

## **TALAT Lecture 3705**

# **Drawing of Automotive Sheet Metal Parts**

30 pages, 37 figures

Advanced Level

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### **Objectives:**

- to describe the special requirements for the successful fabrication of automotive aluminium sheet metal parts with respect to material properties, machinery and drawing equipment and tools

### **Prerequisites:**

- General production engineering background
- Background in sheet metal forming principles
- TALAT Lectures 3701 - 3704

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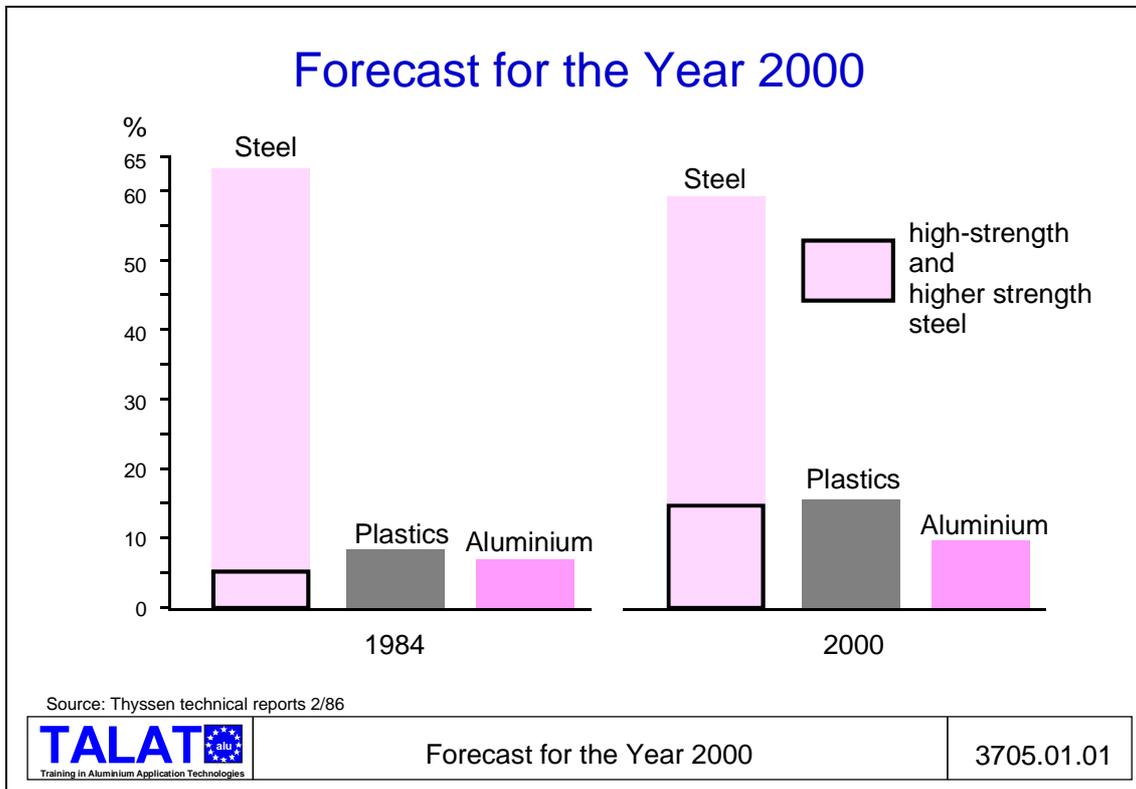
# 3705 Drawing of Automotive Sheet Metal Parts

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## 3705.01 Introduction

Forecasts for the year 2000 predict that the proportion of steel used in cars will shrink compared to 1984. At the same time the proportion of high strength steel will increase sharply as will the share of automotive aluminium, see **Figure 3705.01.01**.

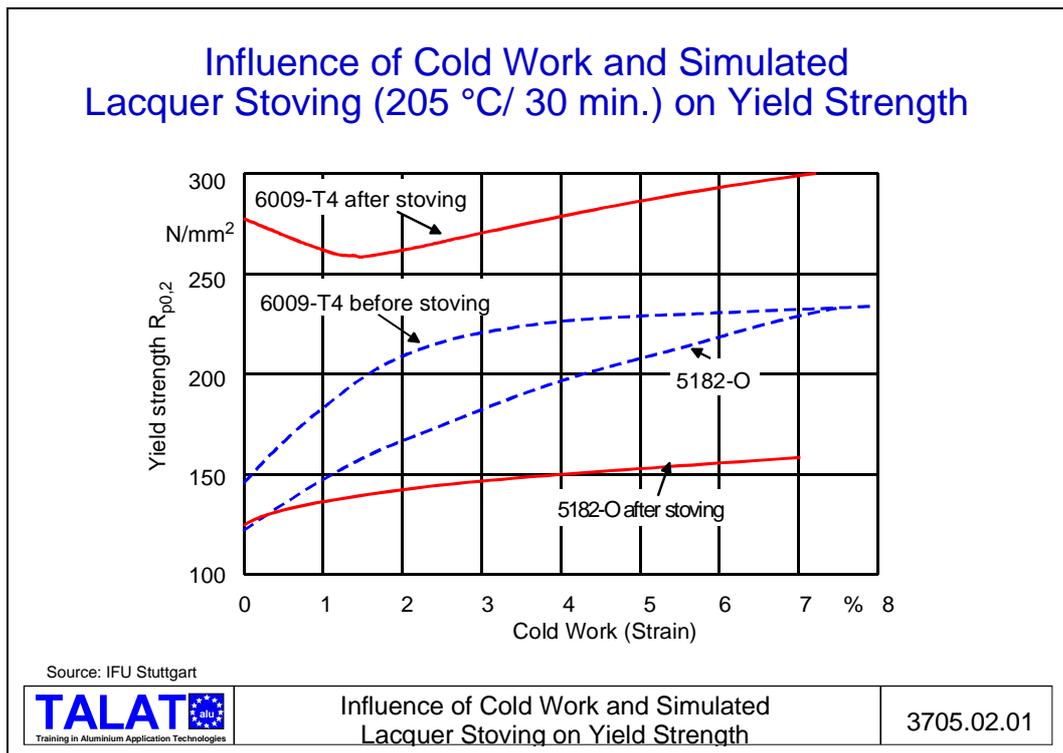


Among other applications in the car, aluminium alloys will be used to substitute steel in carbody sheet components. Previous experience with the production of aluminium sheet metal components for cars has demonstrated that special attention has to be given to the peculiarities of aluminium carbody sheet in the fabrication of car components. The fabrication process of carbody sheet metal components is a mixture of deep drawing and stretch forming. Aluminium and steel behave differently with regard to these two basic forming operations. It is, therefore, necessary to consider the basic technology of sheet metal drawing for aluminium carbody components in view of the material properties, the behaviour during the drawing process and the special requirements with respect to the drawing equipment and the tooling.

## 3705.02 Characteristic Materials Parameters

### Effect of Paint Bake Cycle on Strength

**Figure 3705.02.01** shows the influence of cold forming and paint stoving on the yield stress  $R_{p0,2}$  of typical aluminium carbody sheet alloys. It is apparent that age-hardening alloys profit from the baking cycle while strain-hardening alloys may suffer a reduction in yield strength values.



### Anisotropy

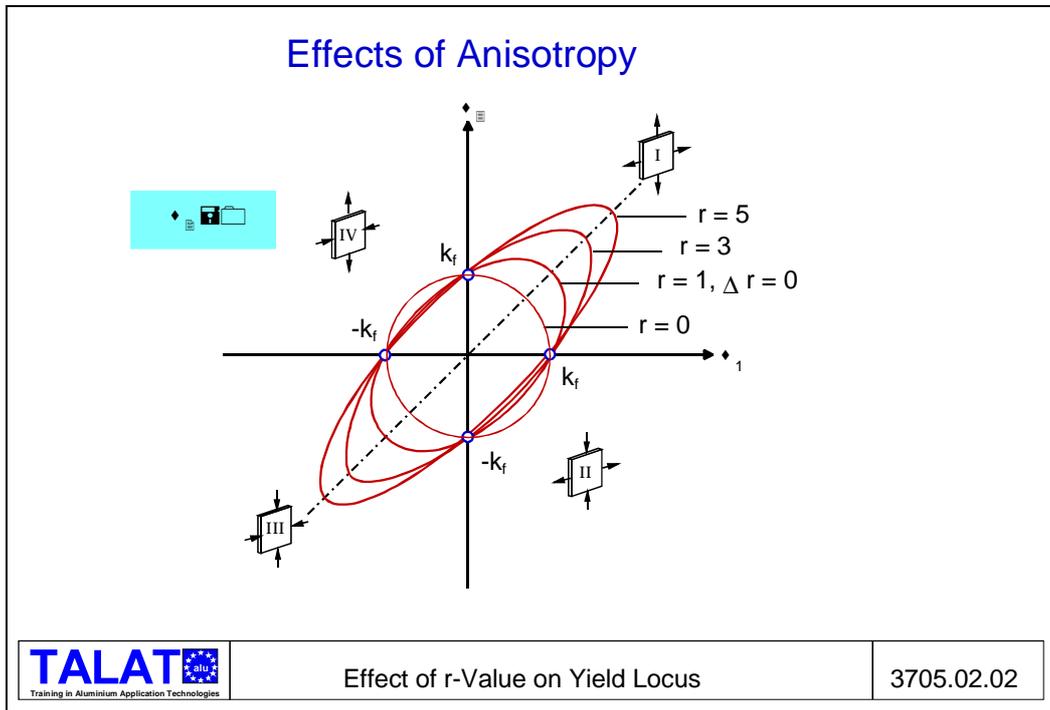
**Figure 3705.02.02** shows the yield criteria for a plane state of stress as a function of the  $r$  value. A value of  $r = 1$  indicates an isotropic behaviour.

Under a tensile-compressive state of stress, as in the flange of a deep drawn part, the stress required to maintain a plastic state decreases with increasing values of  $r$ . This means that increasing values of  $r$  result in lower drawing forces.

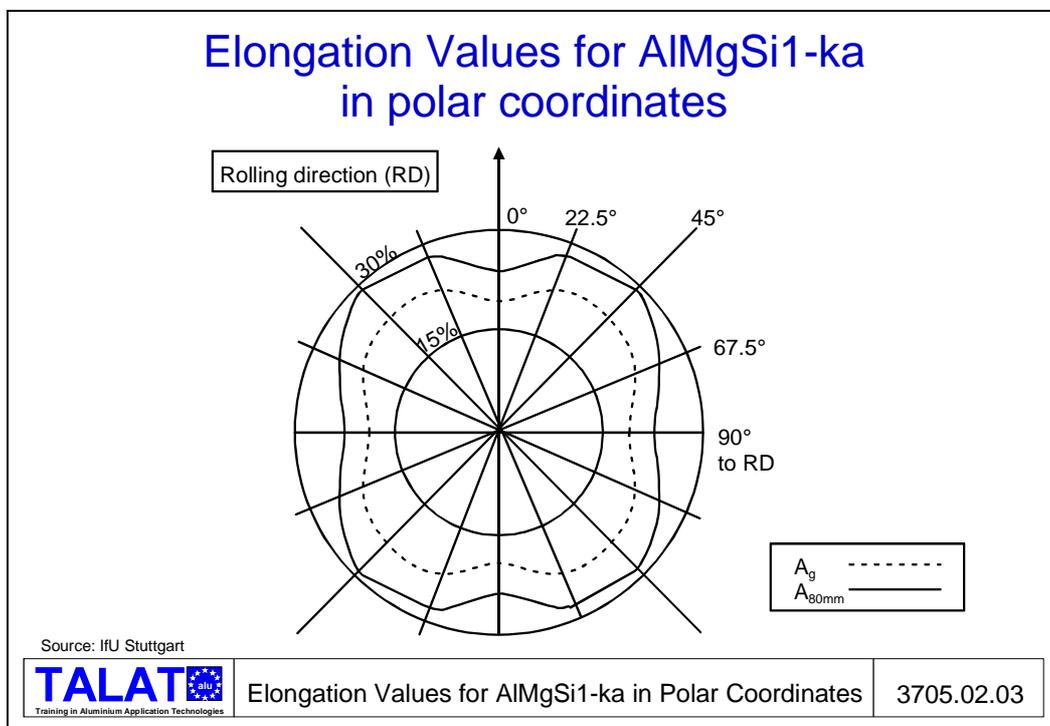
During tensile-tensile stressing, e.g. in the body of a deep drawn part, larger axial stresses can be transmitted with increasing values of  $r$ .

By increasing the value of  $r$ , one can increase the strength of the body and at the same time lower the strength in the flange. This explains why the limiting draw ratio increases with increasing  $r$  values.

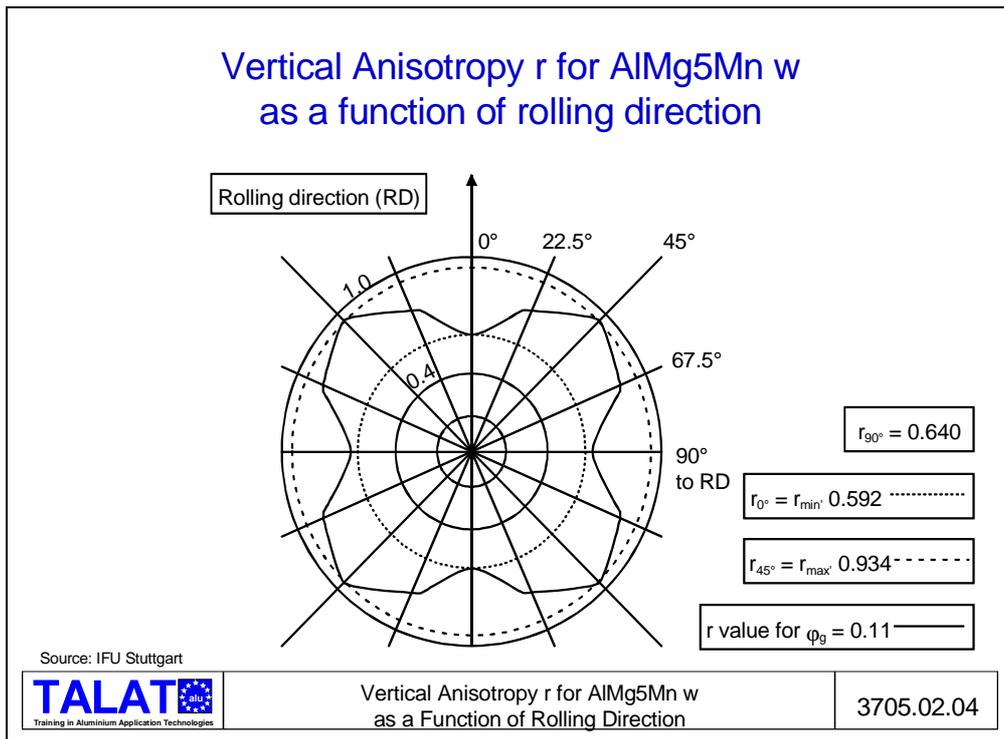
Aluminium sheet alloys in a state of good drawing quality generally have values of  $r \leq 1$  which vary with respect to the rolling direction.



**Figure 3705.02.03** illustrates the elongation values  $A_g$  and  $A_{80}$  for the alloy AlMgSi1-ka (EN-AW 6082-T4) using polar coordinates.



**Figure 3705.02.04** shows the vertical anisotropy  $r$  for the alloy AlMg5Mn-w (EN-AW 5182-0) using polar coordinates.



The varying elongation behaviour and the varying values for anisotropy are a result of the texture of the individual materials. The values shown here are exemplary and depend on the material as well as on the processes of cold and warm rolling and on the heat treatment.

### 3705.03 The Drawing Process

#### Stretch Forming

Basic elements of stretch forming are shown in **Figure 3705.03.01**. During stretch forming, the sheet is clamped on two sides. As a result, the increase in the sheet surface area due to the activation of the punch, is accompanied by a decrease in sheet thickness. A tensile state of stress exists. The forming zone starts at the clamping grips and proceeds to the punch middle. In order to ensure that, in spite of the hindering action of the friction, even this portion of the sheet is strained, it is desirable to keep the coefficient of friction between sheet blank and punch low and to have a high strain hardening coefficient.

### Stretch Forming

Two-sided clamping  
 Due to rigid clamping, increase of surface compensated for by decrease in sheet thickness with little participation of parts not under tension.  
 The forming zone spreads out, starting from the end of the gripping jaw to the middle of the forming punch.

Aims:

As small a coefficient of friction  $\mu$  as possible between sheet and forming punch.  
 A high strain hardening coefficient  $n$

Source: IFU Stuttgart

<b>TALAT</b> <small>Training in Aluminium Application Technologies</small>	Stretch Forming	3705.03.01
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### Stretch Forming a Bulge with a Spherical Punch

**Figure 3705.03.02:** During the stretch forming of a bulge with a spherical punch the blank is clamped firmly under the blankholder so that no material can flow in from the flange to supply material for the increasing surface area during drawing. The enlargement of the hemispherical surface area can only be achieved by a decrease in sheet thickness.

### Mechanical drawing

Clamping force  $F_K$  prevents flowing-in of sheet  
 All-around clamping  
 Forming zone spreads out from clamping location to punch dome  
 Increase of surface area compensated for only by decrease in thickness.

Aims:

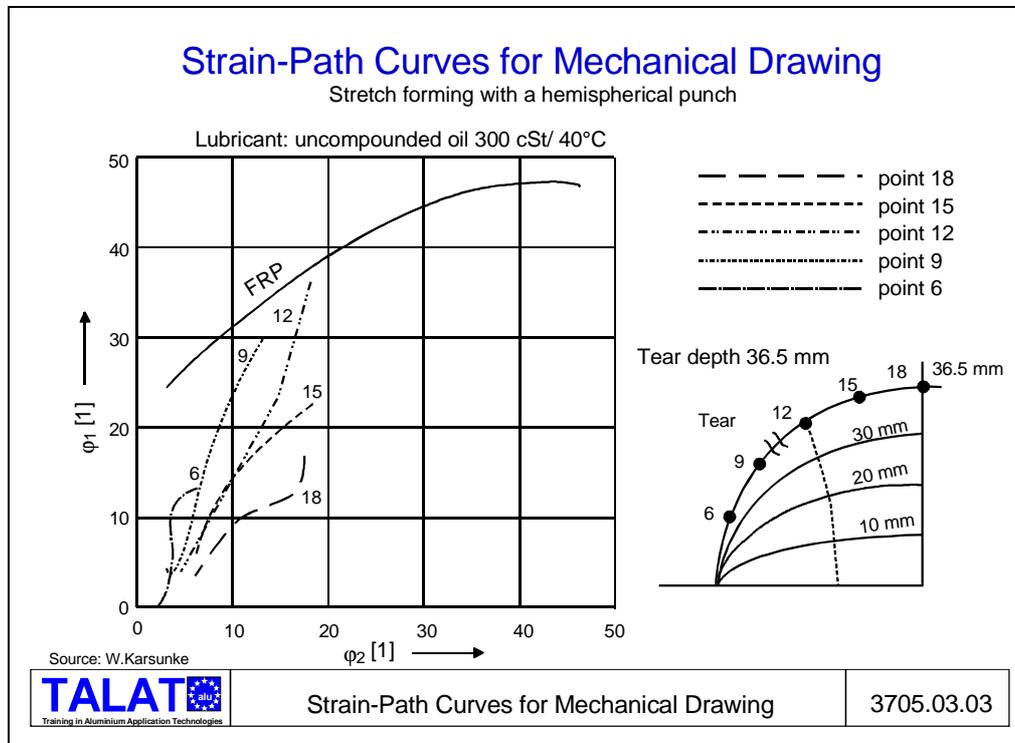
- $r_{min}$  large
- $\Delta r$  small
- $n$  large

Coefficient of friction  $\mu$  between sheet and punch should be kept small.

Source: IFU Stuttgart

<b>TALAT</b> <small>Training in Aluminium Application Technologies</small>	Mechanical Drawing	3705.03.02
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The forming zone starts at the clamping grips and proceeds to the spherical punch pole. For this stretch forming process it is desirable to have as low a value of  $\Delta r$  as possible and as high a value of  $r_{min}$  and strain hardening coefficient  $n$  as possible. The coefficient of friction between sheet and punch should be kept low.

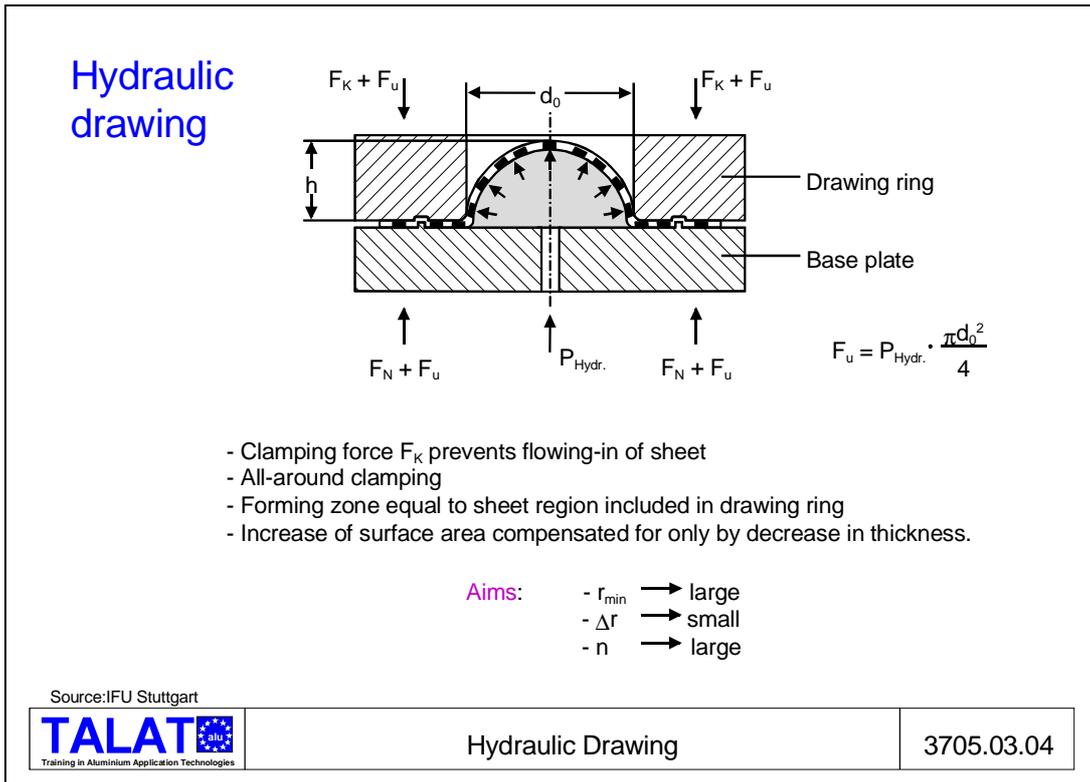


**Figure 3705.03.03** illustrates the traces of the principal strains at different locations of the drawn bulge during stretch forming with a hemispherical punch. The traces of strain from locations 9 and 12 approach the forming limit curve closest. Not surprisingly, tearing occurs at a location next to these points on the bulge.

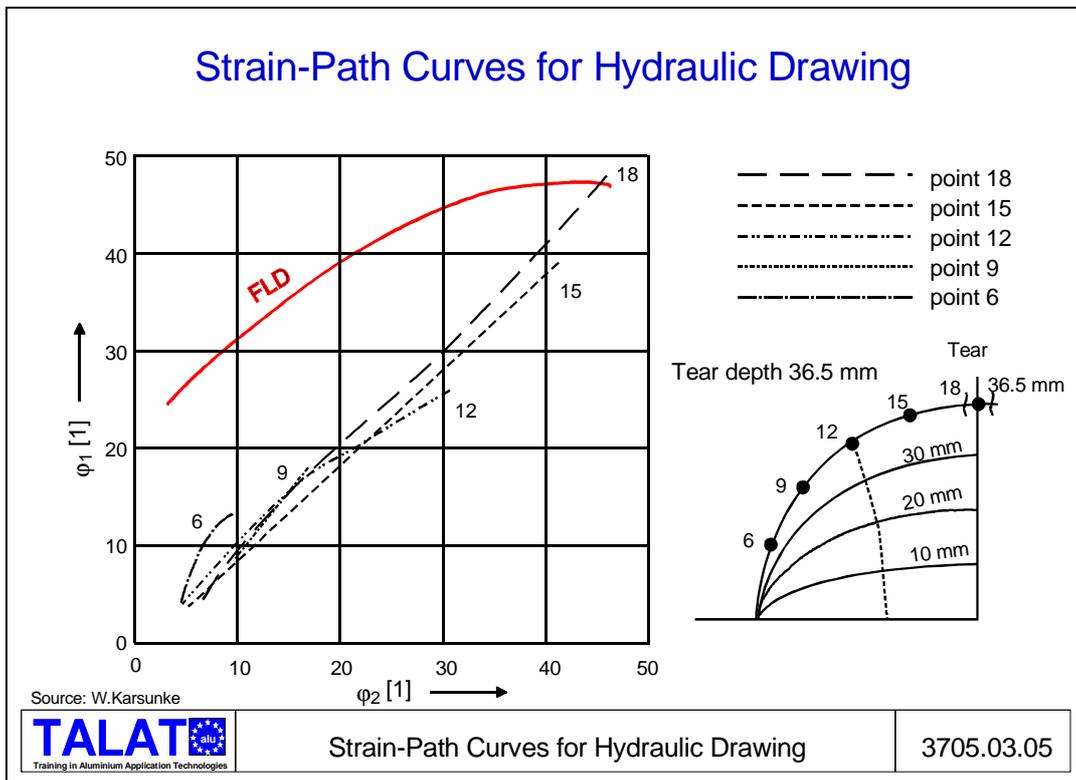
### Hydraulic Stretch Forming

During hydraulic drawing, the blank is clamped all around its edges so that the forming zone is the portion within the drawing ring, see **Figure 3705.03.04**. Like in the previous case, the increase in surface area has to be compensated for by a decrease in the sheet thickness.

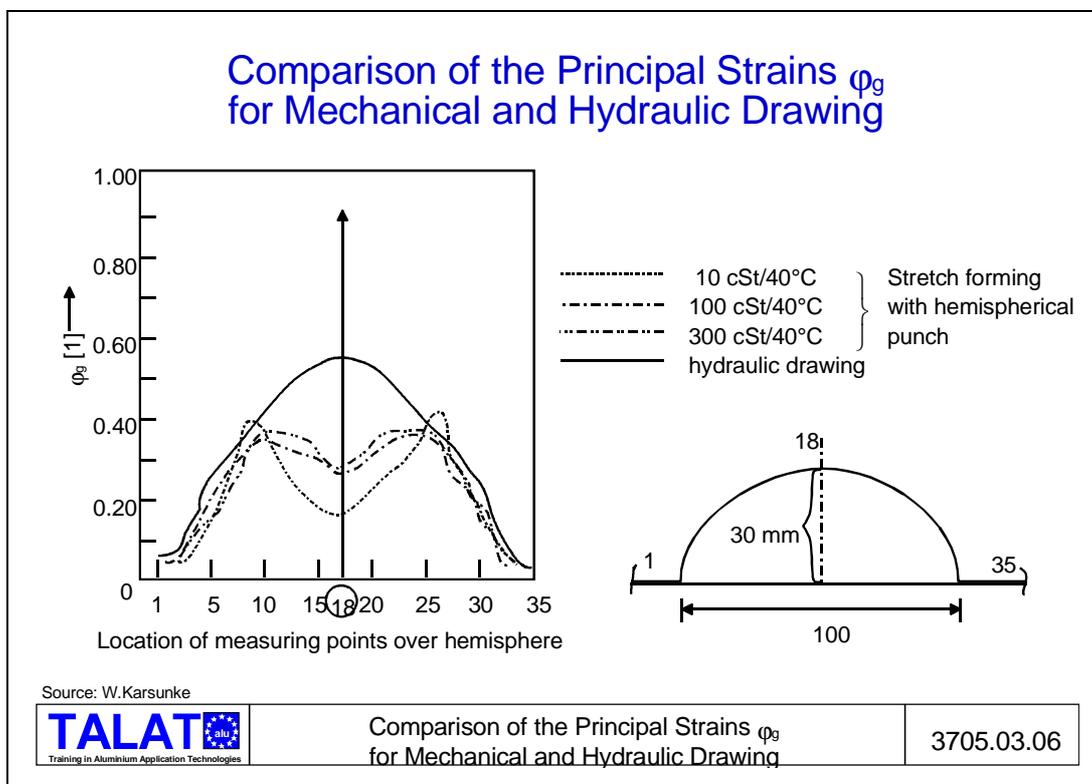
As far as the characteristic sheet values are concerned, large values for  $r_{min}$  and low values for  $\Delta r$  are desirable. The strain hardening coefficient  $n$  should be as high as possible.



**Figure 3705.03.05** illustrates the traces of the principal strains at different locations on the drawn part during hydraulic stretch forming. One notices that the differences between the individual measuring locations is much smaller than for mechanical buldge drawing, indicating that the deformation strain is much more uniformly distributed over the component.



In **Figure 3705.03.06**, the principal strains  $\varphi_g$  for mechanical and hydraulic drawing are compared.



### Deep Drawing with a Hemispherical Punch

**Figure 3705.03.07:** In deep drawing with a hemispherical punch, the forming zone covers the region between the flange outer edge and the location where the drawing part leaves the drawing ring curvature. In contrast to stretch forming, the surface areas of the blank and the drawn part are about the same, so that the sheet thickness remains almost constant.

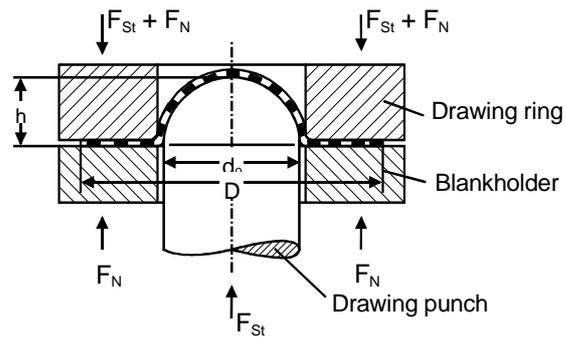
The blankholder force prevents the formation of „type 1“ folds. The base of the drawing part is formed according to the principle of mechanical drawing.

As far as the characteristic sheet values are concerned, large values for  $r_{min}$  and low values for  $\Delta r$  are desirable. The strain hardening coefficient  $n$  should be as high as possible.

The coefficients of friction  $\mu$  for the combinations punch/lubricant/sheet, blankholder/lubricant/sheet, drawing ring/lubricant/sheet and drawing ring rounding/lubricant/sheet should be as low as possible.

## Deep Drawing with a hemispherical punch

- blankholder force  $F_N$  prevents type 1 folds.
- Forming zone is the sheet area between flange outer diameter ( $D = f(h)$ ) and the location at which the sheet leaves the drawing ring curvature ( $d_0$ ).
- Surface area of drawn part is approximately equal to the surface area of the original blank. Consequently, sheet thickness is almost constant.
- Dome (bottom of part) is formed by stretch forming



- Aims:
- $r_{min}$  → large
  - $\Delta r$  → small
  - $n$  → large

Coefficients of friction should be kept small for the following combinations:  
 hemispherical punch surface / lubricant / sheet,  
 blankholder / lubricant / sheet,  
 drawing ring / lubricant / sheet and  
 drawing ring rounding / lubricant / sheet.

Source: IFU Stuttgart

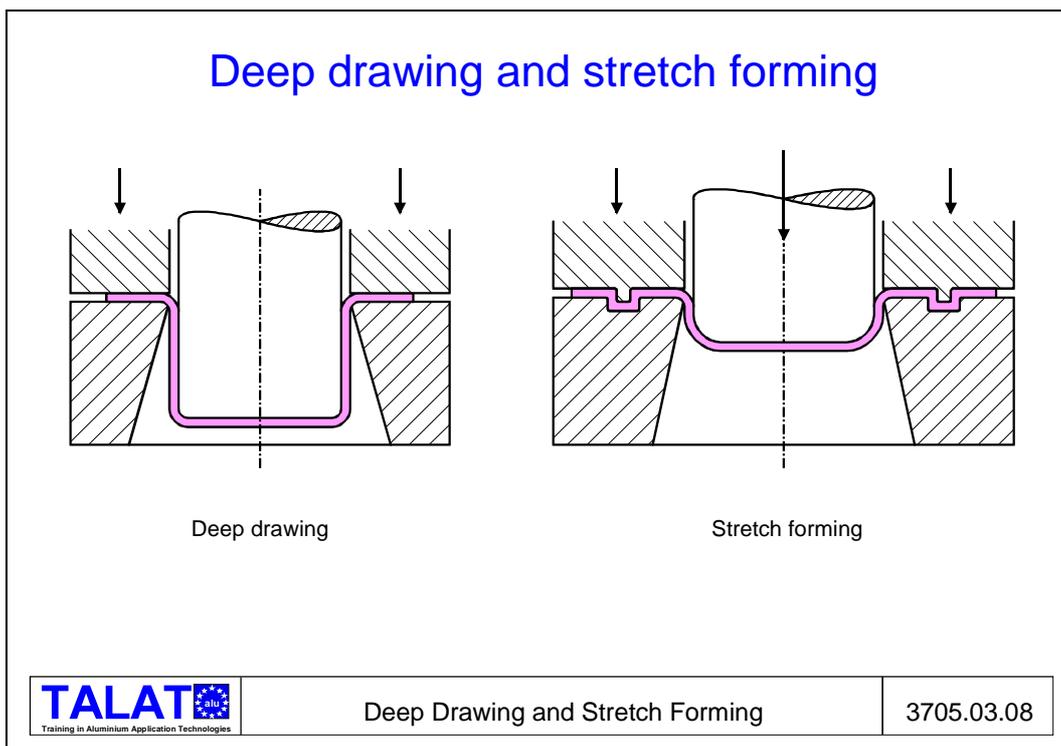


Deep Drawing with a Hemispherical Punch

3705.03.07

## Deep Drawing and Stretch Forming

Figure 3705.03.08 shows two separate schematics for the comparison of the deep drawing and stretch forming processes for a flat bottomed cup.



Deep Drawing and Stretch Forming

3705.03.08

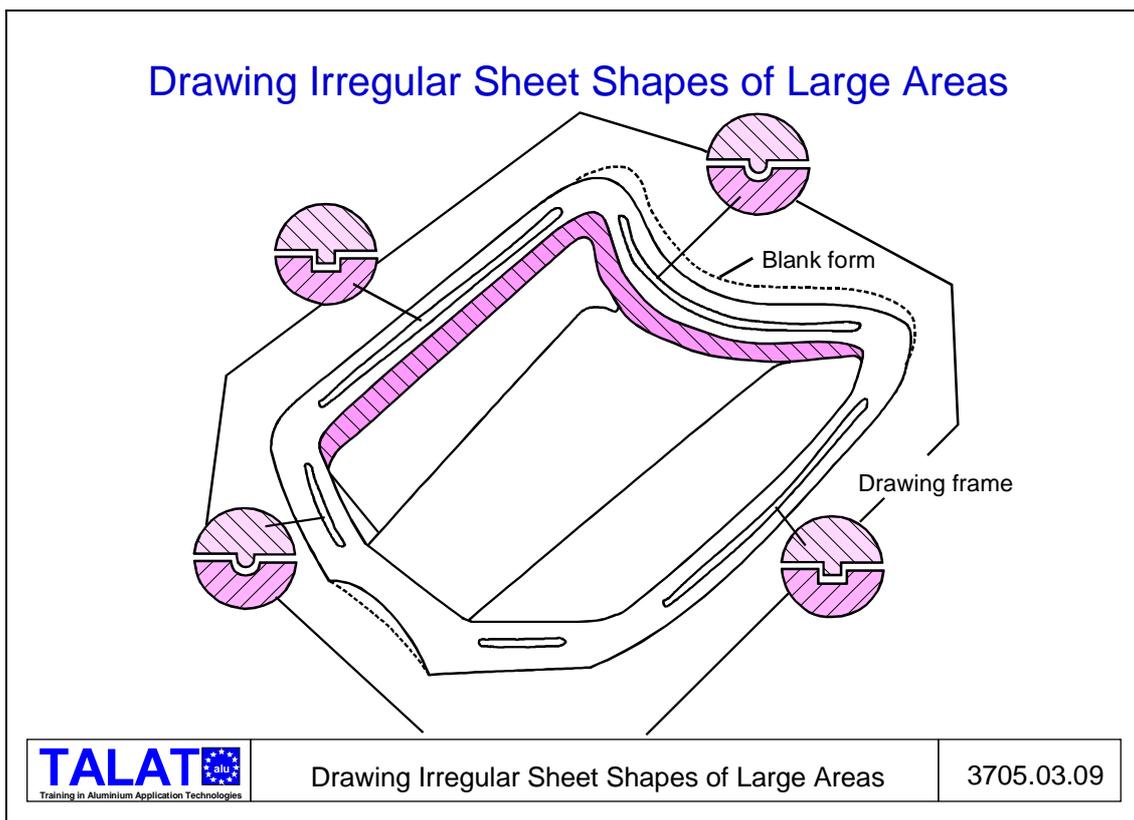
Sheet metal parts with large surface areas are usually formed using a combination of deep drawing and stretch forming.

A state of pure stretch forming exists only in very few cases. In such cases, the outer edge of the blank is clamped so that the increase in surface area can only come out of the sheet thickness.

Deep drawing is the other extreme in which the blankholder holds the sheet so that it can flow in during forming. The sheet thickness remains approximately constant and the surface areas of the shaped part and the starting blank are about the same.

### Drawing Irregular Sheet Shapes of Large Areas

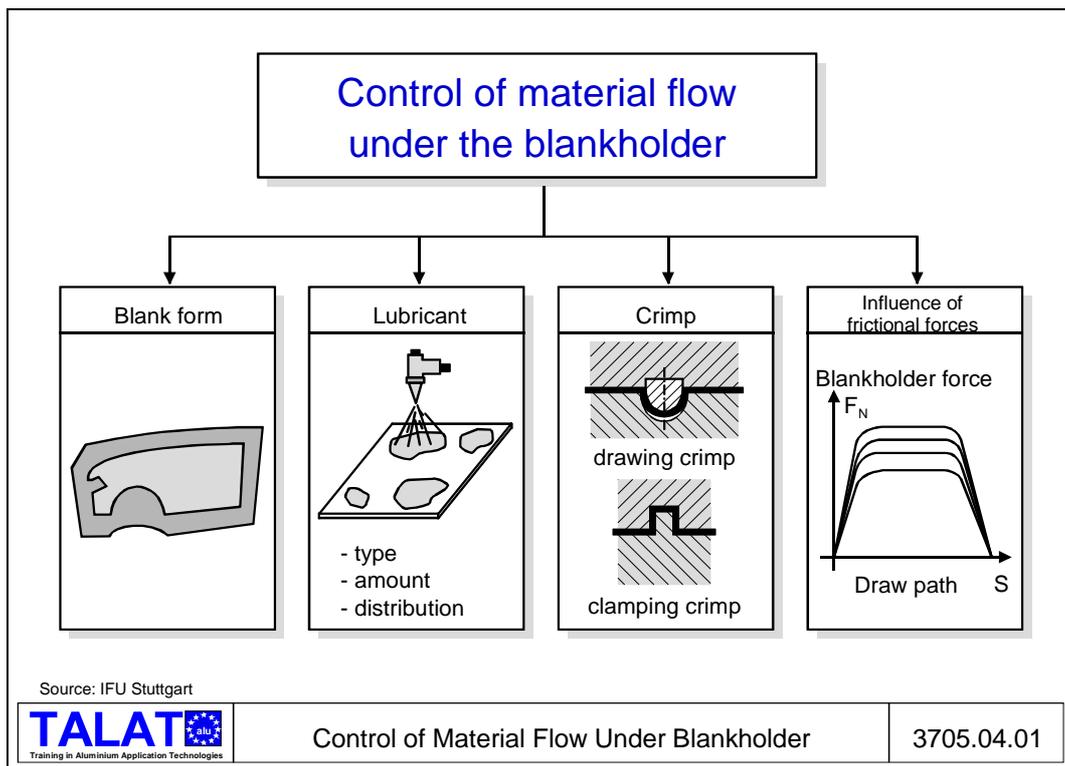
Two types of drawing beads are shown in the **Figure 3705.03.09**. The clamping beads have a rectangular section and absolutely prevent any sheet material from flowing in. Brake rolls serve only to create an additional forming work.



## 3705.04 Possibilities of Controlling the Material Flow

In processes which are not purely deep drawing but consist instead of a combination of deep drawing and stretch forming, it is necessary to control the flow of material under the blankholder. This can be achieved using different methods, individually or in combinations.

### Control of Material Flow under Blankholder



**Figure 3705.04.01** shows a number of possibilities for controlling material flow under a blankholder:

#### Blank form

Large sheet blank areas under the blankholder require large forming forces.

#### Lubricants

One method is to use a blank with nonuniform lubrication, i.e., different lubrication conditions at different locations of the blank, before drawing. Another method is to use a blank with a uniform basic lubrication which is then locally enhanced at chosen places by lubricating jets arranged in the tool, i.e., before each pressing stroke, an additional local lubrication effect exists between sheet and work-piece.

### Clamping crimps

Clamping crimps hinder the flowing in of the material to varying degrees, depending on the form and size. It is thus possible to reduce the blankholder force, whereby the drawing force is increased.

### Influencing the frictional forces

By regulating the blankholder force, it is possible to enhance or hinder the flow of material under it. This effect is obtained by locally varying the distance between blankholder and drawing frame, so that higher contact pressures can be brought to bear where the distance is smaller.

Another possibility of controlling the material flow and consequently the deformation strain distribution during the drawing of irregular sheet shapes with varying draw depths, is by using brake rolls and draw beads. These hinder the flow of material by varying amounts, depending on their form and size. Again, it is possible to reduce the blankholder force, whereby the drawing force increases.

As a result of the brake action of the draw beads, the material can no longer freely flow over the draw ring radius into the draw gap during the forming process. Thus it is possible to reduce the stress differences between side walls and corner regions for complicated irregular shapes as well as for square shaped drawn parts.

By optimally arranging the draw beads, one can control the material flow to create a uniform stress distribution such as occurs while fabricating cylindrical shapes. Brake rolls and draw beads ensure that the resistance of material flow over the draw ring radius into the draw gap varies locally, thus simulating the effect of increasing blankholder pressure.

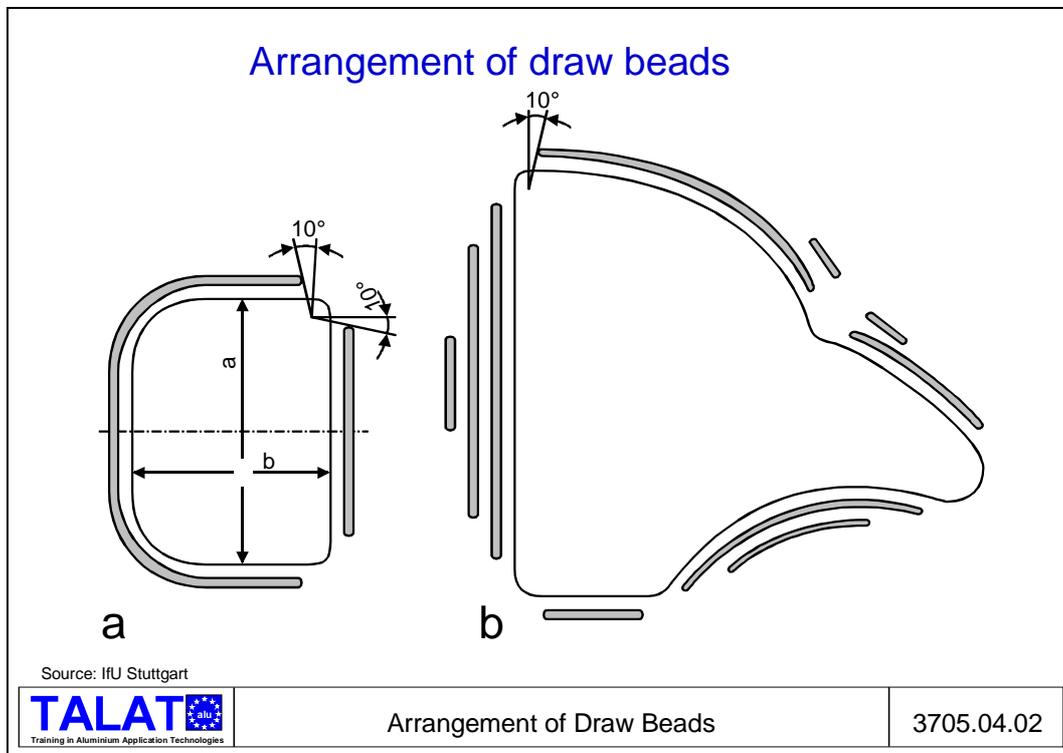
Depending on the design and arrangement in the tool, one can differentiate between draw beads and brake rolls.

Draw beads are arranged at some distance from the drawing ring radius and cause, together with the die radius, a three-fold directional change of the sheet. Draw beads can be arranged in both slanting and straight blankholder surfaces.

Brake rolls are arranged at the die shoulder and create a two-fold directional change of the sheet material. Brake rolls in the draw ring are used mostly for round or oval sheet shapes with a parabolic or similar casing form.

## Arrangement of Draw Beads

Figure 3705.04.02 shows the arrangement of draw beads for a drawn carbody component.

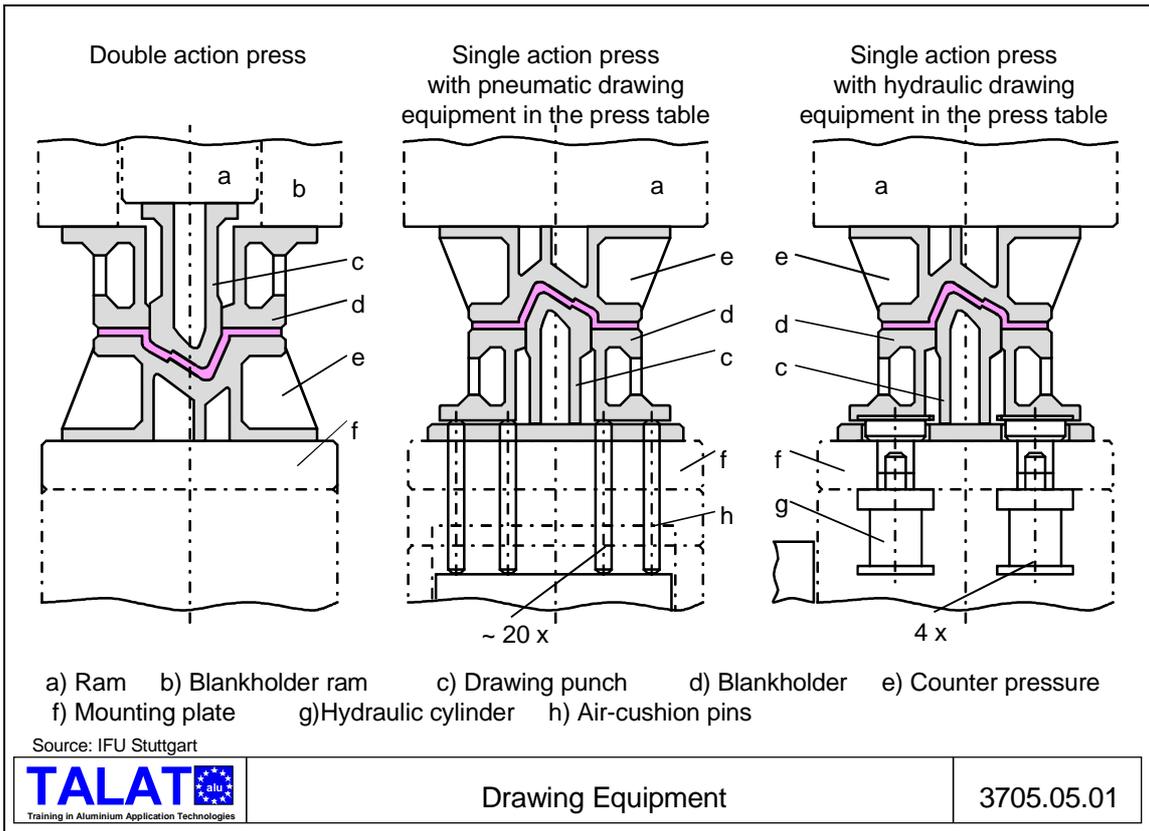


## 3705.05 Adjusting the Die Cushion

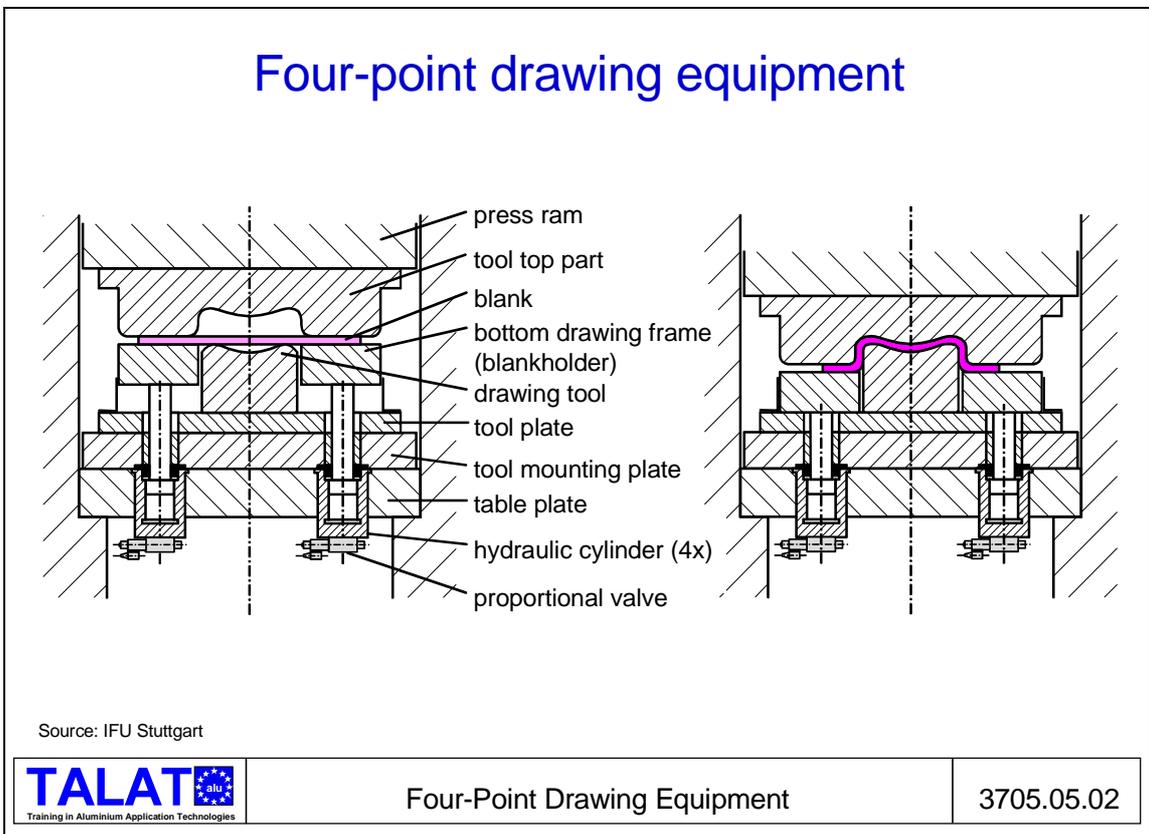
### Mechanical vs. Hydraulic Press Equipment

During drawing with a mechanical double-acting press (press with drawing punch ram and blankholder ram), the blankholder can be locally adjusted at the four points under the crank so that different contact pressures can be applied at the locations front left, front right, rear left and rear right under the blankholder, **Figure 3705.05.01**. A regulation, if at all possible, can only be carried out as far as the pressure is concerned.

With the double-acting hydraulic press it is possible, without any great effort, to regulate the blankholder force during the draw path at each corner point, since each corner point has its own hydraulic cylinder.



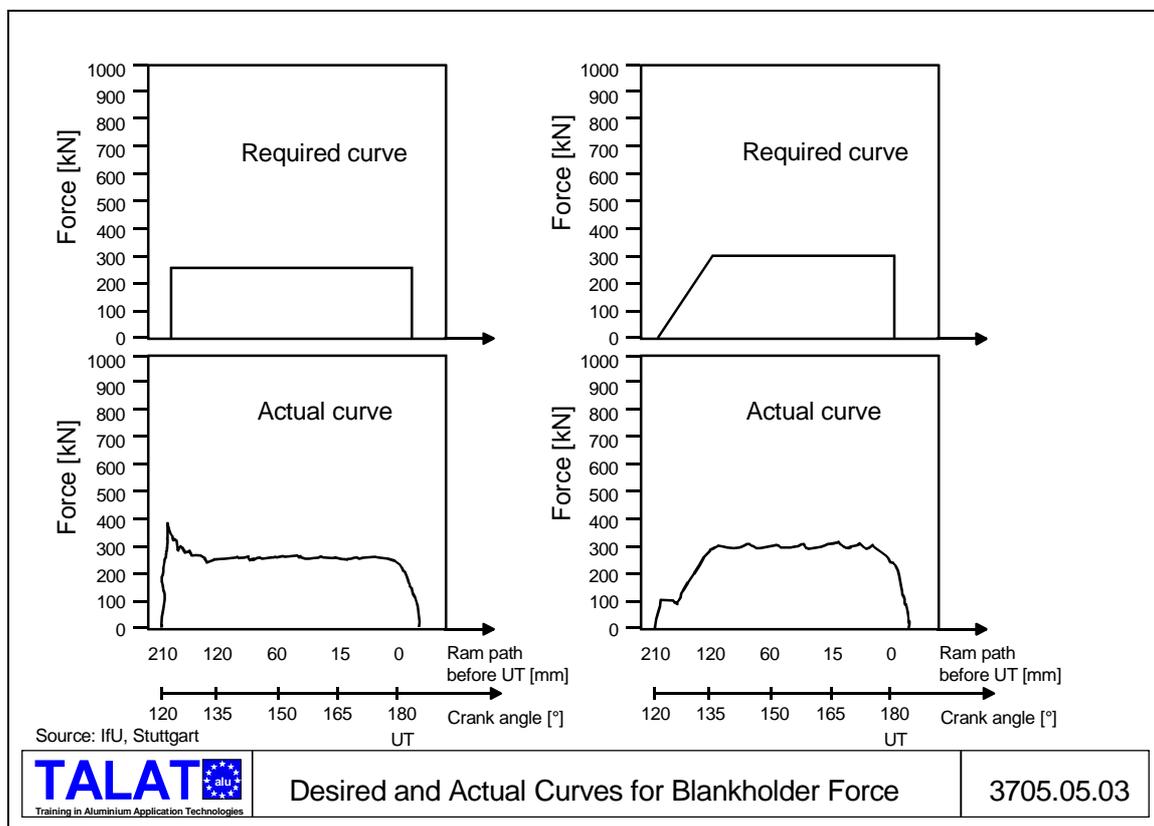
### Four-Point Die Cushion



**Figure 3705.05.02** together with the **Figure 3705.05.01** illustrate that it is possible to draw parts using a three-piece tool not only with a two-fold acting press but also with a simple acting press. In these cases, the blankholder (lower drawing frame) is supported on a drawing form plate (cushion) form with the help of a number of pressure bolts. This drawing form plate is moved up and down or subjected to the blankholder force with the help of pneumatic or hydraulic cylinders.

### Desired and Actual Curves for Blankholder Force

When the top frame contacts the blank lying on the lower frame, an undesirable force peak occurs, causing the lubricant film to break down, **Figure 3705.05.03**. In addition, this causes an undesirable overloading of the tool and machine and is a cause of noise. This undesirable force peak can be avoided by starting the drawing process with a lower pressure in the cylinders and then increasing this pressure to a level which prevents the formation of type-1 folds and allows the necessary material flow to be regulated.



### Advantages of a Servo-Hydraulic Die Cushion in the Press Table

**Figure 3705.05.04** summarises the advantages of a die cushion in the press table of a simple acting press over the mechanical double acting press with a drawing ram and a blankholder ram:

- No overturning operations required between drawing press and trimming press necessary.

- Reduction of the force peaks during initial contact between the top frame and the sheet blank lying on the bottom frame.
- Control of the blankholder force, i.e., the material flow over the draw path.
- Reproducible press operation

### Advantages of a Servo Hydraulic Die Cushion in the Press Table

A servo hydraulic die cushion in the press table of a simply acting press table has following advantages over a two-fold acting mechanical press with drawing ram and blankholder ram :

1. No overturning operations required between drawing press and trimming press.
2. Reduction of the force peak during contact of the top frame and sheet blank lying on the bottom frame.
3. Control of the blankholder force, i.e., the material flow over the draw path.
4. Reproducible press operation.

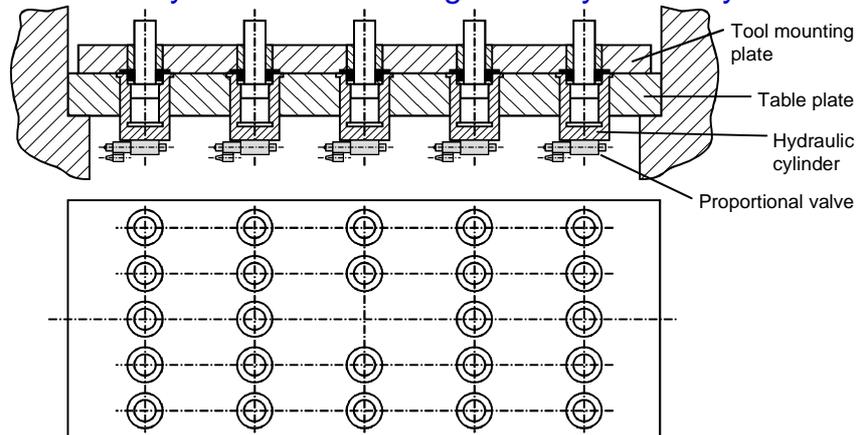


Advantages of a Servo Hydraulic Die Cushion in the Press Table

3705.05.04

### Four-Point Die Cushion in the Press Table

#### Four-point die cushion in the press table with individually controlled and regulated hydraulic cylinders



Source: IFU Stuttgart



Four-Point Die Cushion in the Press Table

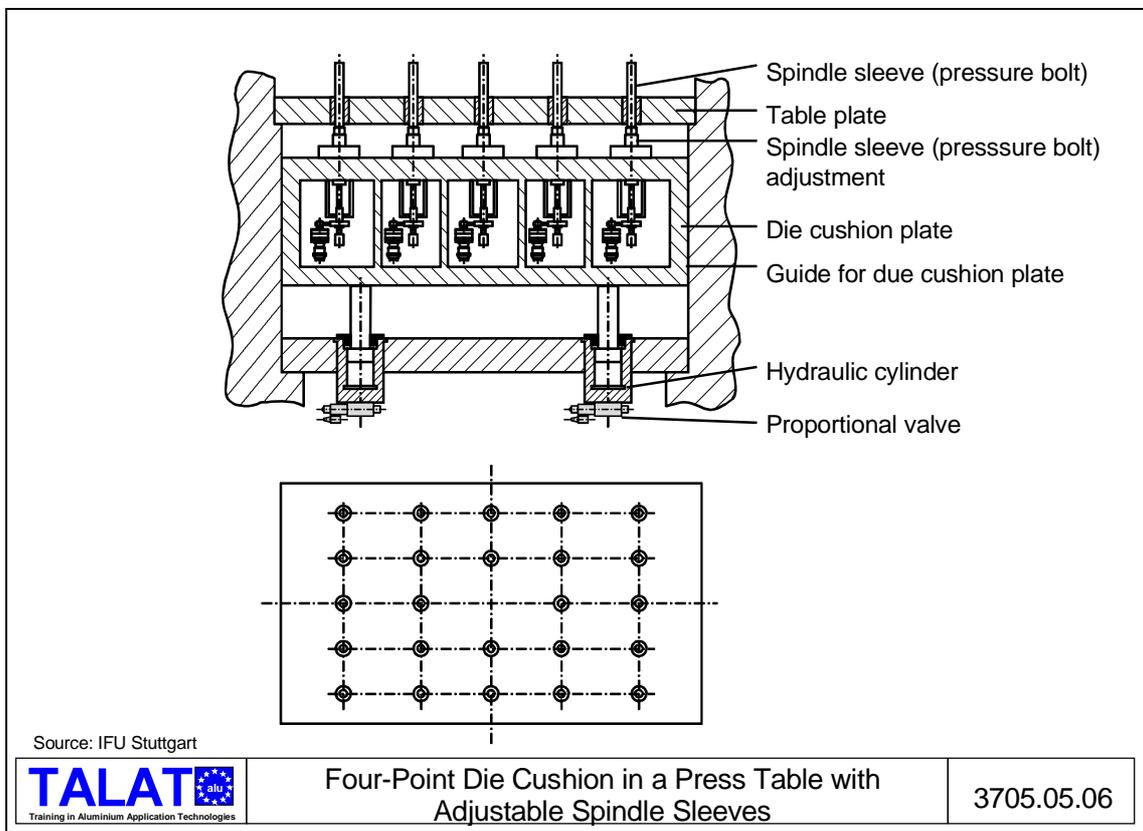
3705.05.05

The present trend is to produce large one-piece pressed shapes, e.g. complete automobile side walls. Conventional four-point die cushion is, however, unsuitable for large parts. One method of developing the die cushion is the possibility of utilising many cylinders instead of four corner cylinders, **Figure 3705.05.05**. In order to prevent the regu-

lating and control mechanism from getting too complicated, the cylinders can be joined together in groups which are controlled in unison.

### Four-Point Die Cushion in the Press Table with Adjustable Spindle Sleeves

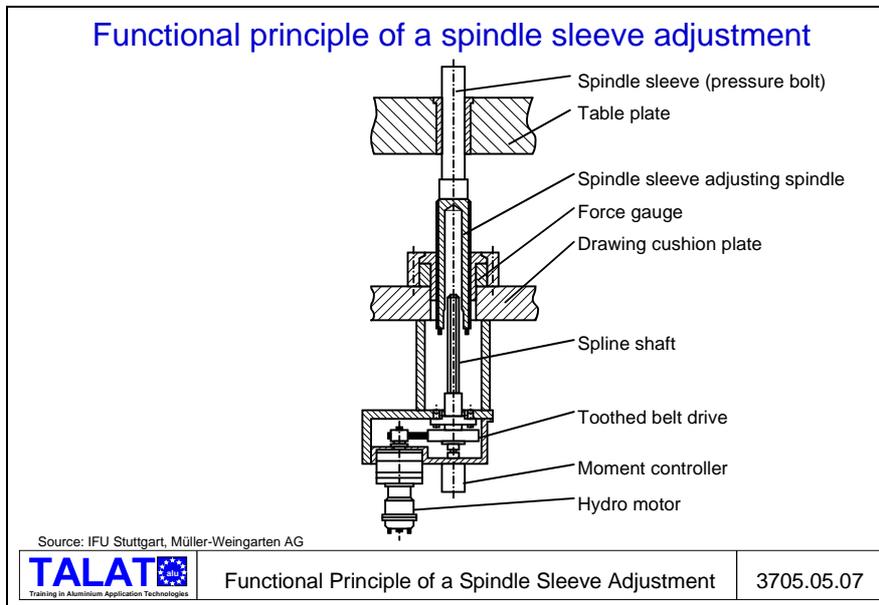
The Institut für Umformtechnik (institute for forming technology) of the University of Stuttgart and the company Maschinenfabrik Müller-Weingarten have developed an alternative method. In the construction shown in this **Figure 3705.05.06** and **Figure 3705.05.08**, the force for the blankholder in the drawing frame is controlled by spindle sleeves with integrated force gauges in which the spindle sleeves can be adjusted to different heights using a stored programme. The spindle sleeves are supported on a drawing cushion which can be regulated and controlled by four hydraulic cylinders.



With this design it is possible to maintain the reliable adjustment of the force-path curve for each corner cylinder. By choosing the spindle sleeve to be activated, an adjustment can be made to suit the drawing frame form. The spindle sleeves not required can remain in their normal position. By choosing the optimal spindle sleeve lengths, the tool can be elastically bent to compensate for the flexure of the drawing frame and drawing cushion plate as well as for regulating the material flow by locally adjusting the contact pressure.

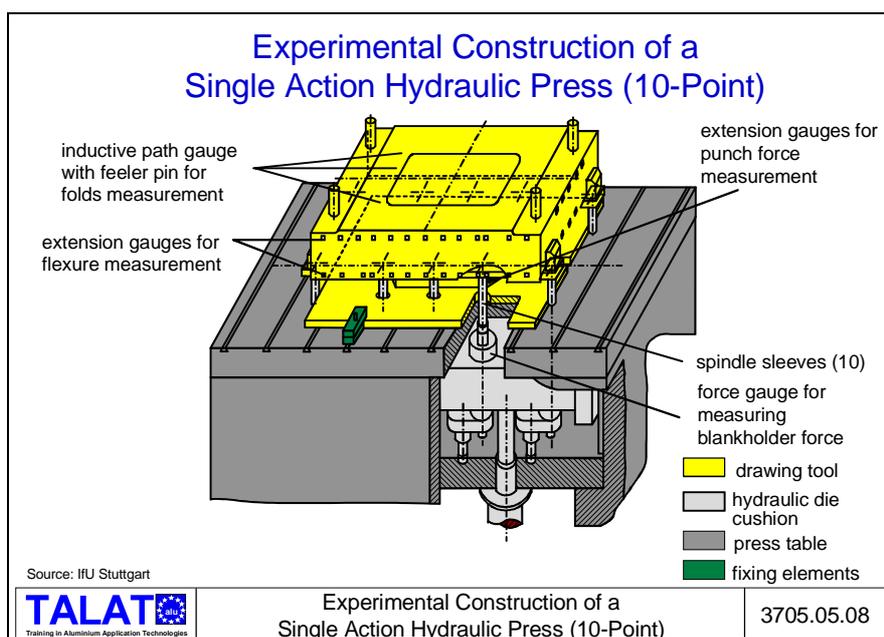
## Functional Principle of a Spindle Sleeve Adjustment

**Figure 3705.05.07:** The adjustable spindle sleeves are supported against pressure gauges fitted on the drawing cushion plate. The spindle sleeves are adjusted by hydro motors, belt drive and spline shaft, whereby the height adjustment is recorded on a moment controller.



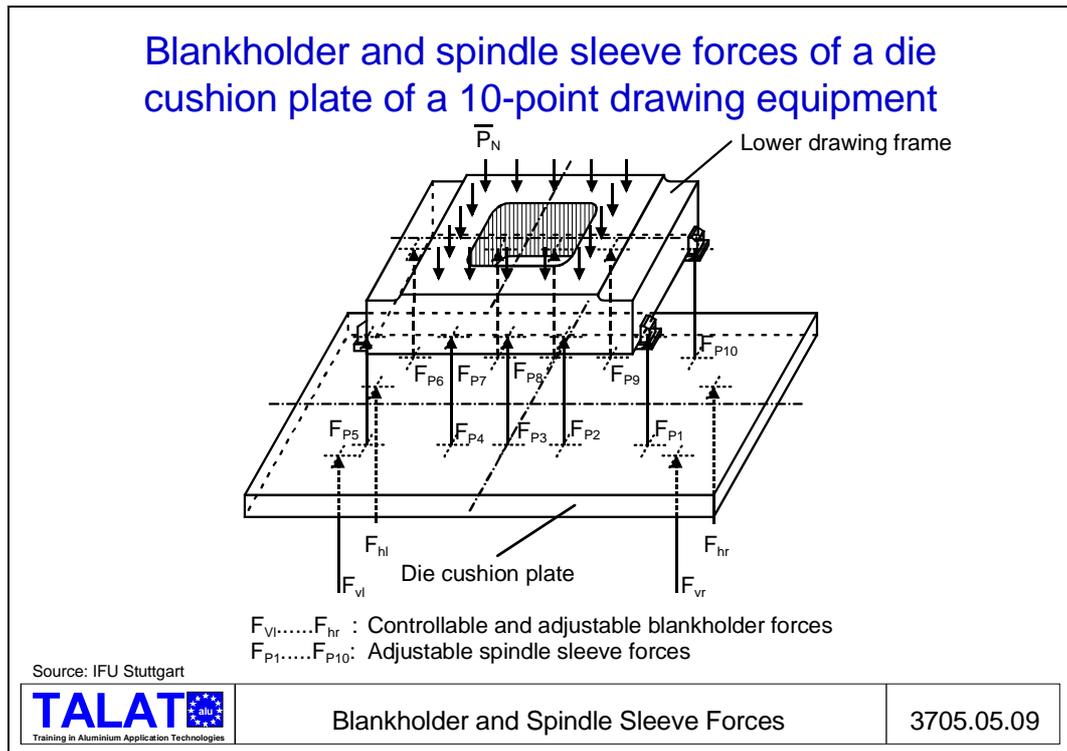
## Experimental Construction of a Single Action Hydraulic Press (10-Point)

**Figure 3705.05.08** shows the experimental construction of a single action hydraulic press with a 10-point die cushion in the press table. For details refer to **Figure 3705.05.06**.



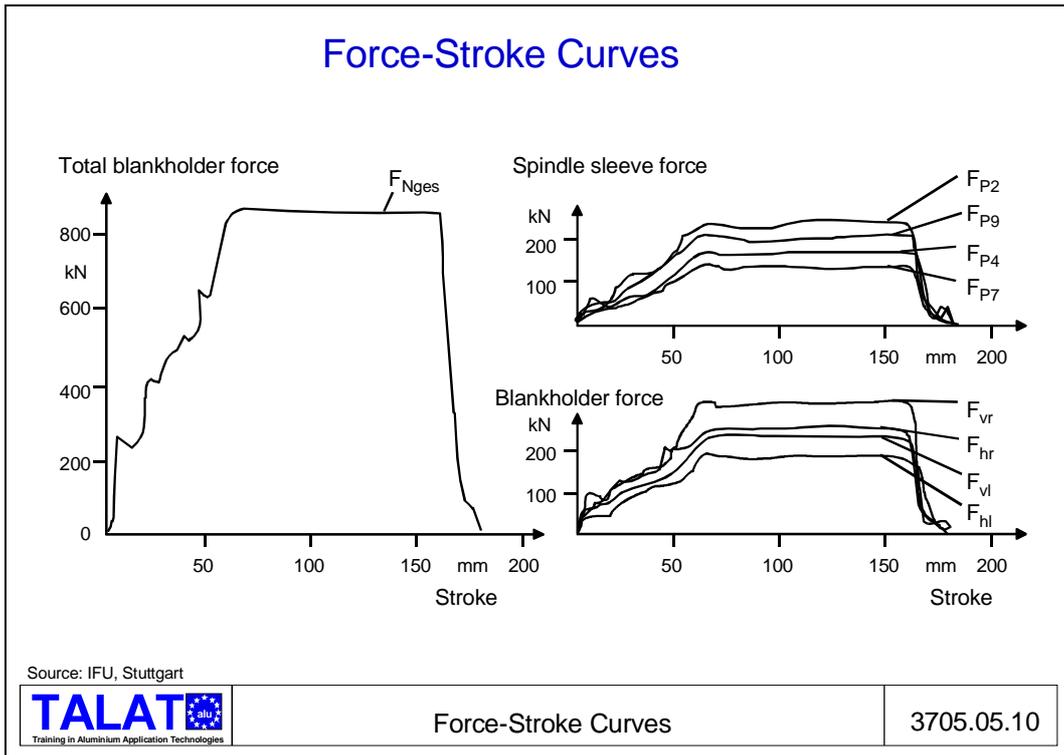
## Blankholder and Spindle Sleeve Forces

**Figure 3705.05.09** shows the blankholder and spindle sleeve forces acting on the drawing cushion plate of a 10-point die cushion based on the principle of four corner point cylinder forces  $F_{vl}$  (front left),  $F_{vr}$  (front right),  $F_{hl}$  (rear left) and  $F_{hr}$  (rear right). The sum of these forces is equal to the sum of the active spindle sleeve forces  $F_{P1}$  to  $F_{P10}$ .

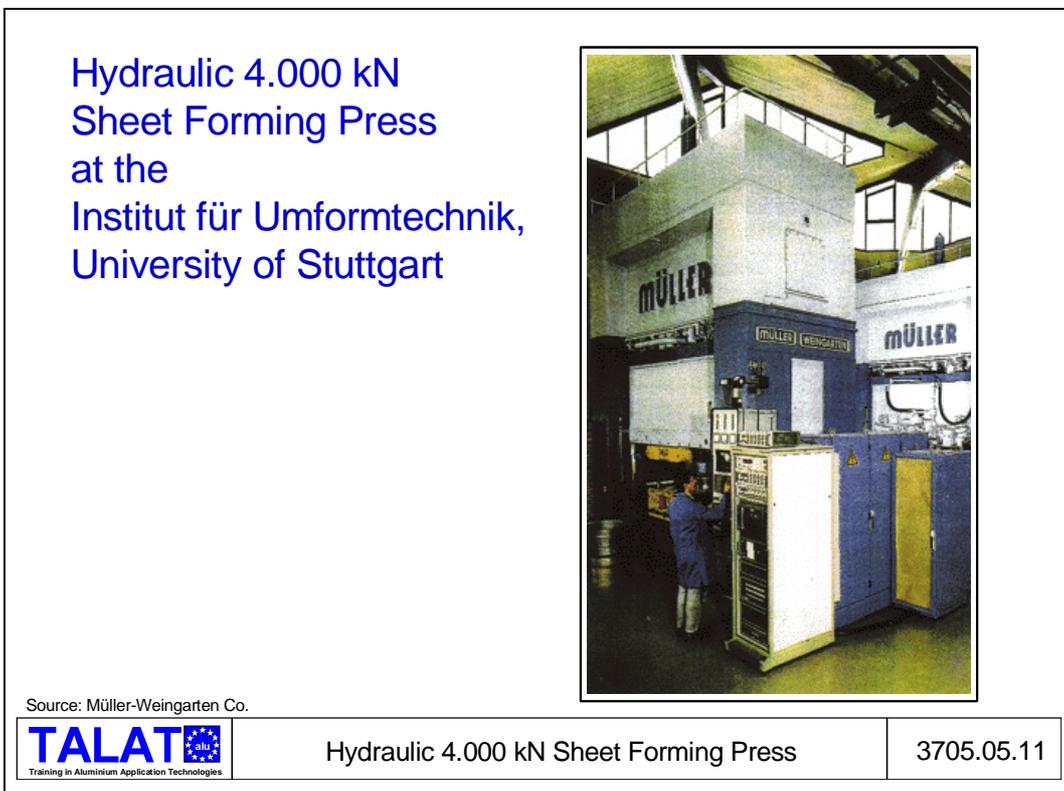


## Force Displacement Curves

**Figure 3705.05.10** shows the force-displacement curves of the total blankholder force  $F_{Ntot}$  (upper diagram) as well as for the four different blankholder forces ( $F_{vr}$ ,  $F_{hr}$ ,  $F_{vl}$ ,  $F_{hl}$ ), which were pre-set in a five-step rising gradient, over the full drawing path. Furthermore, it also shows the force-displacement curves for the four active spindle sleeves ( $F_{P1}$ ,  $F_{P2}$ ,  $F_{P3}$ ,  $F_{P4}$ ) as a function of the drawing path. The formation of force peaks was largely prevented by correctly pre-setting the individual force-displacement curves for the four active spindles.



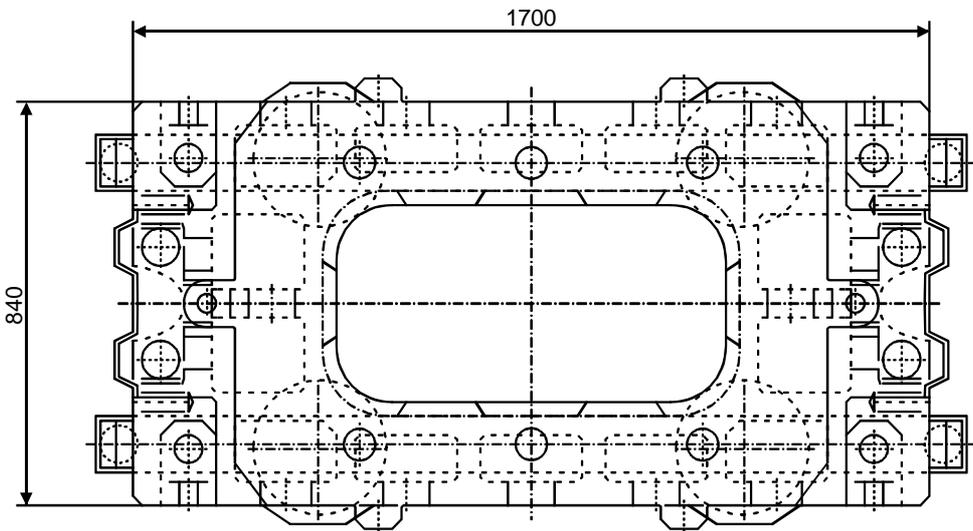
**Figure 3705.05.11** shows the hydraulic simple-acting 4,000 kN press supplemented by a 10-point die cushion at the Institute of Forming Technology (IFU) of the University of Stuttgart.



The characteristics of a multi-point die cushion in the press table of a simple-acting press with respect to the drawing process are summarised in **Figure 3705.05.12**.

<h3>Four-Point Die Cushion in the Press Table of a Simple Acting Press</h3>		
<ul style="list-style-type: none"><li><input type="checkbox"/> Force application to the blankholder can be adjusted to be most suitable for the tool.</li><li><input type="checkbox"/> Material flow controlled by a defined elastic flexure of the blankholder using a stored programmable height adjustment of the spindle sleeves.</li><li><input type="checkbox"/> Control and regulation of the blankholder force over the stroke using four hydraulic cylinders and the proportional valve technology.</li><li><input type="checkbox"/> Reproducible operational behaviour of the die cushion.</li></ul>		
	Four-Point Die Cushion in the Press Table of a Simple Acting Press	3705.05.12

**Figure 3705.05.13** gives an example of a lower drawing frame.

<h3>Lower drawing frame ( I )</h3>		
		
Source: IFU Stuttgart		
	Lower Drawing Frame ( I )	3705.05.13

## Demonstration Case of the Multi-Point Drawing Arrangement

Figure 3705.05.14 shows the lower drawing frame with a four-point force transmission for the forming of a rectangular cup. The flexural elastic deformation of this four-point drawing frame can of course be simulated by FE-calculations.

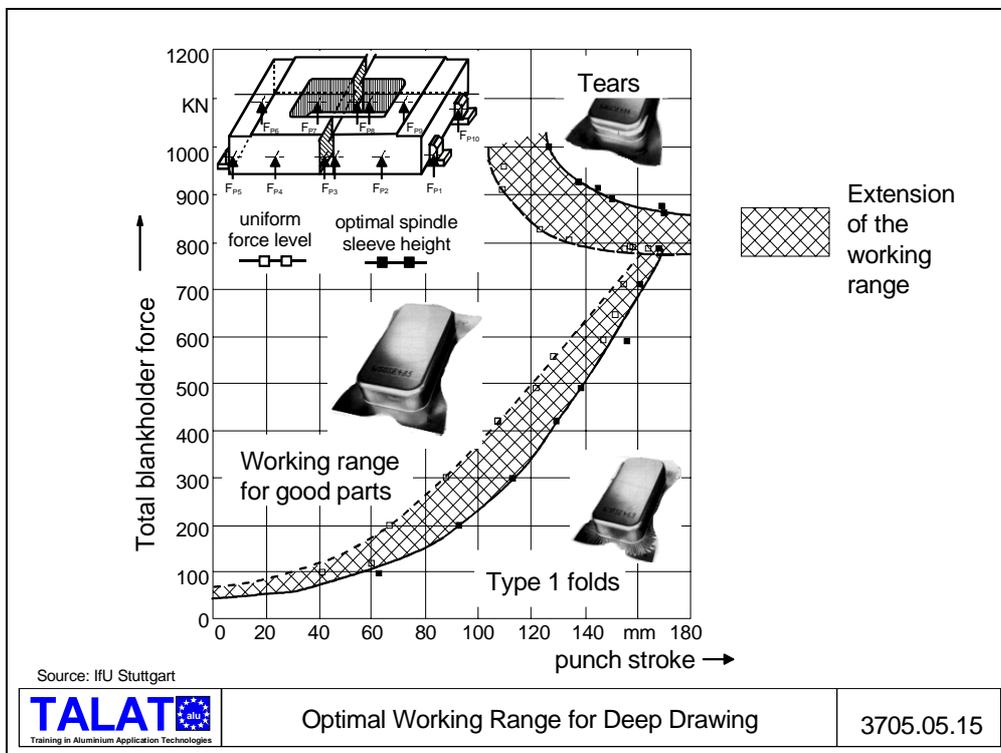
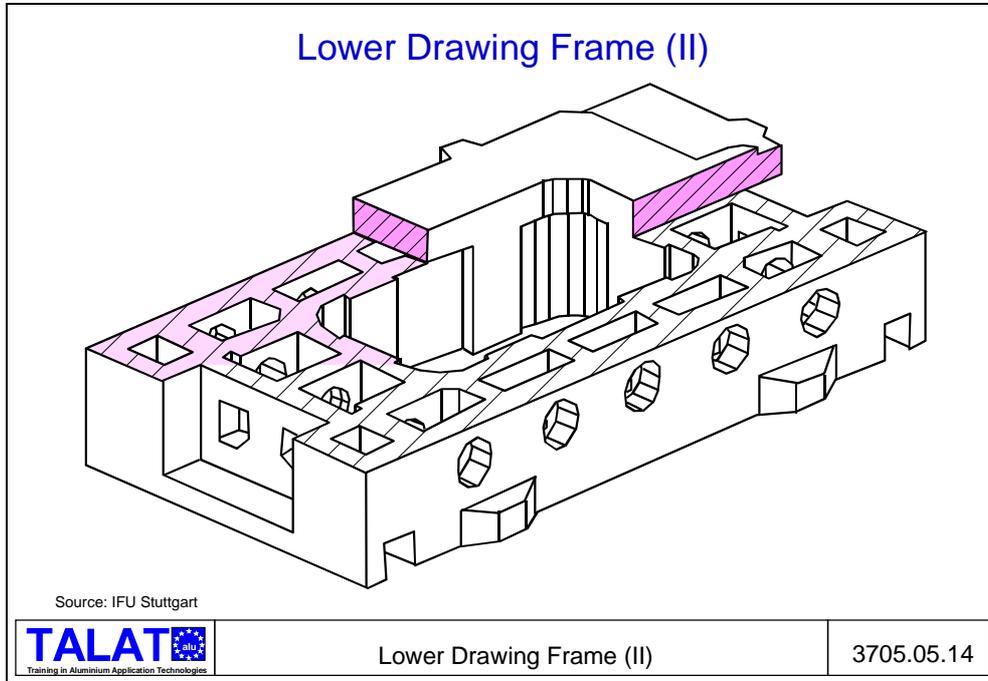


Figure 3705.05.15 shows that the working range for deep drawing can be extended considerably by the adjustment of the local blankholder pressure with the aid of the spindle

sleeves in a multi-point die cushion. The necessary adjustment of the blankholder force distribution depends on the specific tool geometry and can be determined for each drawing tool. The lower limit of the working range is a consequence of the formation of „type 1“ folds in the draw part flange. The upper limit of the working range is a consequence of the formation of tears in the region of the drawn part body. This working range has to be determined anew for each sheet-lubricant combination.

With an optimal adjustment of the spindle sleeves in a multiple point die cushion, it is possible to widen the working range for deep drawing and increase the draw depth.

## 3705.06 Tool Materials for Drawing of Aluminium Sheet Metal Parts

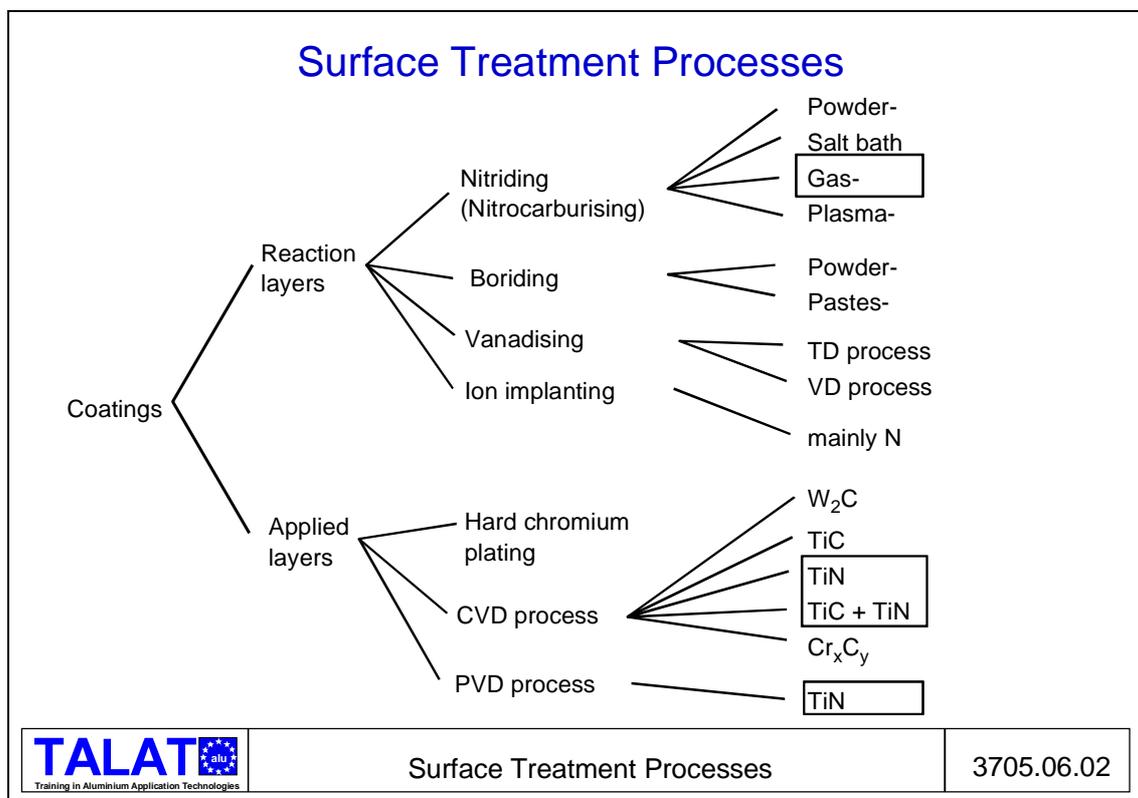
### Tool Materials

**Figure 3705.06.01** lists typical tool materials for drawing automotive steel and aluminium sheet metal parts. As in the case of steel, the drawing tools for aluminium are of grey cast iron quality. Experience has shown, however, that the surfaces of such materials are not suitable for forming aluminium. The materials 1.0443 (GS 45) as well as 1.2769 (GS 45 Cr Ni Mo 4 2) are more suitable, since better surface finishes can be obtained, which in turn reduce the tendency for wear and cold weld adhesion. The aluminium bronze AMPCO also has very good gliding properties.

<h2 style="color: blue;">Tool Materials</h2>		
<u>Steel sheet:</u>		
		0.6025 (GG 25 Cr Mo)
		1.2080 (X 210 Cr 12)
		1.2379 (X 155 Cr V Mo 12 1)
<u>Aluminium:</u>		
		1.0443 (Gs 45)
		1.2769 (G 45 Cr Ni Mo 42)
<p>The tool materials listed for aluminium allow a better surface finishing so that the tendency for cold welding is reduced.</p>		
Source: Haller		
	Tool Materials	3705.06.01

## Surface Coatings for Drawing Tools

Surface treatments are being increasingly used to improve the wear resistance and to prevent or reduce the possibility of cold welding as well as to improve the gliding characteristics. In addition to the classical processes of hardening, case hardening, nitriding, boriding and hard chromium plating, there is an increasing tendency to use hard compound layers based on titanium nitride (TiN) and titanium carbide (TiC). Such layers are applied using either the chemical vapour deposition (CVD) or the physical vapour deposition (PVD) process, see **Figure 3705.06.02**. Coatings deposited using the PVD process are gaining in popularity, since the process reaction temperature of maximum 550 °C is far below the tempering temperature of the tool steel used.



Through the use of coatings, it is possible to utilise the properties of both the protective coating and the base material. The protective coating increases the wear resistance and the base material absorbs the mechanical stresses without affecting the coating.

## 3705.07 Examples

Figure 3705.07.01: CAD depiction of a coupè door planking

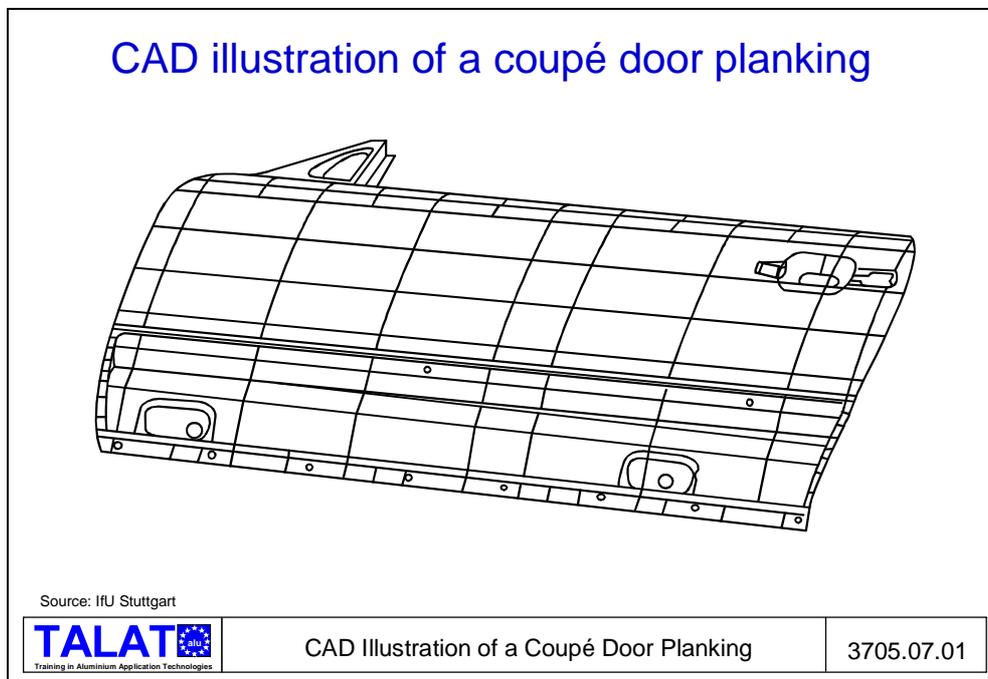
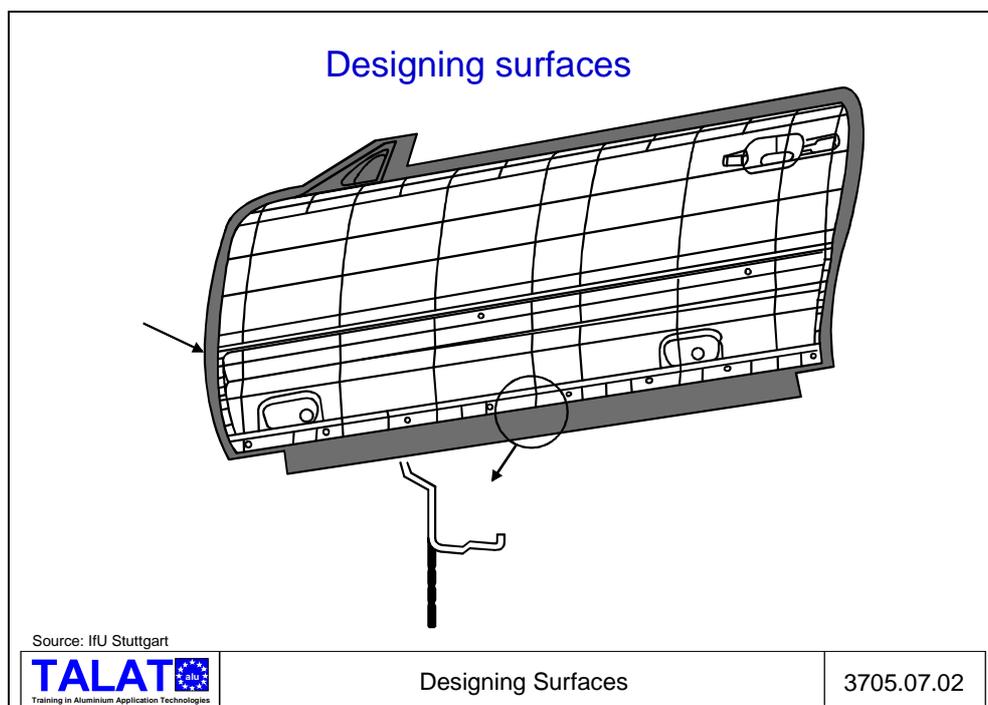
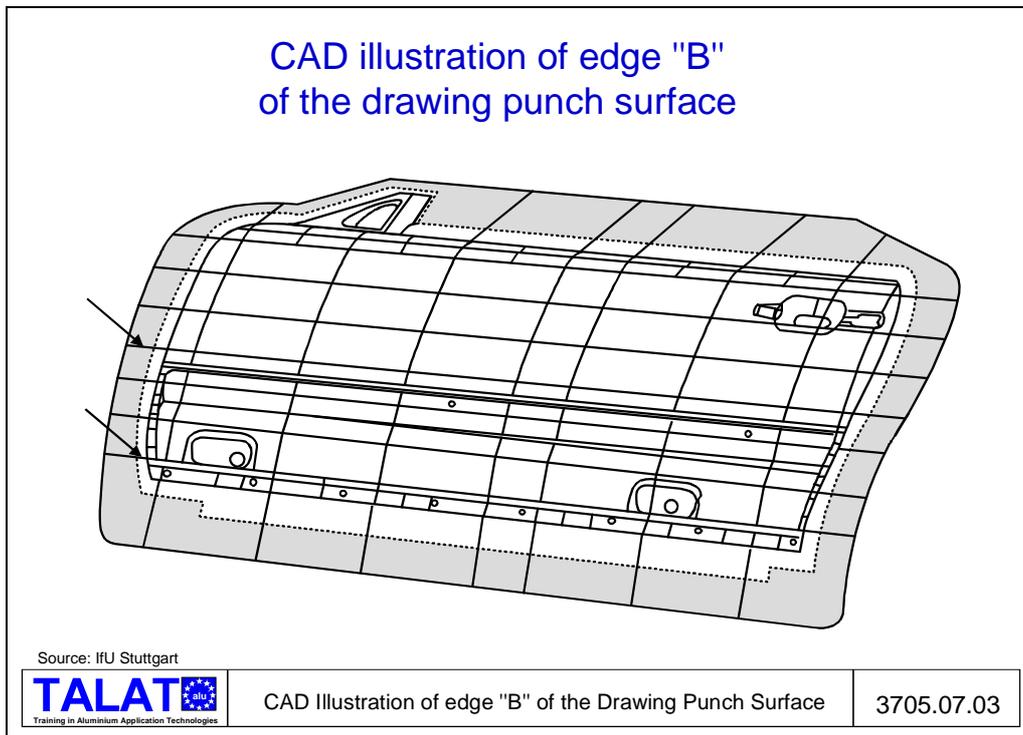


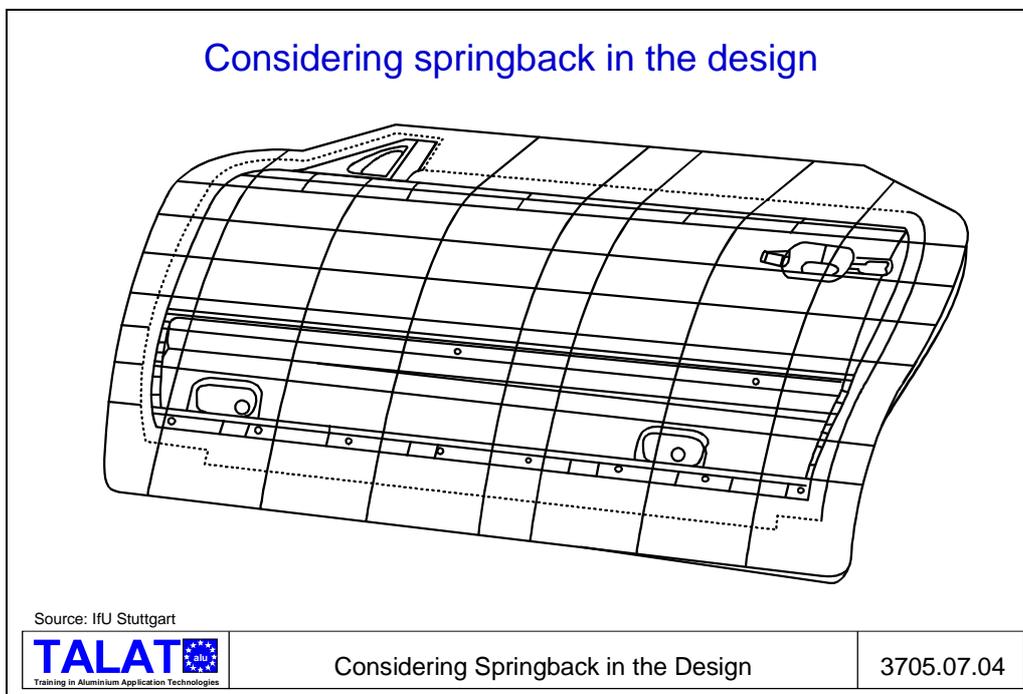
Figure 3705.07.02: Designing surfaces



**Figure 3705.07.03:** CAD depiction of edge "B" of the drawing punch surface



**Figure 3705.07.04:** Considering springback in the design



The a.m. Figures are all examples of computer assisted designing of body parts.

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