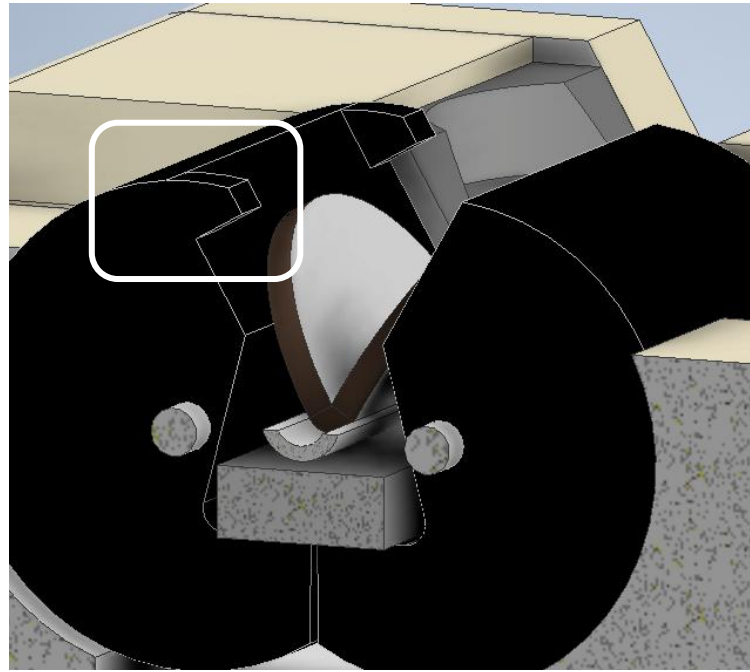
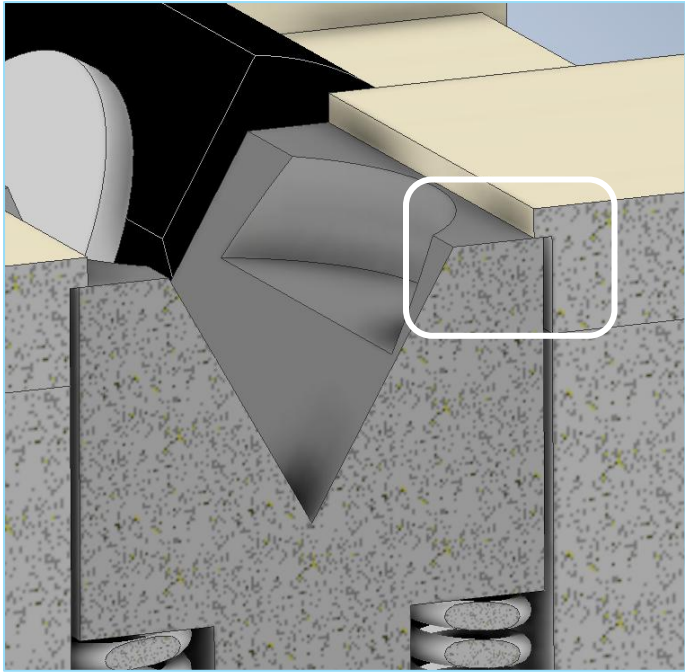
$$a = \frac{(f \cdot S_{ut})^2}{S_e} = 4776.2 \quad (f = 0.82)$$

$$b = -\frac{1}{3} \log \left( f \cdot \frac{S_{ut}}{S_e} \right) = -0.255$$

$$\sigma_{rev} = aN^b$$

$$N = 2.56e + 7$$

## Additional Design Considerations

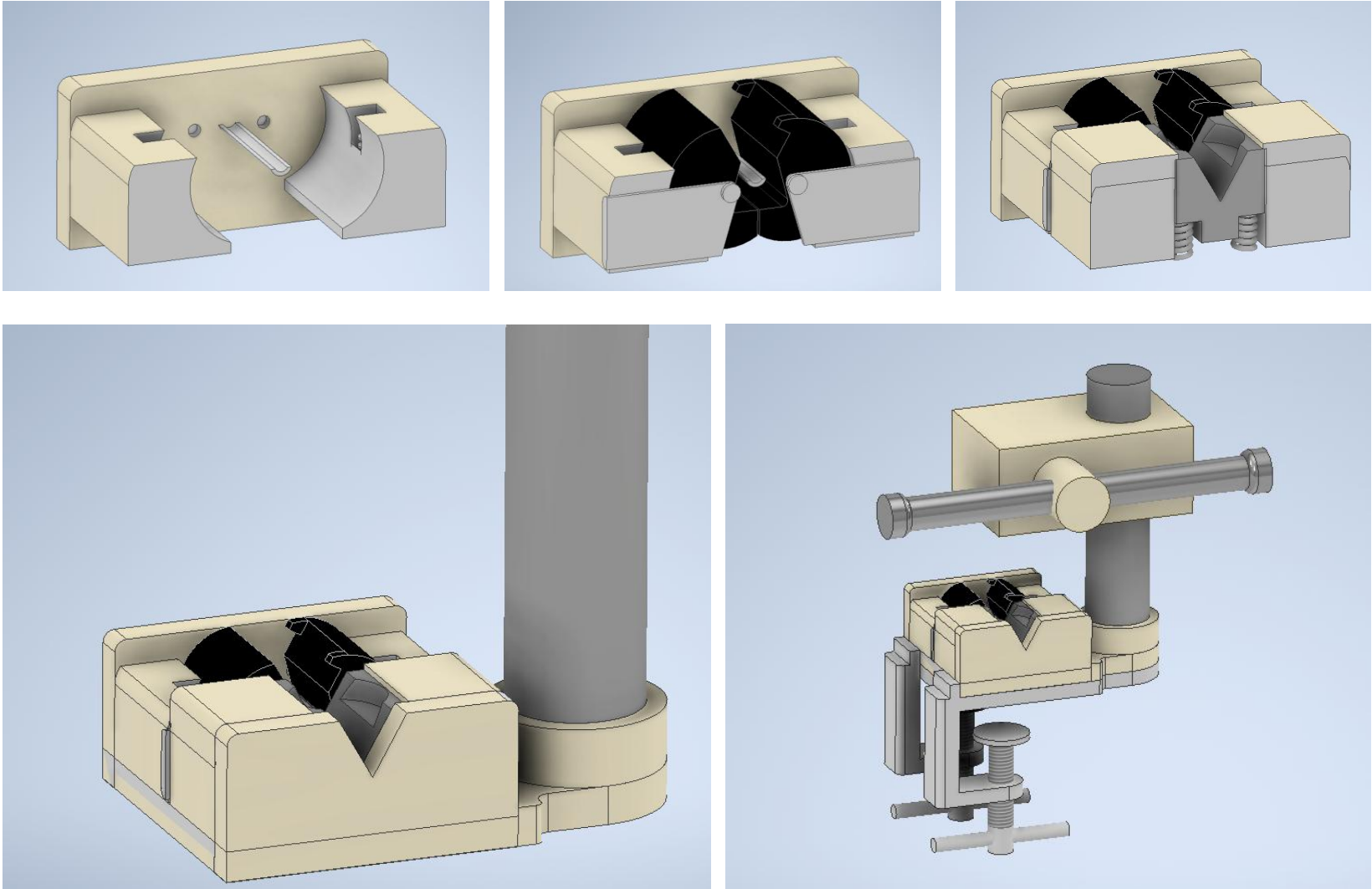


Space  $d <$  coin thickness

## Design Risks and Potential Mitigation

Crack in Coin	<b>Heat treatment</b> to increase tensile reduction of area before bending.
Spring failure due to fatigue loading	Determine service life through spring lifespan test and <b>replace periodically</b> .
High labor costs	Switch to an <b>electric hydraulic system</b> and replace the triangular rod with an electrically controlled mechanism. After the coin is bent to 60°, the rod extends again to push the coin into the rotary die. <a href="https://a.co/d/1EhARLP">https://a.co/d/1EhARLP</a>

# Assembly Sequence



## Conclusion

- The bending process consists of **three key steps** to achieve the desired deformation.
- The **maximum force required from the punch** is **2706.2 N**.
- The **estimated fatigue life** of the machine is  **$2.56 * 10^7$  cycles**.
- To **enhance efficiency and reduce manual labor**, integrating an **electric hydraulic system** is recommended.