Metal Forming – BSc 2025/26-1

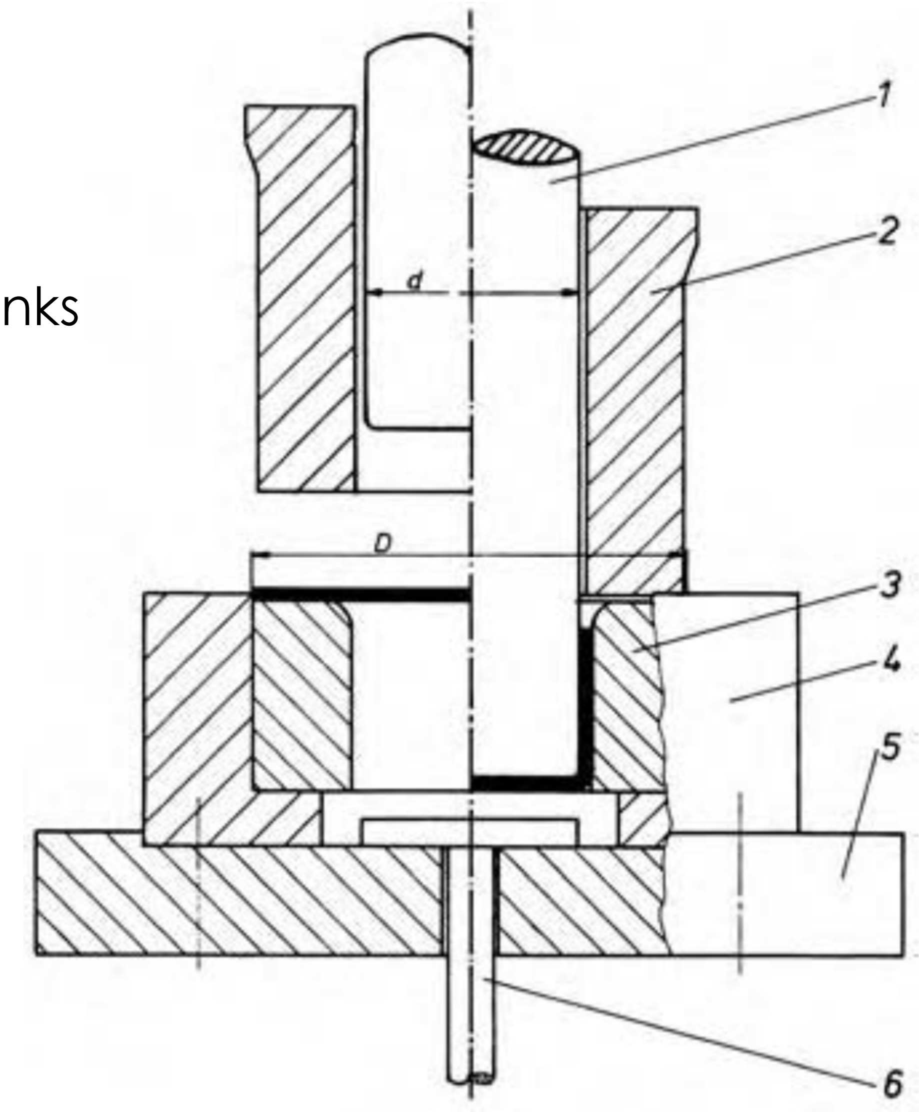
Sheet Metal Forming

Deep drawing

Introduction

Definition of sheet metal: the size in one direction is much smaller than in the other two.

Deep drawing is the forming of sheet blanks **into hollow parts**.

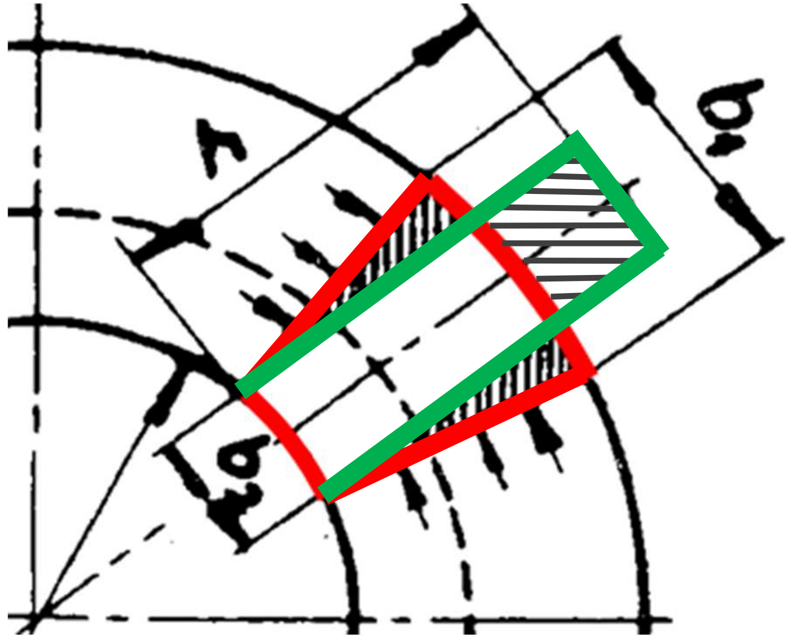


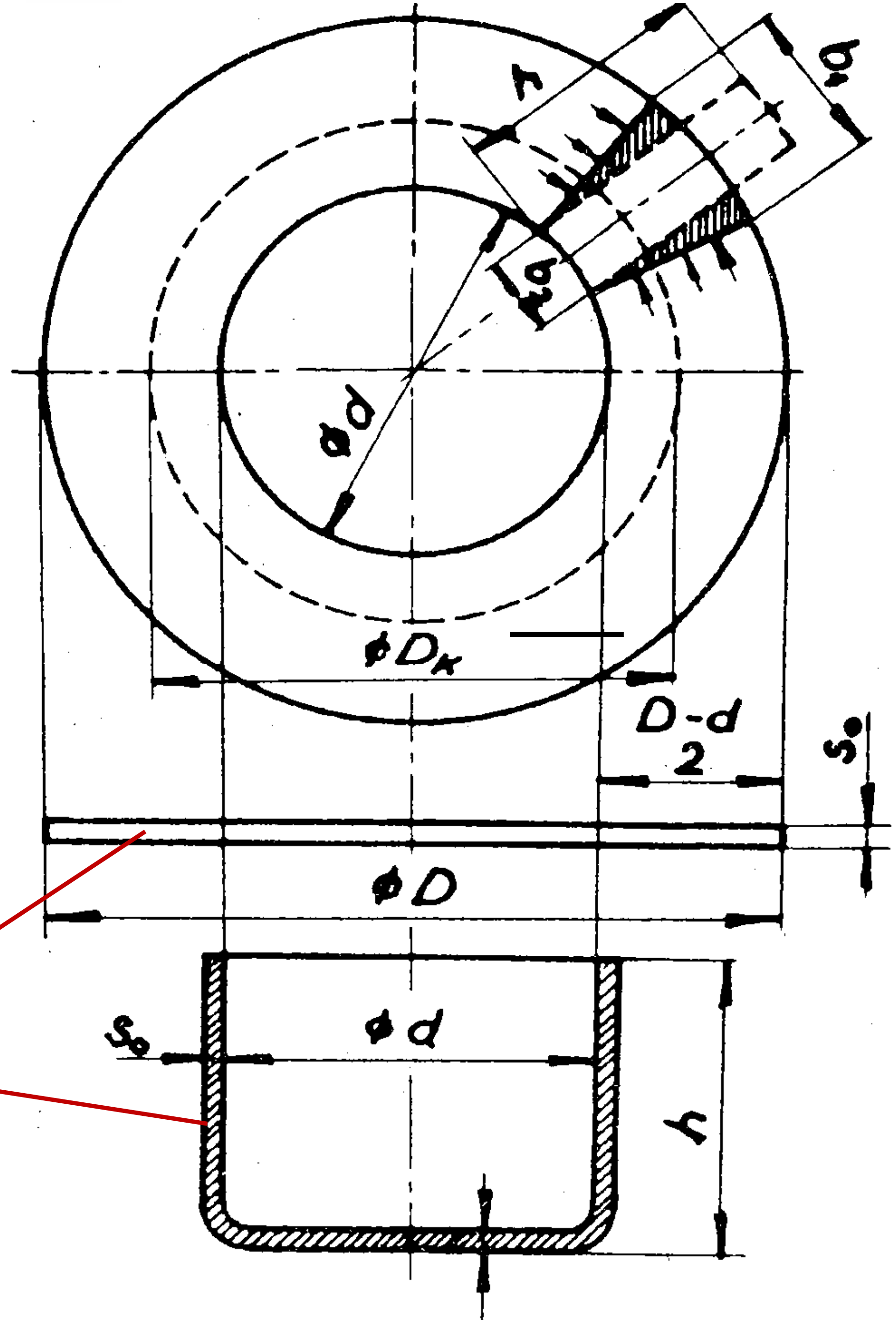
1 *drawing punch*
2 *blank holder*
3 *drawing ring*
4 *container*
5 *base plate*
6 *ejector*

Products

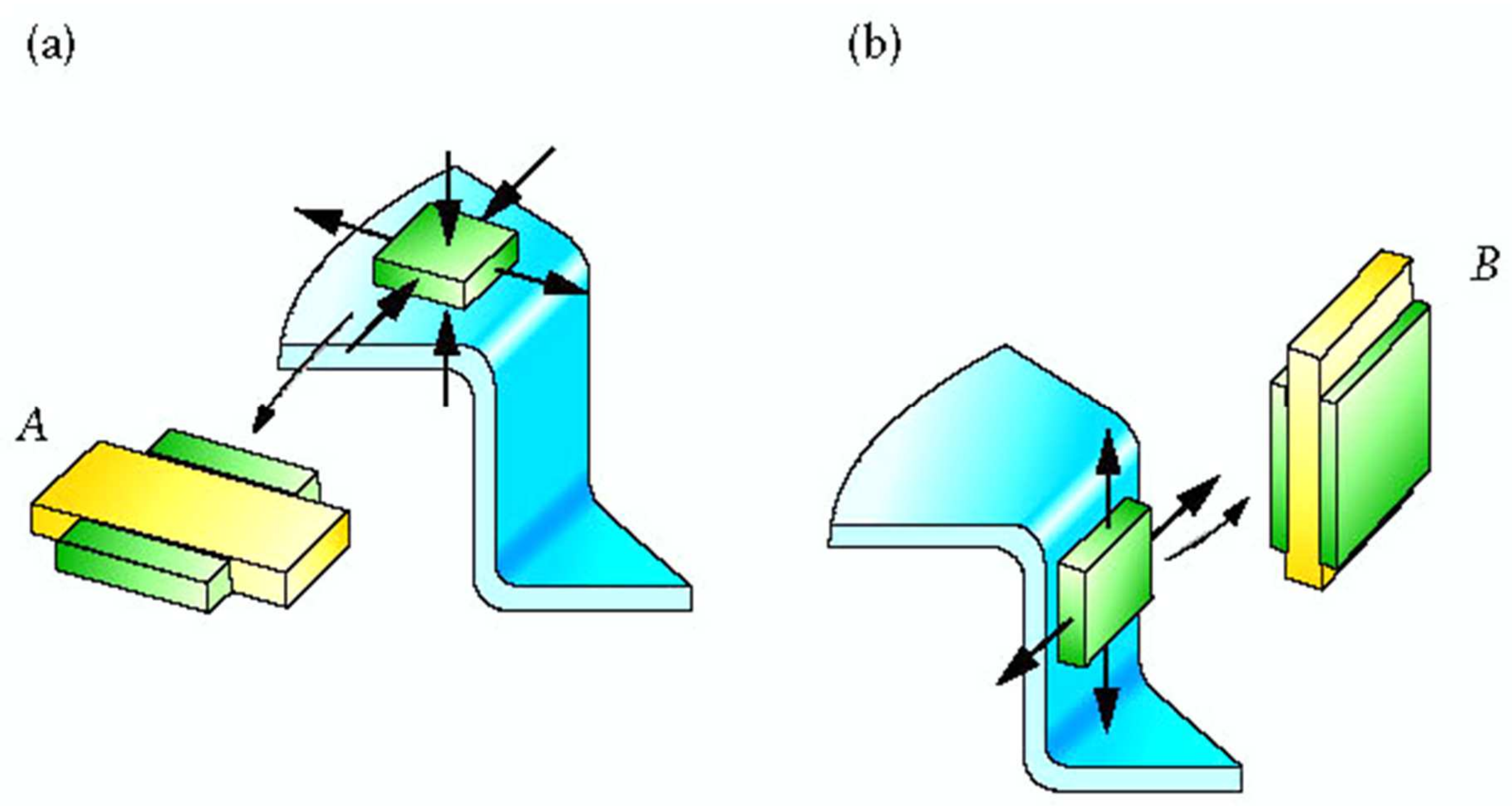
Deformation - stress

Role of tangential stress
(may cause wrinkling)



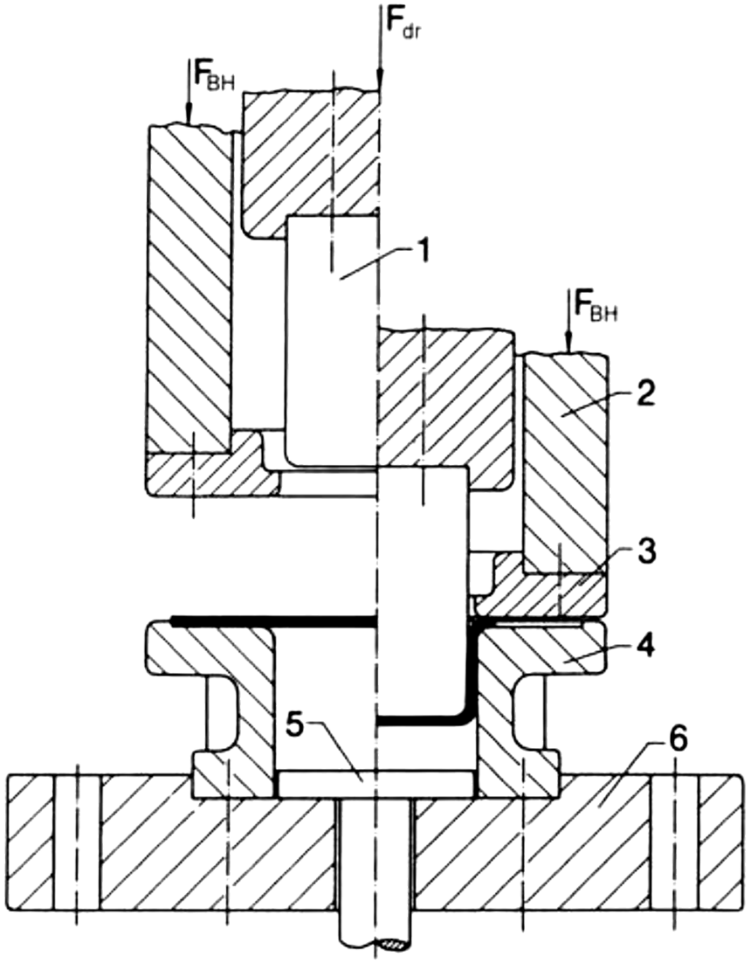


Deformation - stress



Complex inhomogeneous stress and strain state exists.

Role of blank holder

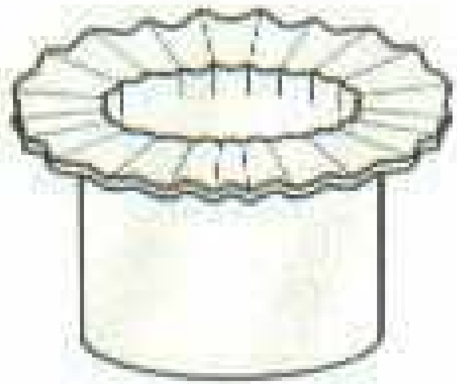


If D/s < 20 (thick sheet),
no blank holder is needed.

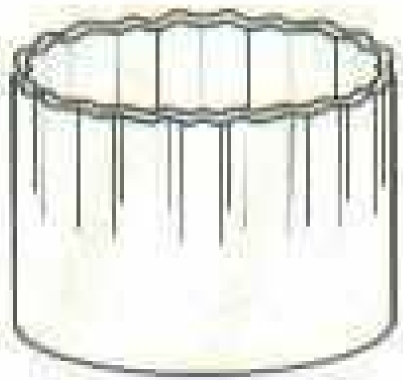
Too low blank holder pressure
→ wrinkling

Too high blank holder pressure
→ crack

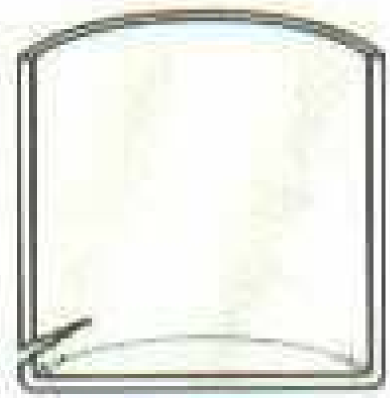
Defects



Wrinkling



Wall wrinkling

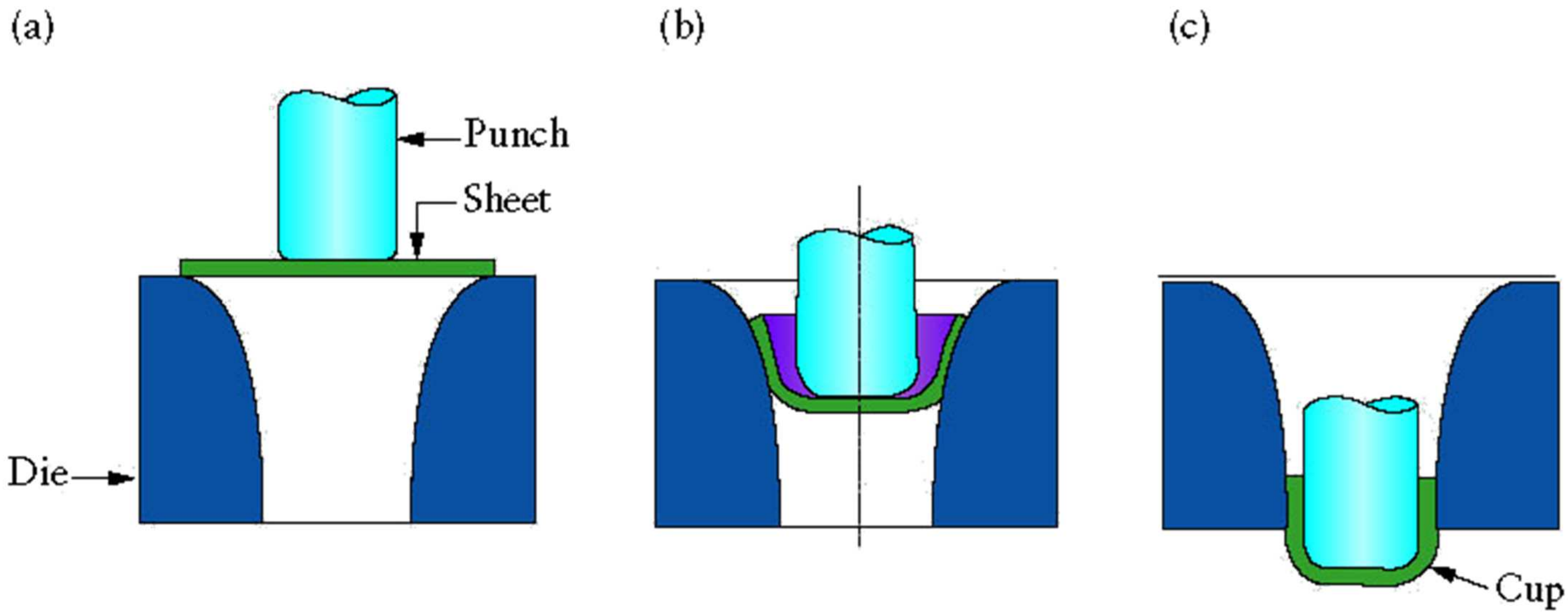


Crack

Earing

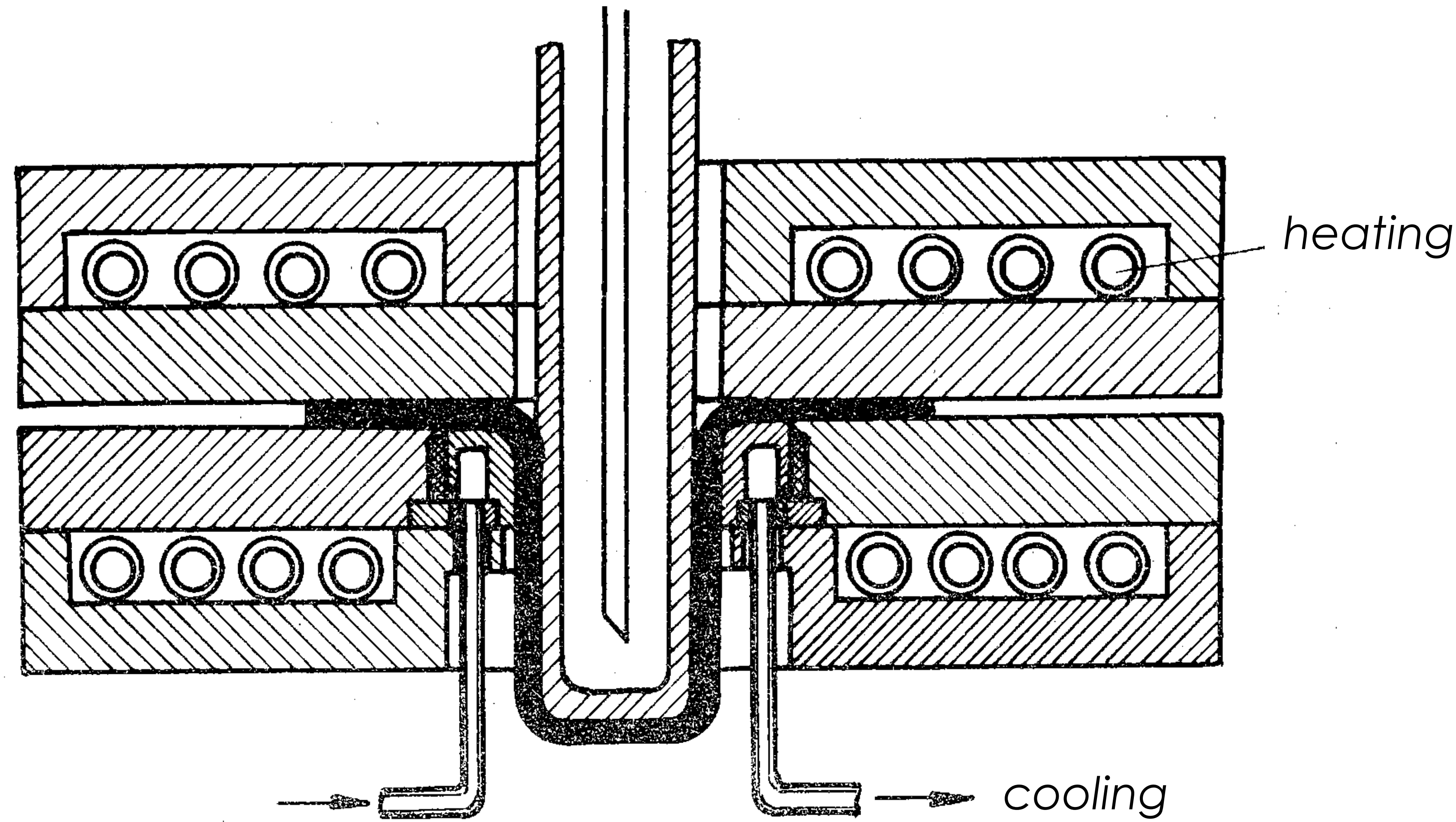
Deep drawing without blank holder

Deep drawing with **tractrix** curved die without blank holder:



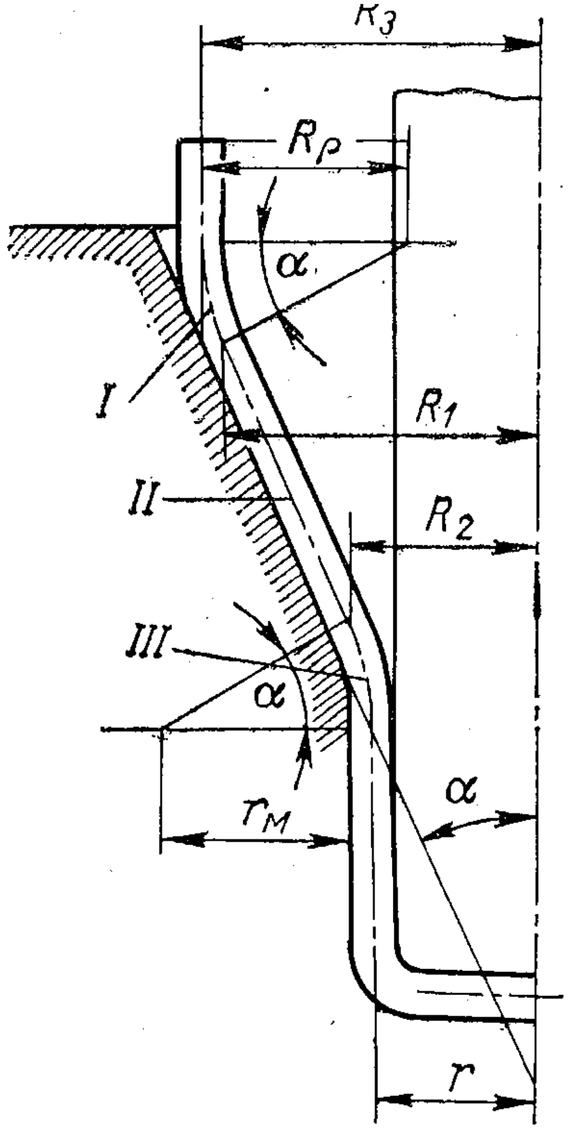
A tractrix is a curve for which the section of the tangent between the point of contact and the y-axis is constant.

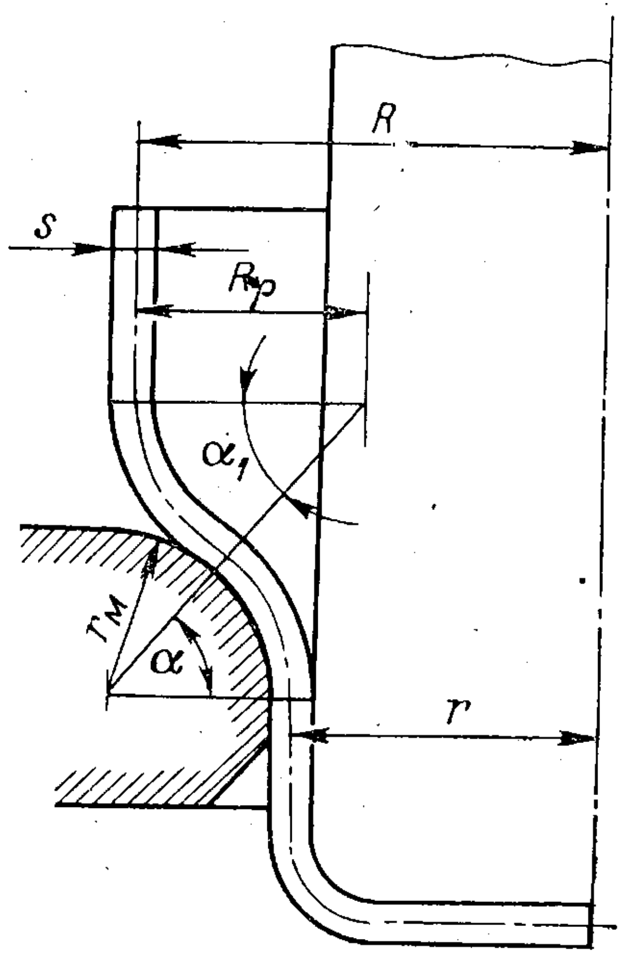
Deep drawing with heated die



For materials with **high strength** and/or with **low deep drawability**

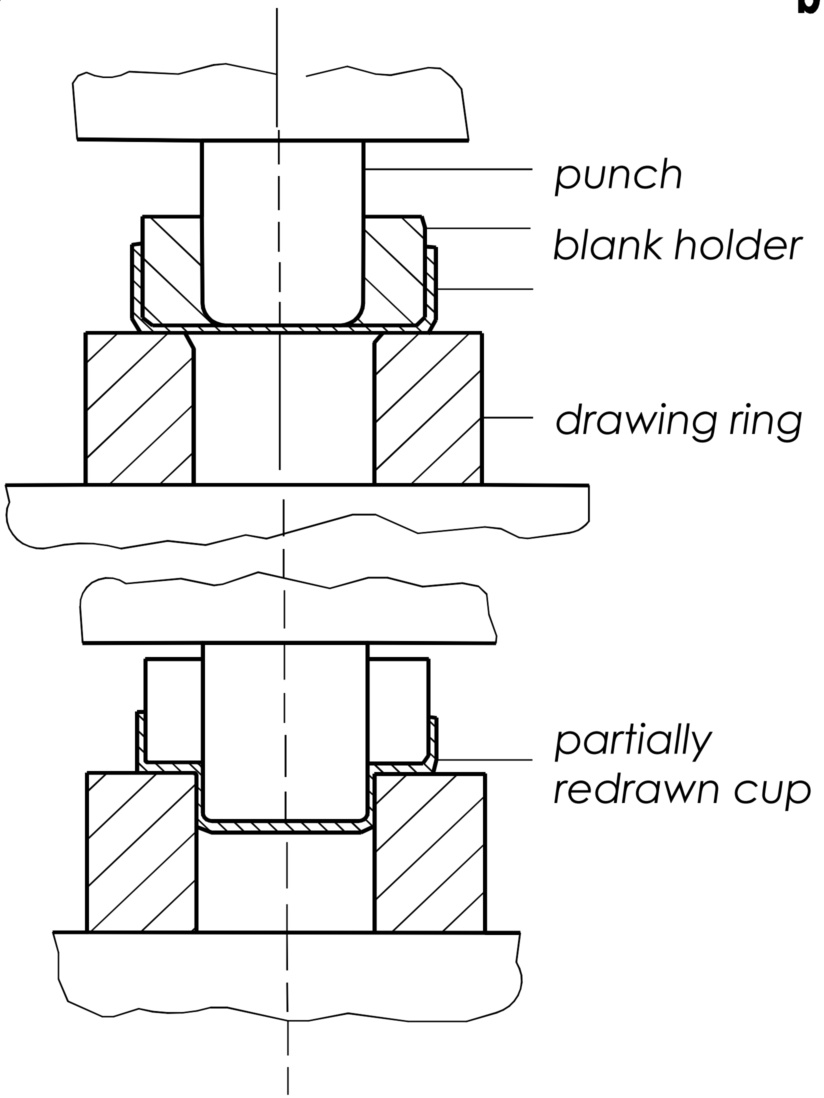
Multistep deep drawing – second step



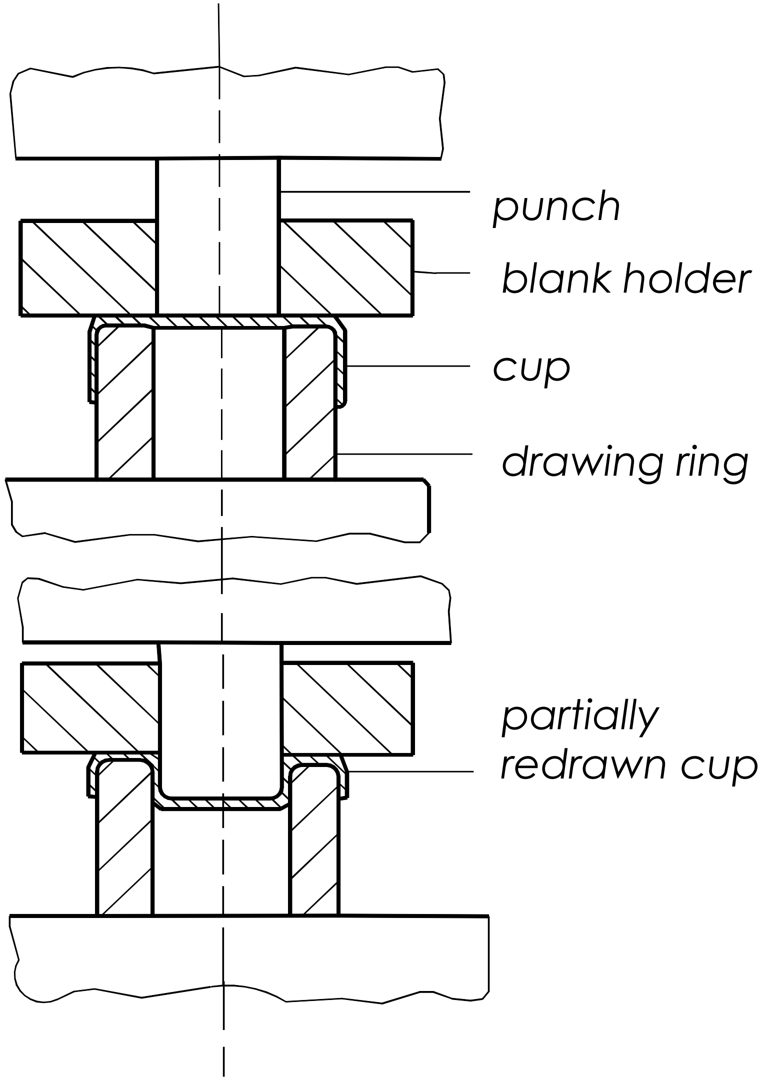


Multistep deep drawing – reverse redrawing

a)



b)

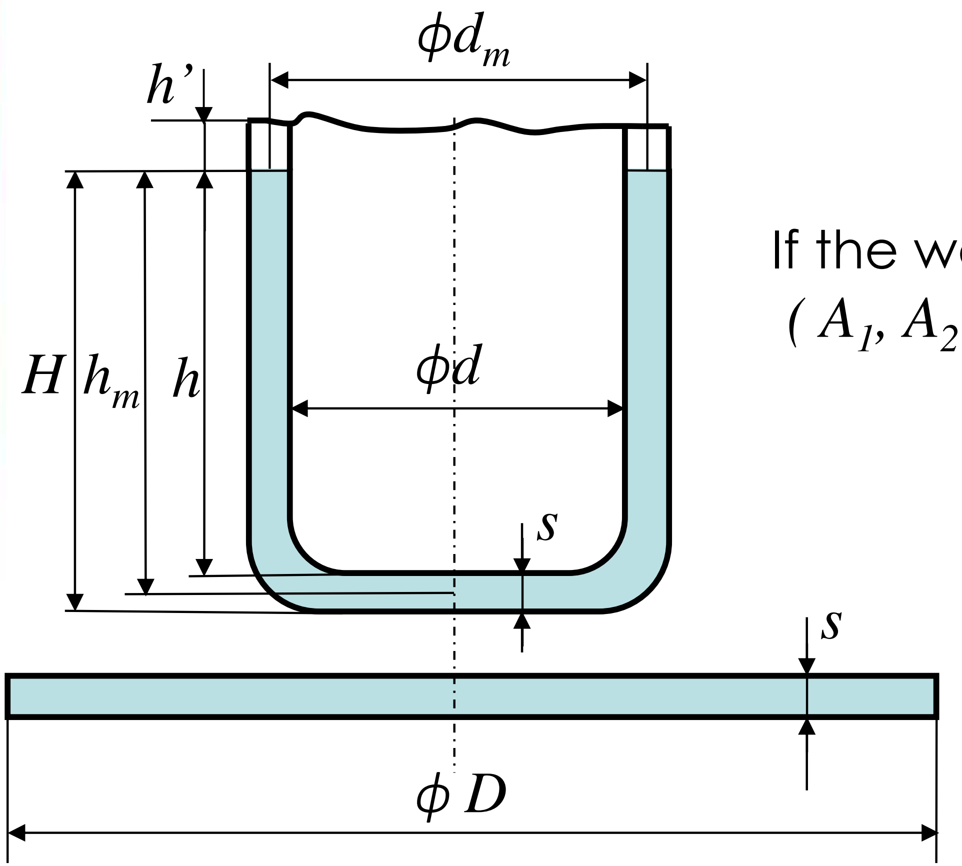


Blank geometry – axisymmetric part

Assuming constant surface area:

$$A = \frac{D^2\pi}{4} = \frac{d_m^2\pi}{4} + d_m\,\pi\left(h_m + h'\right)$$

$$D = \sqrt{d_m^2 + 4d_m\left(h_m + h'\right)}$$



If the workpiece consist of simple shapes ($A_1, A_2 \ldots\ldots A_n$)

$$A = \frac{D^2\pi}{4} = \sum_{i=1}^{n} A_i,\quad D = \sqrt{\frac{4}{\pi}\sum_{i=1}^{n} A_i}$$

h/d=0.5…4, h=20…300 mm,
h'=2…12 mm

Technology planning

Due to the material and geometric limits, not any geometry can be done in one step. The drawn cup can be further formed in subsequent deep drawing steps. For each step, a draw ratio $m_t=d_n/d_{n-1}$ can be defined; the ratio of the diameters in the n^{th} and $n-1^{th}$ step.

Its maximal values are material dependent, but $m=0.55\text{-}0.6$ for the first step (forming a cup from a planar blank) and $m_t=0.75\text{-}0.85$ for the further drawing steps are the ranges of their values.

The material is characterised by a maximum total draw ratio of q_{max} .

(If q_{max} is smaller, the drawability is better!)

Blank for cylindrical pieces

1) Assuming that the **surface area is constant**;
   the surface area of the final geometry is calculated.

2) If the material is **anisotropic**, the **cup height is increased with 5-15%** depending on the anisotropy value of the material

3) The blank diameter D is calculated.

Technology planning

Knowing the maximal drawing ratio, the first diameter is $d_1 = mD$, and the further drawing diameters are: $d_2 = m_t d_1 = m_t mD$, $d_3 = m_t d_2 = m_t^2 mD$ ...

Diameter after ***n*** drawing: $d_n = m_t^{n-1} mD$

If *D* and d_n are known, then the **number of** necessary drawing **steps**:

$$\boxed{n = \frac{\ln d_n - \ln(mD)}{\ln m_t} + 1}$$

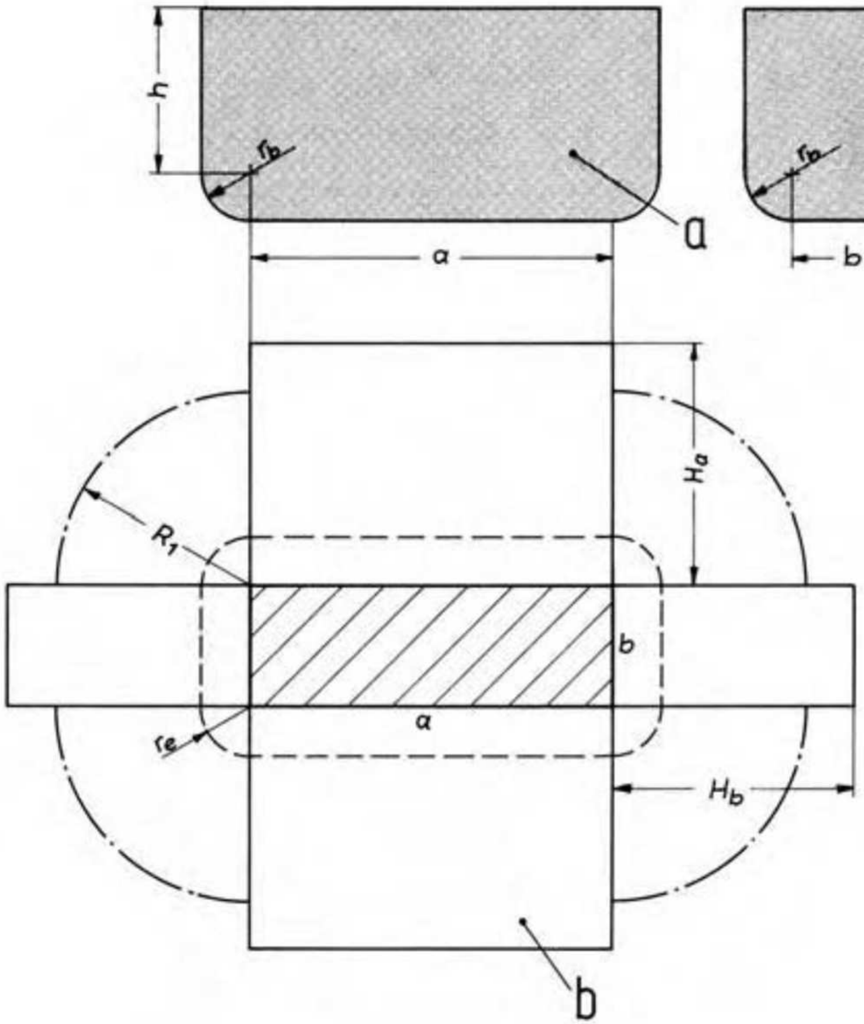
The result must be **rounded up.** Therefore, it is useful to continuously increase a bit the ratios from the first step to distribute the difference.

The number of drawing steps to the first annealing:

$$\boxed{k = \frac{\ln q_{max} - \ln m}{\ln m_t} + 1}$$

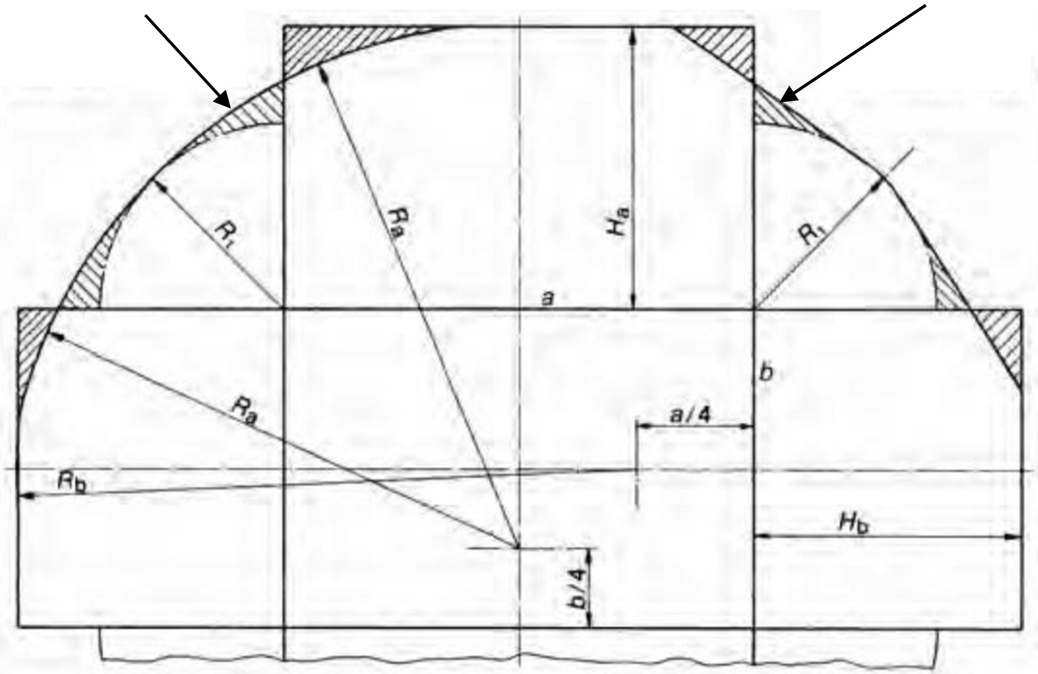
The result must be **rounded down.**

Blank for complex geometries



Balancing out with arcs

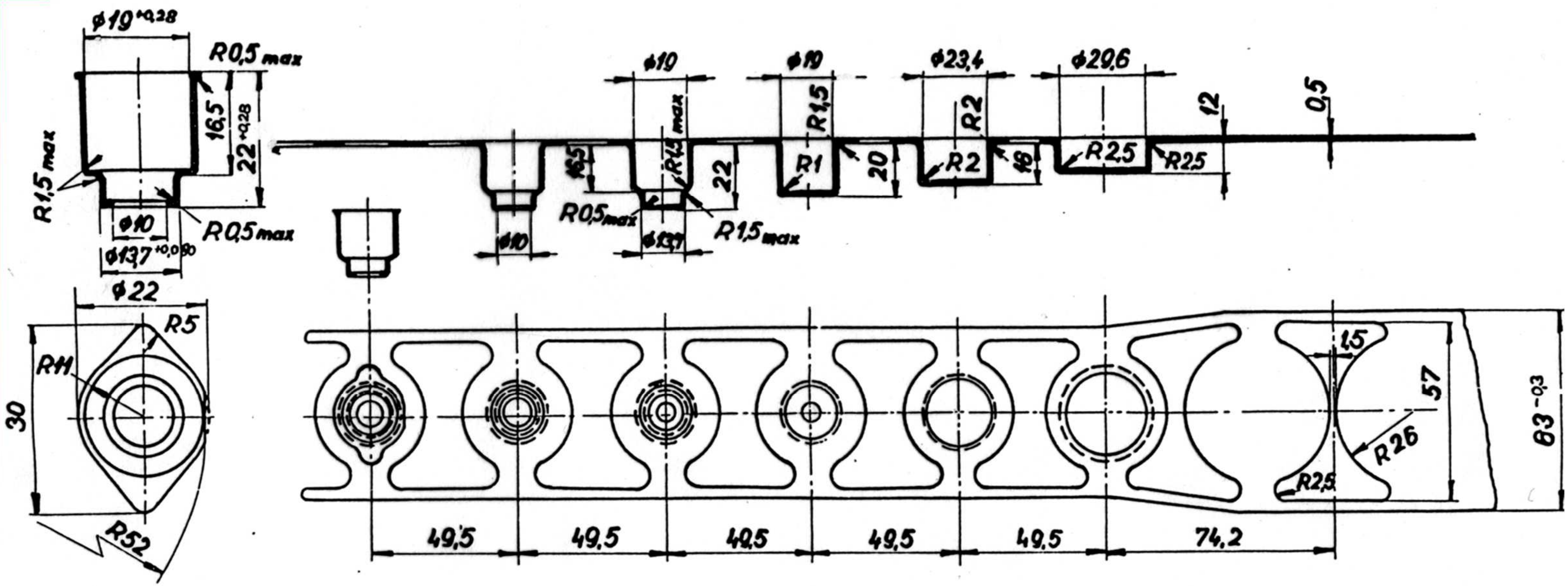
Balancing out with straight lines



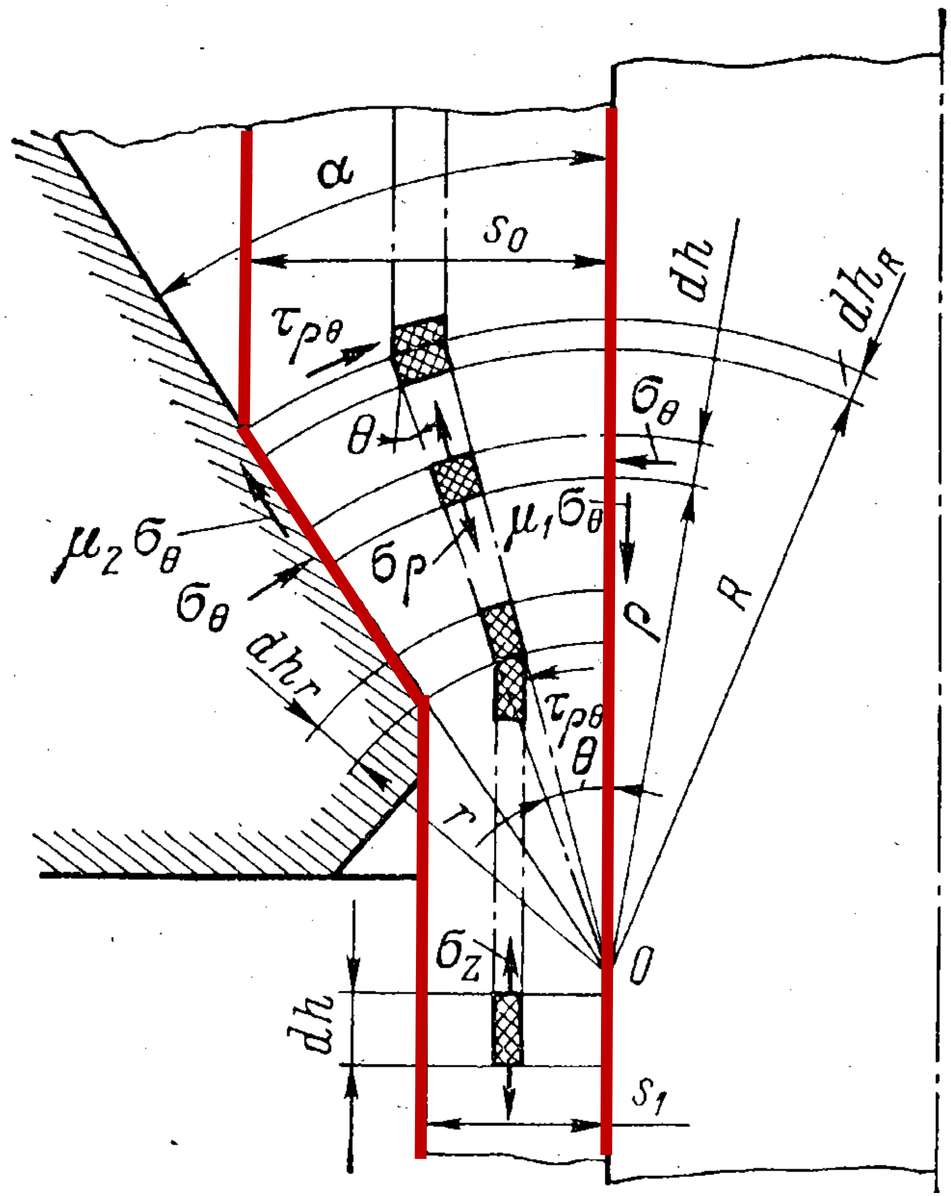
Breakdown of a rectangular hollow part into elements of equal area

Balancing out the design of the blank using arcs or straight lines

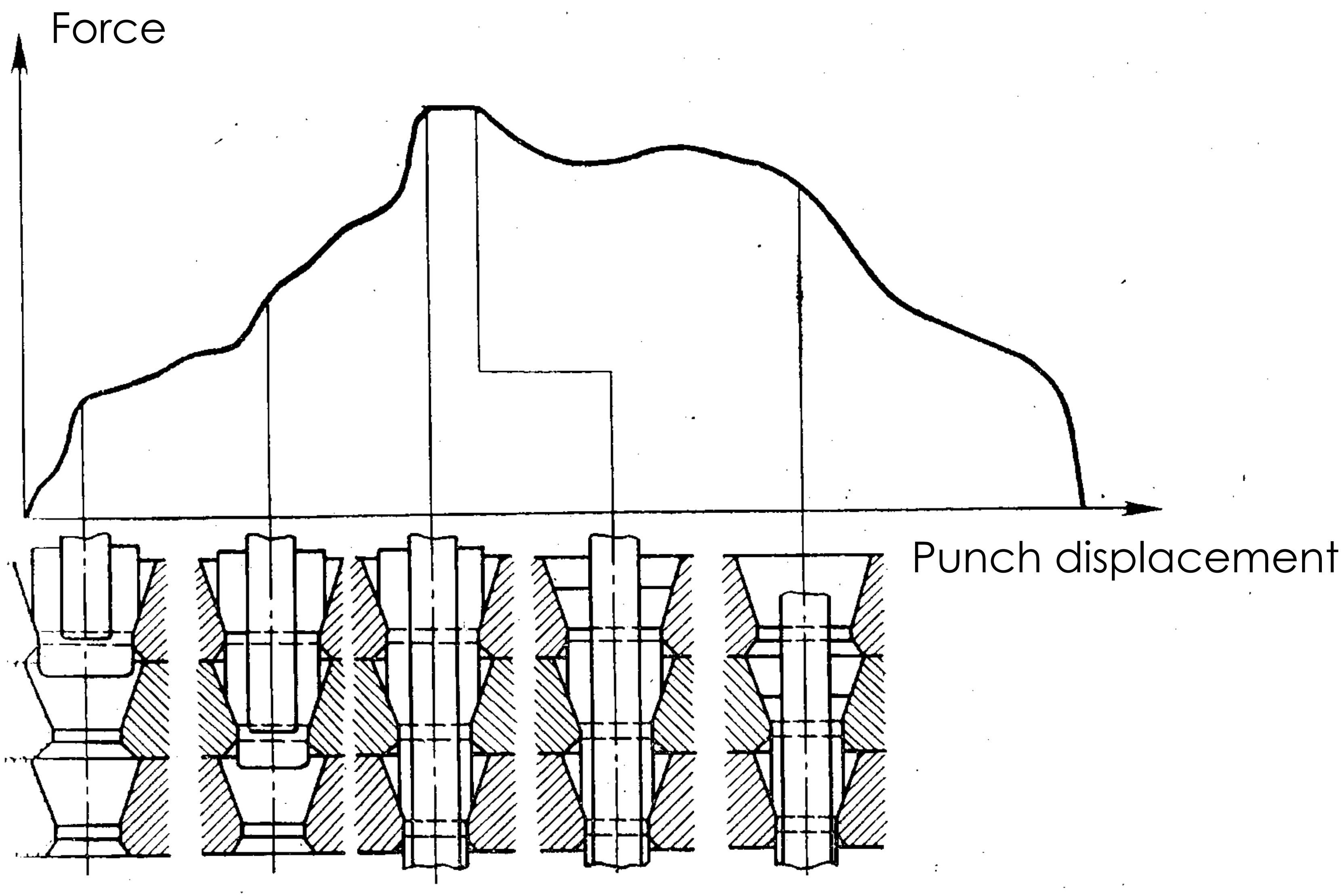
Technology planning



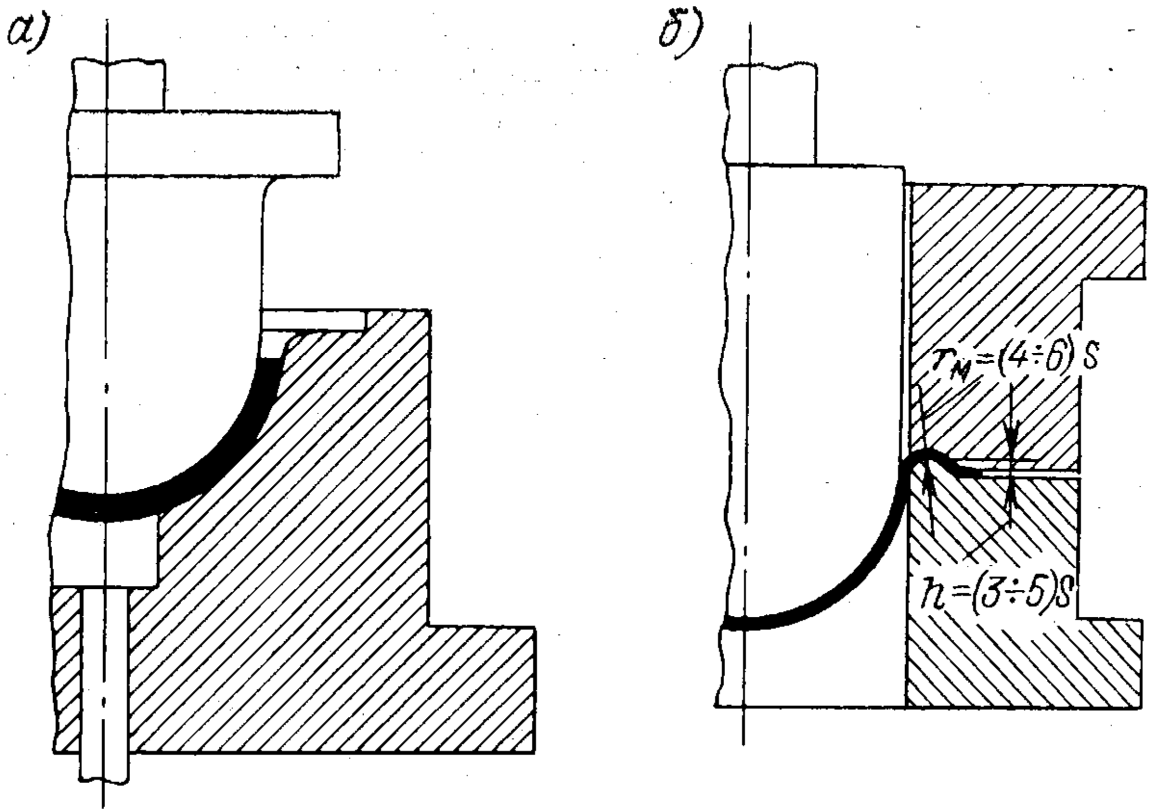
Related technique - ironing



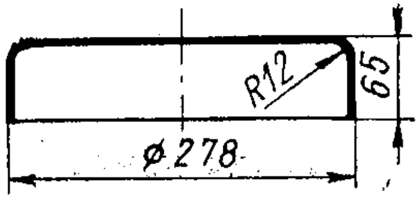
Multistep redraw with ironing



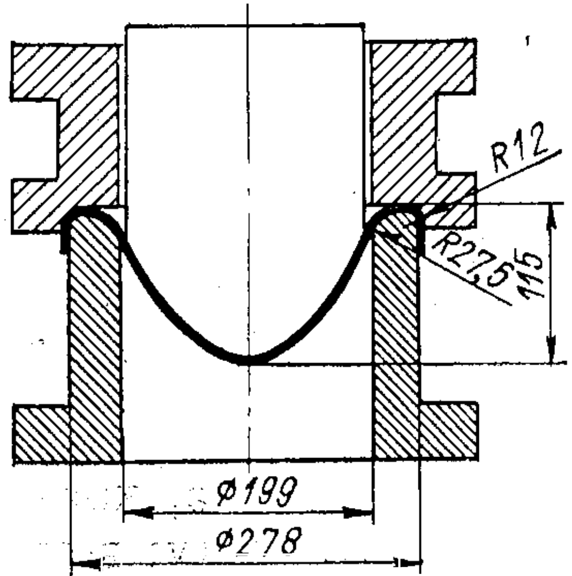
Die design examples



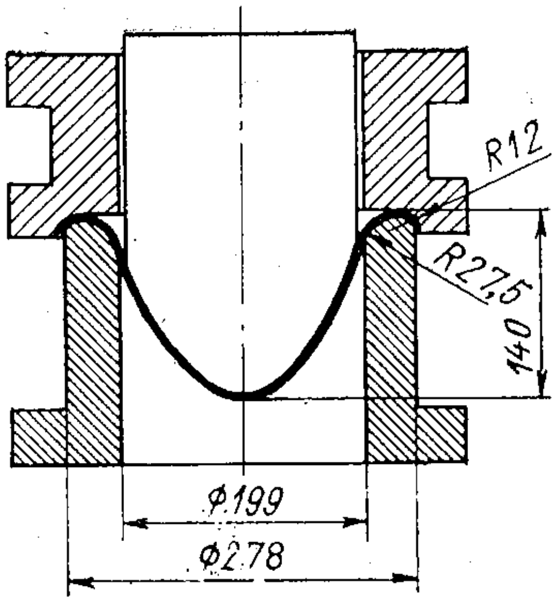
Die design examples



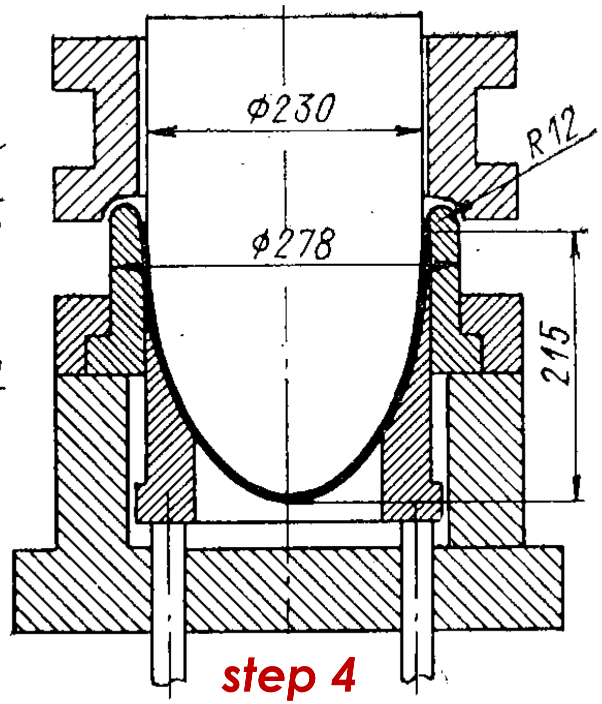
step 1



step 2

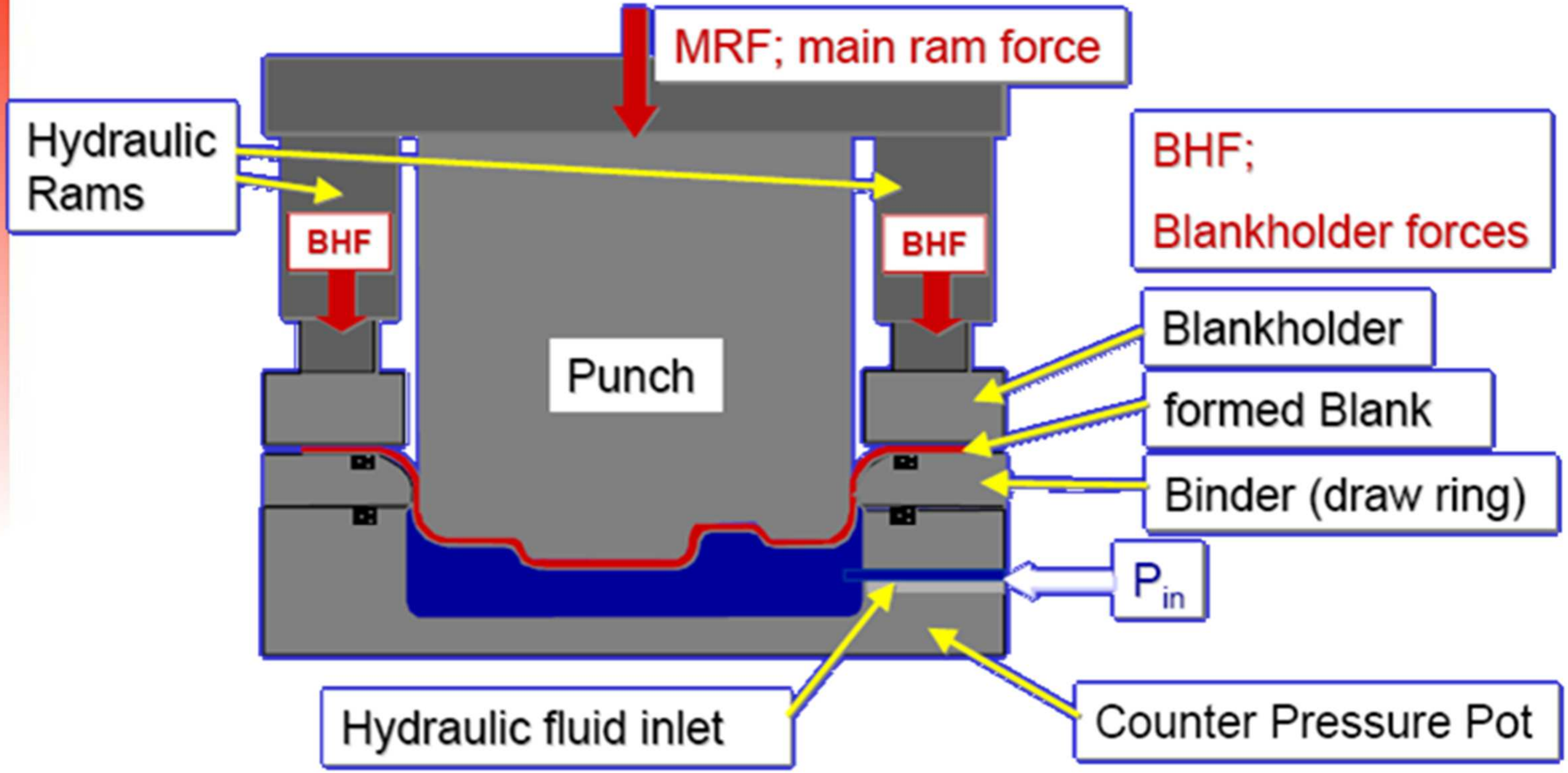


step 3



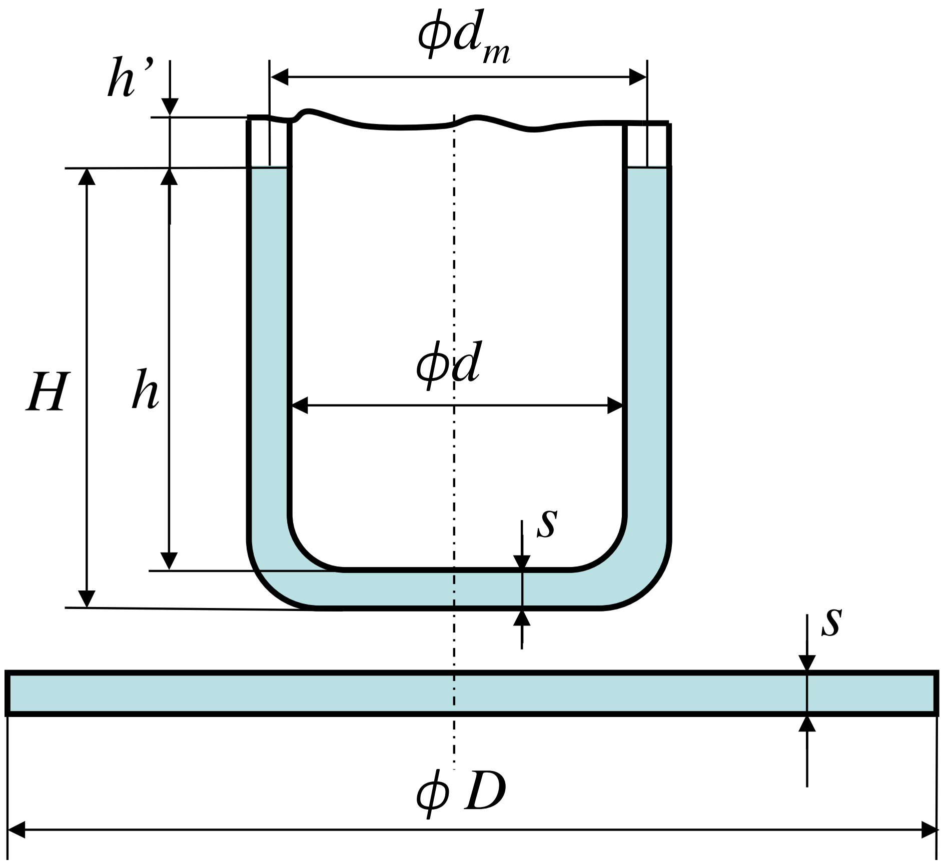
step 4

Hydro-mechanical deep drawing



Example

Calculate the total number of drawing steps and the number of steps to the first annealing:



$d_m = 30\,mm$

$h = 70\,mm$

$s = 2\,mm$

$D = ???$

$n = ???$

$annealing$??? ($q_{max} = 0.5$)

($m = 0.6$)

($m_t = 0.85$)

Thank you for your attention!