

AN OVERVIEW ON SHEET METAL HYDROFORMING TECHNOLOGIES

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ABSTRACT

The hydroforming process is a nonconventional method for producing sheet metal deep drawing pieces, under the direct or indirect action of a high pressure fluid on the inner or outer side of work piece wall. This process it's known since the 1900s and it has continuously developed, being today a field of research in the universities from country and abroad. The design of the hydroforming process can be done according to empirical, analytical and numerical methods to obtain high precision of the hydroforming piece and to ensure a large deformation of the material. The hydroforming parts can be used in various fields such as the automotive, aircraft and aerospace industries, having relatively low costs compared to parts obtained by other types of processing such as rolling, forging or stamping. The paper gives an overview regarding the sheet metal hydroforming processes, methods and the equipment used, as well as the process limits and defects that can occur during hydroforming.

KEYWORDS: sheet metal, hydroforming, punch, presses, defects

1. INTRODUCTION

The main feature in the manufacturing technologies of sheet metal hydroforming processes is the liquid pressure medium acting on the blank [1].

Sheet hydroforming process is increasingly being practiced in the modern manufacturing industry and results in a better condition of the strain in the workpiece so as to obtain a deeper depth of deep drawing [2].

Hydroforming is very advantageous in obtaining from a single operation of the deep drawing of whole components, which normally could be made from several stampings joined together. [3].

The components of the sheet hydroforming system are shown in figure 1. Those components requires a careful analysis, namely: the quality of the sheet in the deformation process, issues, such as friction or lubrication, related to the workpiece interface with the interface of the die, designing the equipment for effective application of the blank holder force and to avoiding leakage, the connection between the internal fluid pressure and the blank holder force, press and work equipment, the

dimensions and properties of the hydroformed part [4].

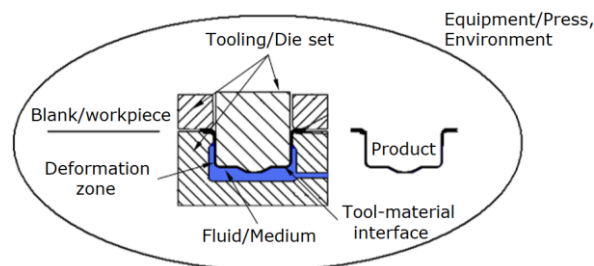


Fig. 1. Components of the hydroforming system [4]

Hydroforming may also have other specific names: hydromechanical deep drawing, hydraulic deep drawing or deep drawing with punch.

The hydroforming process includes a number of advantages [5]:

- deep drawing dies are simple, the punch is made of steel only in the case of steel sheet parts but also then it's used thermally untreated. For deep drawing of non-ferrous materials, the punch of the hydromechanical die is made of aluminum-zinc alloys, plastic or hardwood. Only an active element is rigid, so it's no longer necessary achieving precise

and uniform clearance of deep drawing and the processing can also be done without using the press;

- the pressure exerted by the liquid on the blank is uniform; the high and uniform pressure fluid creates a more advantageous state of stress and strain, allowing to obtain conical, spherical, parabolic, cylindrical, complex and deep parts;

- the precision and the quality of deep drawing parts are better than the pieces obtained by the ordinary deep drawing due to the absence of sliding friction between the blank and the die. The economic efficiency of the hydroforming process is more obvious in the case of complex shaped parts processing which are difficult to obtain by the usual deep drawing methods;

- reducing the cost of the die;

- increasing the depth of deep drawing.

As disadvantages of the process, can be mentioned:

- relatively low productivity in most situations of use mainly due to the particularities of the hydraulic systems in general;

- high cycle time;

- high cost of equipment; due to the pressure acting against the punch, hydroforming requires presses of high capacity compared to stamping;

- lower dimensional accuracy in complex geometries.

2. HYDROFORMING METHODS

Sheet hydroforming is classified as shown in figure 2.

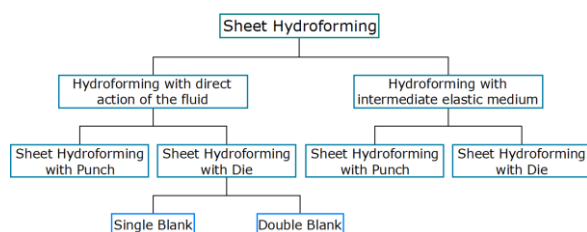


Fig. 2. Classification of hydroforming process

In the case of *sheet hydroforming with punch* (see figure 3.a), the die used in conventional stamping is replaced by the pressure. The pressure pot is generated by a pressurizing fluid, therefore the blank is deep-drawn to form the punch surface against a pressure [4].

The fluid in the pressure pot can be „actively” pressurized by an external pump or „passively” pressurized during the active stroke of the punch by controlling the pressure by a safety valve, allowing the fluid flow while the punch and the sheet are pushed into the pot.

In the case of *sheet hydroforming with die*, the sheet is formed against die by the hydraulic pressure of the fluid as shown in figure 3.b. During the forming process, the intermediate plate acts as a blank holder to control the material movement from the

flange and also seals the fluid medium to avoid leakage.

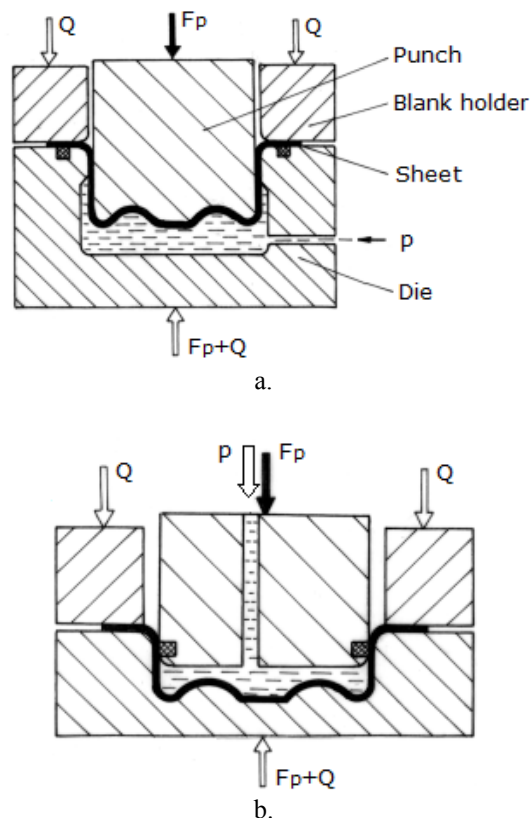


Fig. 3. Technological variants of sheet hydroforming process [5]

The hydroforming process with direct action of the fluid is also known as hydromechanical deep drawing. The deformation can be done by moving the flange or blocking its movement [5].

The method can be used to obtain conical parts, which, in classical terms, these parts are obtained from several deep drawing operations (see figure 4).

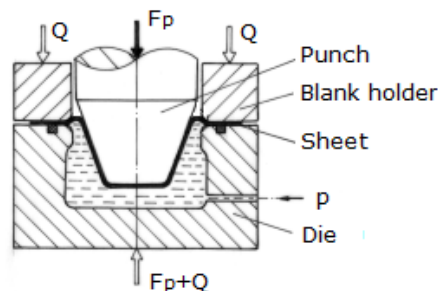


Fig. 4. Schematic of hydromechanical deep drawing of conical parts [5]

In the case of *hydroforming with an intermediate elastic medium*, a rubber elastic diaphragm or a rubber chamber is placed between the blank and the fluid. The working methods may be, as in the previous case, with die or rigid punch.

If a *rubber diaphragm* is used, it can be directly positioned on the blank or can be independent of it and connected to the fluid chamber.

The deformation can be done by moving the flange or blocking its movement in which case will occur the stretching of the material.

The pressure required for deformation may reach up to 200 MPa , depending on the material.

In this case, the deformation depth is not high, at most 50 mm , but different profiles can be obtained on the deformed surface.

The components of the hydroforming process using a rubber diaphragm are shown in the figure 5.

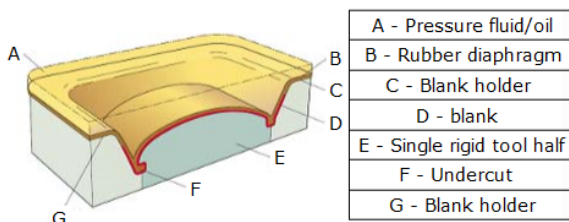


Fig. 5. The components of the hydroforming process using a rubber diaphragm [4]

In the case of hydroforming with a *rubber chamber* (see figure 6), the sheet deformation, T , is produced under the water action, A , pressurized into a closed chamber, C , whose walls are pressed against the sheet, forcing it to take the form of the punch, P , pressed with the active force, F_a [6].

The pressure, P_a , exerted by the water, is transmitted and evenly stretches the walls, avoiding the wrinkles formation.

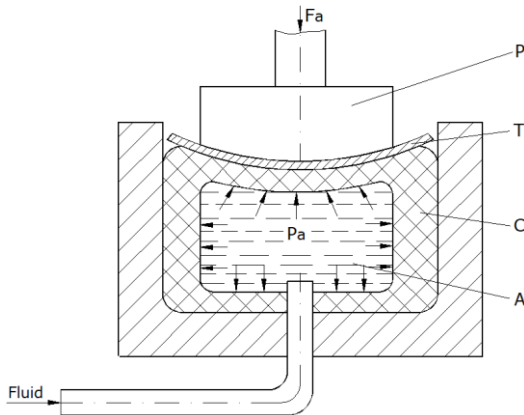


Fig. 6. The hydroforming process using a rubber chamber [6]

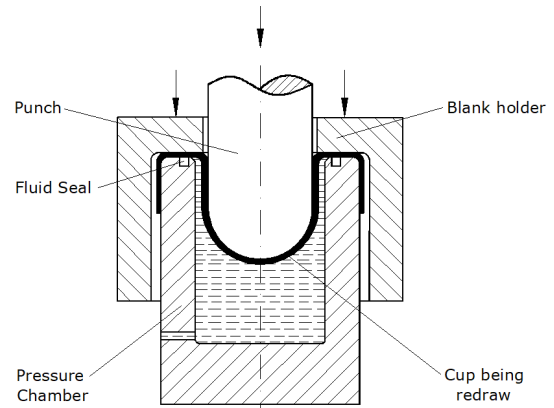


Fig. 7. Hydromechanical redrawing process [9]

Other unconventional methods within the hydroforming process are [9]:

- *hydromechanical redrawing* (see figure 7): has the same processing method as the hydromechanical deformation process except that, in this case, the former starts with a cup instead of a blank. The friction between the punch and the sheet metal reduce the tensile stress in the critical areas.

- *aquadraw* (see figure 8): this process differs from the classical hydroforming processes the disadvantage being a substantial leakage of fluid into the pressure chamber due to the absence of the fluid seal; this can be avoided if a very large blank holding force is applied;

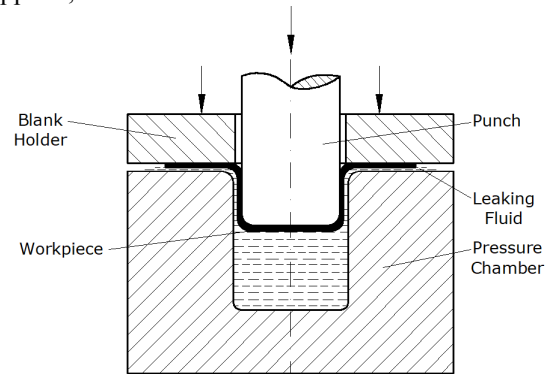


Fig. 8. Aquadraw process [9]

- *counter pressure deep drawing* (see figure 9): this method is also known as the radial pressure deep drawing process and is similar to aquadraw, except for the radial push and the top surface lubrication of the blank; compared to the classical hydroforming processes, this method uses a bypass on the periphery of the blank and includes a radial push;

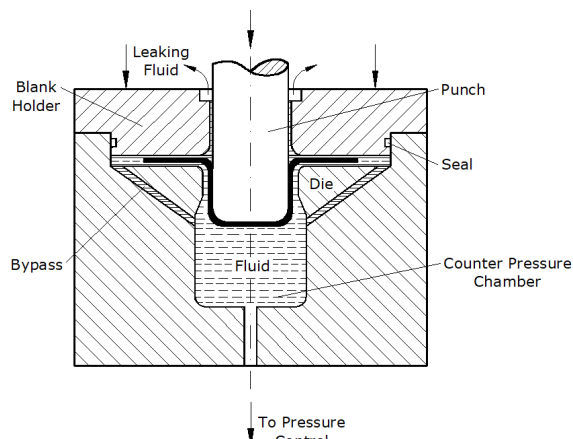


Fig. 9. Counter pressure deep drawing process [9]

- redrawing with counter pressure (see figure 10): in this case, the brim of the cup is pushed by the hydraulic pressure obtaining redrawing ratios of up to 2.3. This method possesses good features compared with conventional hydroforming processes such as higher accuracy, reduction of frictional resistance between die or blank holder surface and higher forming limit.

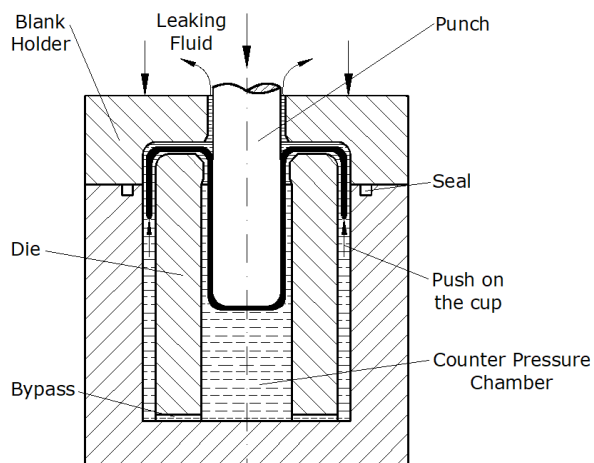


Fig. 10. Redrawing with counter pressure process [9]

- high-pressure radial extrusion of cups (see figure 11): the extrusion effect is given by keeping the clearance less than the blank thickness between the punch and the die. The blank is surrounded by very high-pressure fluid up to 700 MPa. To prevent excessive pinching of the blank a positive stop provided by a ring placed between the blank holder and the die is used.

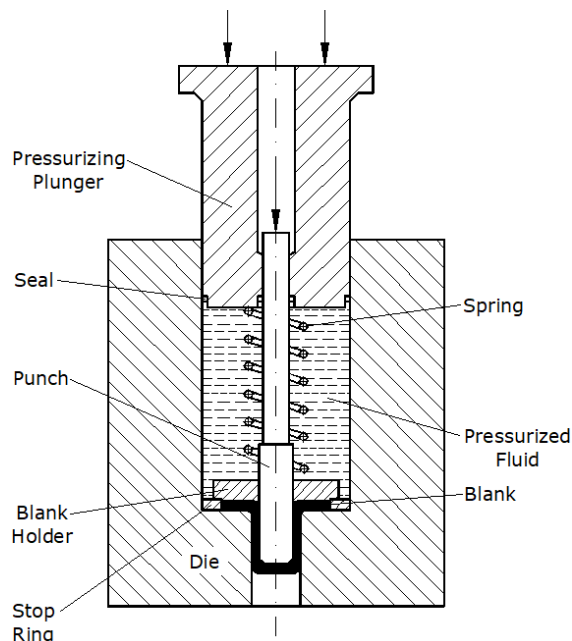


Fig. 11. High-pressure radial extrusion of cups process [9]

- hydraulic-pressure augmented deep drawing technique (see figure 12): in this process a hydraulic pressure is generated. The pressure must be proportional to the punch force and is applied on the end of the cup flange. This method was invented and developed at the Nanyang Technological University. This method no longer needs a cushion because the deep-drawing process can be easily carried out on a single-action press [10].

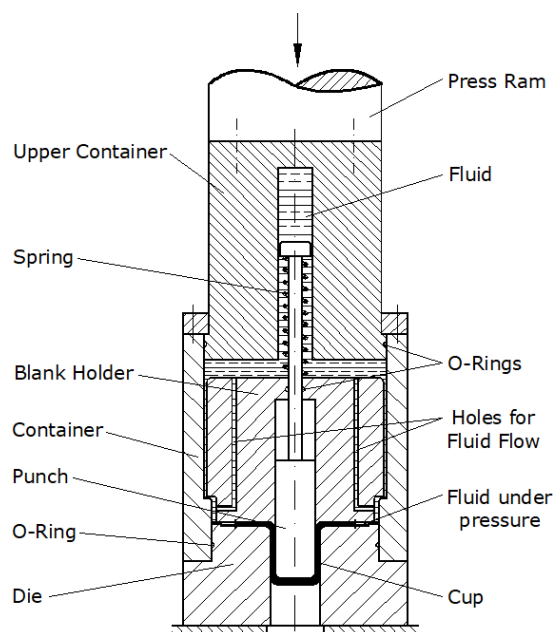


Fig. 12. Hydraulic-pressure augmented deep drawing technique [9]

3. HYDROFORMING EQUIPMENTS

3.1. Presses for sheet hydroforming with punch

In this hydroforming method, hydraulic presses are used which contain a counter pressure pot and provides high ram forces. A press used for the sheet hydroforming with punch process is shown in figure 13.

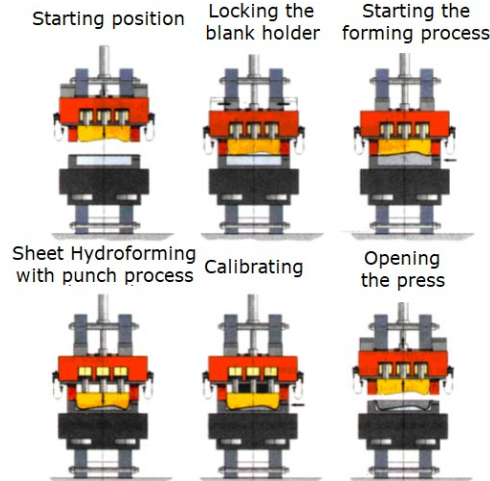


Fig. 13. Press used for sheet hydroforming with punch process designed by Müller Weingarten [4]

This press, weighing 3500 tons, is designed by Müller Weingarten, who uses the „short stroke” concept [4].

A similar press with the one designed by Müller Weingarten is the press introduced by Schnupp Hydraulik using the „short stroke” cylinder concept (see figure 14), having about the same operation sequence like the one presented in figure 13. The press has multi-point cushion systems that provide the advantage of changing the blank holder force in space over the flange area and during the sheet hydroforming with punch process.

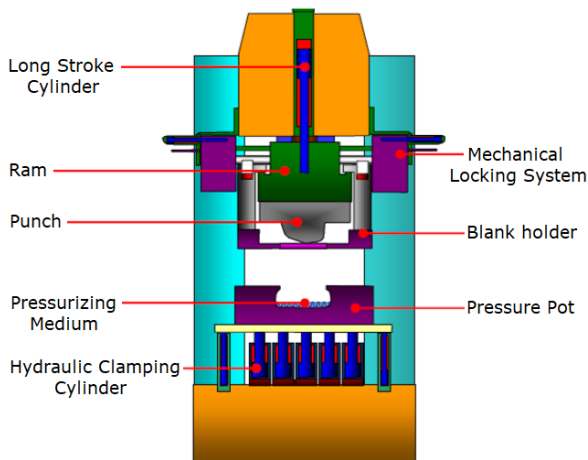


Fig. 14. Press used for sheet hydroforming with punch process designed by Schnupp Hydraulik [4]

Figure 15 shows a press used in „Active-Hydro-Mec” process. This concept was developed by Schuler SMG GmbH and Co. KG [Stremme et al., 2001] where a double-action straight side press is used.

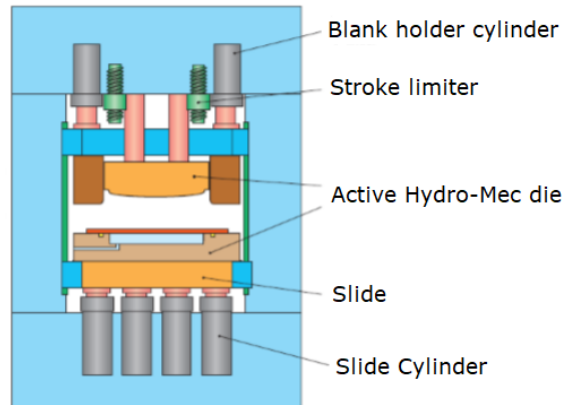


Fig. 15. Press concept for „Active-Hydro-Mec” process [4]

3.2. Presses for sheet hydroforming with die

In the case of large automobile parts hydroforming, a 100 mN press was built by the University of Dortmund (LFU), Germany, in collaboration with Siempelkamp Pressen Systeme, Germany, a necessary press in the sheet hydroforming with die process (see figure 16). The advantages of this press are: inexpensive compact design because of the horizontal mounting of the press, easy part handling and short strokes for the cylinders to reduce the cycle time production [4].

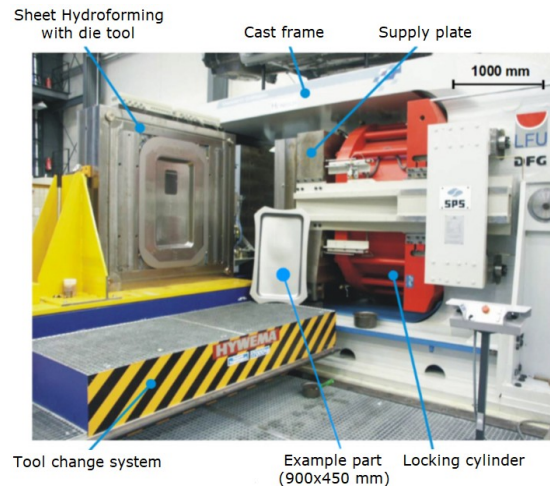


Fig. 16. Horizontal sheet hydroforming with die press [4]

4. PROCESS LIMITS AND DEFECTS IN HYDROFORMING PROCESSES

4.1. Sheet hydroforming with punch

The defects that may occur during the sheet hydroforming with punch process are: excessive thinning, flange and sidewall wrinkles, excessive bulging (see figure 17.a) and surface marks (see figure 17.b). These defects can lead to fracture of the material and leaking of the pressurizing medium [4].

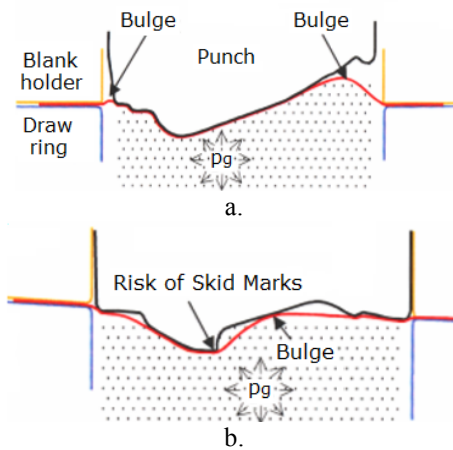


Fig. 17. Bulge formation in sheet hydroforming with punch [4]

Thereby, due to excessive bulging of the sheet, in figure 18 is shown a section of an automotive fender which can be seen the bulging of the sheet.

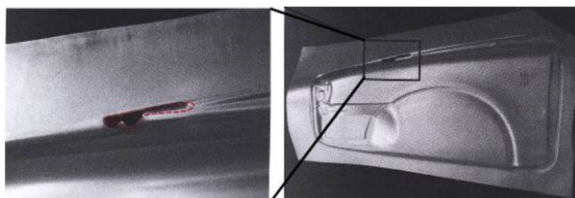


Fig. 18. Tearing of the sheet due to excessive bulging [4]

The combination of the process parameters of the sheet hydroforming part is called the process window. This process ensures the part to be formed with no defects. Thereby, an example of a process window is shown in figure 19, being used as process parameters the blank holder force and the pot pressure.

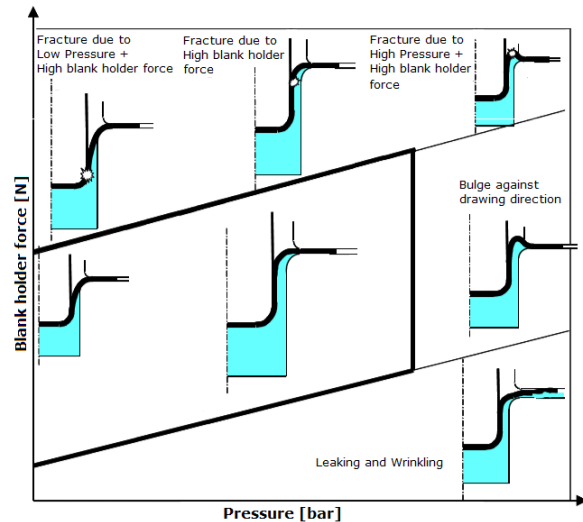


Fig. 19. Process window for the sheet hydroforming with punch process [4]

Fracture can be avoided by increasing the pot pressure or by decreasing the blank holder force. Also, bulging can be avoided by decreasing the pot pressure [4].

4.2. Sheet hydroforming with die

In this case, the defects in sheet hydroforming with die during forming are: excessive thinning, wrinkling and the leaking of the pressurizing medium [7].

In figure 20 is shown the process window defined using the forming pressure and the blank holder force as process parameters.

This process window was studied by Novotny et. al, 2001, Shulkin et al., 2000 and Kleiner et al., 2004.

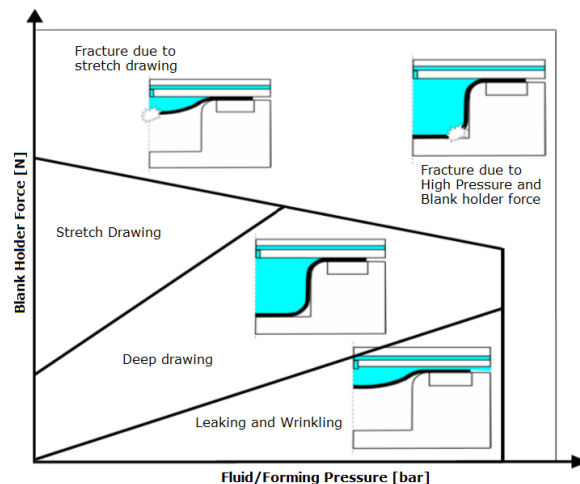


Fig. 20. Process window for the sheet hydroforming with die process [4]

5. THEORETICAL MODELS FOR THE ANALYSIS OF HYDROFORMING PROCESSES

The schematic of hydromechanical deep drawing process is shown in figure 21.

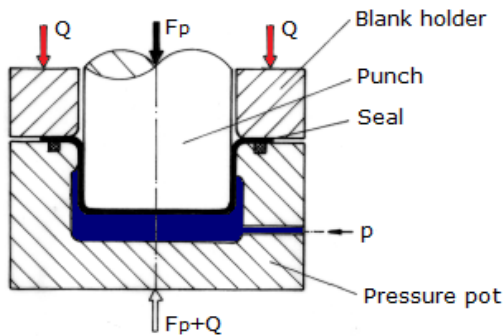


Fig. 21. Schematic of hydromechanical deep drawing [5]

The total pressing force, F_t , can be determined with:

$$F_t = p \cdot A + F_p + F_{spr} + F_{spa} + Q, \quad (1)$$

where: p is the hydraulic pressure, which may have the following values: for aluminum, $p=50...200$ bar; for steel, $p=200...600$ bar; for stainless steel, $p=300...1000$ bar;

- A - the cross section of the punch;
- F_p - deep drawing force;
- F_{spr} - the friction force between the blank and the blank holder;
- F_{spa} - the frictional force between the blank and the die;
- Q - blank holder force.

The minimum pressure, p_{min} , is the lowest pressure that will initiate the sheet hydroforming process and can be [8]:

$$p_{min} = \frac{\sigma_{yield} \cdot t}{r_{min}}, \quad (2)$$

where σ_{yield} is the yield strength of the blank material, [MPa];

- t - the wall thickness of the blank, [mm];
- r_{min} - the minimum radius of the part, [mm].

The maximum pressure, p_{max} , is the highest pressure that will break the sheet:

$$p_{max} = \frac{\sigma_{UTS} \cdot t}{r_{min}}, \quad (3)$$

where σ_{UTS} is the ultimate strength of the blank material, [MPa].

The minimum blank holder force, $MinF_{BH}$ is:

$$MinF_{BH} = p_n \cdot \frac{\pi}{4} \cdot (D_0^2 - D_s^2) + F_{BH/pressure} + F_{BH/bulge}, \quad (4)$$

where p_n is the blank holder pressure;

- D_0 - outgoing blank diameter;
- D_s - sealing diameter;
- $F_{BH/pressure}$ - the vertical force from pressure acting on the blank holder;
- $F_{BH/bulge}$ - the bulge force acting on the blank holder.

The blank holder pressure, p_n , is:

$$p_n = 0,002...0,0023 \left[(\beta_0 - 1)^3 + 0,5 \cdot \frac{D_{punch}}{100 \cdot t_0} \right] \cdot \sigma_{UTS}, \quad (5)$$

$$\text{where } \beta_0 = \frac{D_0}{D_{punch}}; \quad (6)$$

- D_{punch} - punch diameter;
- t_0 - outgoing blank thickness.

$F_{BH/pressure}$ is the vertical force acting in the space between the die and the sheet metal on the blank. It can be determine by:

$$F_{BH/pressure} = \frac{\pi}{4} \cdot p_c \cdot (D_s^2 - D_{BH}^2), \quad (7)$$

where p_c is the working pressure;

- D_{BH} - inner blank holder diameter.

$F_{BH/bulge}$ is the bulge force acting on the blank holder in the space between the inner diameter and the contact line:

$$F_{BH/bulge} = \sigma \cdot D_{BH} \cdot \pi \cdot t, \quad (8)$$

$$\text{where } \sigma = \frac{p_c}{4 \cdot t} \cdot (D_{BH} - D_{contact}); \quad (9)$$

where $D_{contact}$ is the contact line diameter.

5. CONCLUSIONS

The hydroforming process consists in the fact that on the planar blank or on the semifinished piece acts, directly or through an intermediate elastic medium, a high pressure liquid, giving them the shape of the inside of the die or the outer contour of the punch.

The pieces are generally obtained from a single operation, replacing complicated technologies with many operations.

The increasing application of sheet hydroforming technologies in automotive and aerospace industries is due to its advantages over classical processes as stamping or welding.

The wrinkling, the leaking of the pressurizing medium and the bulging of the sheet metal are the

common defects that can appear during the hydroforming processes.

Studies have been devoted to the hydroforming processes allowing the prediction of the material flow and the contact boundary evolution during the process.

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REFERENCES

- [1] **Bakhshi-Jooybari, M., Gorji, A., Elyasi, M.**, *Developments in Sheet Hydroforming for Complex Industrial Parts, Metal Forming - Process, Tools, Design*, INTECH, 2012;
- [2] **Koc, M.**, *Hydroforming for advanced manufacturing*, Woodhead publishing limited, 2008, pag. 396;
- [3] **A., Kocanda, H., Sadlowska**, *Automotive component development by means of hydroforming*, Archives of Civil and Mechanical Engineering, Vol. 8, No. 3, Decembrie, 2008, Polonia;
- [4] **Ajay, D., Yadav, M.S.**, *Process Analysis and Design in Stamping and Sheet Hydroforming*, The Ohio State University, 2008;
- [5] **V., Păunoiu, D., Nicoară**, *Tehnologii de presare la rece a tablelor*, Ed. Cartea Universitară, 2004, București;
- [6] *****Internet** <http://www.scribub.com/tehnica-mecanica/Ambutisarea-hidraulica-cu-came1851413116.php>;
- [7] **Hariharasudhan, Palaniswamy, M.S.**, *Determination of Process Parameters for Stamping and Sheet Hydroforming of Sheet Metal Parts using Finite Element Method*, The Ohio State University, 2007;
- [8] **Thanasan, Intarakumthornchai, Suwat, Jirathearanat, Siricha, Thongprasert, Pramote, Dechaumphai**, *FEA Based Optimization of Blank Holder Force and Pressure for Hydromechanical Deep Drawing of Parabolic Cup using 2-D Interval*, Engineering Journal, Volume 14, Issue 2, 2010;
- [9] **S., Thiruvardhelvan, F.W., Travis**, *Hydraulic-pressure-enhanced cup-drawing processes - an appraisal*, Journal of Materials Processing Technology, 2003;
- [10] **S., Thiruvardhelvan, H., B., Wang**, *Pressure generated in the hydraulic-pressure augmented deep-drawing process*, Journal of Materials Processing Technology, Volume 74, Issues 1–3, February, 1998.