INTRODUCTION TO THE HYDROFORMING PROCESSES

Alessia Mentella
Università di Cassino

Sheet Metal Hydroforming (SHF)

To try to answer some of the most important global demands of current designs, such as economic efficiency of technical solutions, careful handling of energy and raw materials, optimized work-piece properties innovations in processes and approaches, near to more conventional solutions, are developed.

Moreover it is to consider that the increasing technological demands concerning the function of products, for instance in structural parts of cars, in medical instruments or in household hardware, are further reasons for increasing difficulties in the production of more complex work-piece geometries. At last it is to consider that consumer behaviour is changing: the trend is going away from mass-production articles towards the more custom made products; in fact, if the low-cost production of mass-products has in the past always been in the foreground, today new processes are being developed, which are making the economical small-lot production of custom-made products possible.

Conventional sheet metal forming processes will not be able to meet these varieties of demands and new manufacturing technologies, such as Hydroforming, using fluids as a replacement or support of rigid tools, could prove to be more flexible and efficient: this would enable the production of distinctly more complex component shapes with high surface quality and optimized structural properties. This will lead to a completely new category of sheet metal formed parts, made of sophisticated materials, produced in only one manufacturing process, offering new prospects for light-weight constructions and for cheaper products taking care of the environment.

All working media based methods can be classified into groups according to:

- the working media role (punch or die);
- the blank-holder presence or absence;
- the form of contact between the work-piece and the working media (direct or indirect).

So it is clear that by combining all the previous possibilities, the number of potential versions increases.

Hydromechanical Deep-Drawing

Hydromechanical deep-drawing with working media as a die and adjustable blank-holder force is very controllable process and the products quality is very high.

If a hydraulic counter pressure is applied during deep-drawing of rotationally symmetrical sheet metal parts, the sheet metal is pressed against the punch. The counter pressure is generated by penetration of the punch, i.e. by “passive” compression of the hydrostatic medium (fig 1.1). When the punch ends his stroke and is situated at the lower dead centre, it is possible that the sheet is not completely formed and does not perfectly adhere to the punch, especially in the concave zones with small curvature radius; so the smaller the contour radius \( R \) and the higher the sheet thickness \( t \), the higher the pressure for calibration, to make it completely adherent to the punch.

\[ P_{\text{max}} = f (R_{\text{min}}, s, t) \]
Therefore, it is indispensable sometimes to increase the pressure up to 250 MPa (2500 bar) in the counter pressure pot, actively, by a pressure generator.

The material flow in the forming zone is affected by the blank-holder force and, when it is absent, the effective control of the sheet draw-in is difficult, so the blank-holder task is assigned to the working media. Consequently the force that restrains the sheet flow on its horizontal plane is proportional to the working media pressure, so that, with high pressure values, a hydromechanical stretch forming process is obtained. It is characterized by tractive stresses along both principal directions on the sheet plane instead of tractive stresses along one direction and compressive stresses along the other one.

The main technological advantage of this process over conventional deep-drawing is the greater material adhesion to the punch already during first forming steps; this behaviour prevents localized thinnings, especially close to convex contour.

Furthermore, the higher thickness uniformity in hydromechanical deep-drawn parts allows to gain limiting drawing ratio $\beta$ (the ratio between the maximum initial blank diameter possible to draw without tearing and the punch diameter) higher than those attainable by conventional deep-drawing, so parts which could be formed with a certain number of different steps, here can be performed in a single operation.

With this forming method there is the possibility of reducing the product specific tool and die costs to a significant degree and thereby reducing the production costs; in fact the Hydromechanical deep-drawing method requires instead of a complex lower binder (female die) a simple and easy to manufacture counter-pressure pot.

![Figure 1.1: Hydromechanical deep-drawing](image1)

![Figure 1.2: process limit “bulge against the drawing direction”](image2)
The main process limits are related to the whole system cost (presses and pressure intensifier), to the slowness and particularly to some technological intrinsic limits such as wrinkling, tearing and “bulging against drawing direction”, between the draw-ring radius and the sheet metal/punch contact line (fig. 1.2).
In the first case the blank-holder force is not enough high to avoid the upload from its plane and when this appends, the material flow in the forming zone become uncontrollable, with wrinkling; in the third case, especially with tapered components, when the counter pressure is higher than its bursting pressure, we can have the bulge bursting. One possibility concerning the reduction of the bulge against drawing direction and concerning the prevent of a burst in the bulge, establishes an integration of an upper support chamber in the upper binder (fig. 1.3). It is possible to build up this pressure support chamber through a sealing between the punch and blank-holder as well as through a sealing between the blank and the blank-holder and the draw-ring.

A different version of the previous method consists in a combination of hydraulic stretch forming and hydromechanical deep drawing, also known as “Active Hydromech” or “Prebulging”. As shown in figure 1.4, with flat parts it is possible to initially perform hydraulic stretch forming with active pressure built-up from an external pressure source in order to achieve work hardening the middle areas of the part. After stretch forming the panel to approx. 2% of the principal strains in the middle area, reverse drawing can be accomplished by travelling the punch downwards. In this case the pressure is generated passively by penetration of the punch, i.e. by compression of the hydrostatic medium.

**Flexforming**

The trends in sheet metal forming industry appear to be towards a wider variety of models on few platforms, shorter development and program cycles, and more low volume production. Increased quality and safety
requirements have, at the same time, resulted in increased development costs for prototype building and testing. These trends and circumstances continue to increase the industry’s interest in low investment/short lead time sheet metal forming methods for the manufacture of development and production sheet metal parts.

Flexforming is one such method for the manufacture of development and production parts, and at considerably lower cost and with shorter lead times than can be achieved with traditional methods.

Flexforming is a sheet metal forming method that requires only one rigid shape-defining tool half to form and, if desired, trim a part to final shape. The sheet metal blank is forced to assume the shape of the rigid tool half by a flexible diaphragm pressurized by a high-pressure fluid. Fig. 1.5 shows the principle of a Hydroforming cycle. The blank is positioned on the single rigid tool half, which is placed on the press table; the table is moved into the press frame, where the other tool half, a flexible diaphragm with oil back up, is located. The oil is pumped into the press above the diaphragm and forces it to wrap the blank around the rigid tool half. The high and uniform forming pressure ensures close tolerances and makes undercuts and trimming possible. After decompression of the pressure fluid, the diaphragm returns to its initial upper position, leaving the formed part on the single rigid tool half to be removed after the press table is moved out of the press frame.

Although very high forces are required in Flexforming processes, maximal attainable pressure are anyway moderate, so this process seems to be particularly fitted for high dimension parts with small drawing ratio.

For very deep and complicated deep-drawing parts, a movable punch is used also with a flexible rubber diaphragm as the other universal tool half.

Generally the blank-holder is not present and the blank is holded by the flexible diaphragm, which is pressurized by the overhanging fluid; so that the material flow depends only on the pressure value and it results less controllable process, which requires dies and punches careful design and shrewd selection of initial blank dimensions.

The minimal concave curvature radii attainable depends on blank material and thickness $t$ and on the maximal forming pressure. Moreover its value is limited by the presence of the flexible diaphragm, which sometimes, to resist to the high pressure value, has higher thickness than the blank, so that circumstance make it difficult to penetrate in small cavities. Another Flexforming characteristic is the possibility to integrate in the forming process, a trimming operation, which is feasible because of the presence of the rubber diaphragm: when the metal begins to tear during trimming, the diaphragm continues to seal off the pressure fluid and maintains the high pressure required to complete the trimming operation.

In conclusion, the main advantages of applying Flexforming for the low-volume production and development parts are:

![Figure 1.5: the principle of Flexforming, before, during and after forming.](image-url)
• only one single rigid tool half is required to form a part;
• tool cost reductions of 50 – 90%;
• reductions in tool and part lead time of 50% and up;
• various blank materials and different thickness can be formed using the same tool half;
• the single tool half can easily be modified at low cost to accommodate part design changes;
• parts have higher quality and closer tolerances due to the fact that the parts are formed to finished shape and hand forming/finishing is reduced or eliminated.

Double Sheet Hydroforming
The use of liquid-based forming processes represents an excellent way to manufacture complex sheet metal components with reproducible shapes and functions. However solutions for the production of complex hollow components in a single manufacturing step are offered only by the tubes hydroforming. Currently, new requirements, particularly in automotive industry, such as economical production of recessed products and the requirement for the improved material and component characteristics allow the assumption that this process will be used to a significantly higher extent in the future.

The initial part is produced using two flat or pre-shaped sheet metal plates, arranged in parallel and in contact with one another with the same or different sheet metal thickness and of the same or different type of material with identical edge dimensions and welded to one another at the edge. The double plate produced in this manner is inserted into a tool consisting of upper and lower dies; after the tool is closed, the edge area of the plate including the weld is located between the sheet metal retaining surfaces at the upper and lower tool part with higher or lower width. The component is shaped by a pressure medium between the plates (fig. 1.6). Depending on the material used and the component geometry, the flange can be clamped stationary or the flange can be allowed to flow into the tool die.

Moreover it is necessary to integrate a suitable docking system into the tool to allow the pressure medium to be fed in during the forming process. Various docking systems are suitable for injecting the pressure medium between the two plates depending on the material flow requirements and the most familiar are the “sealing lance” and the “hemispherical sealing ram”.

The sealing lance, is inserted at the unwelded point between the plates with the tool closed; the upper and the lower dies have a recess in this area, so that, the penetrating lance displaces the sheet metal material in the radial direction in the recess. This system is suitable for parts or part areas where a high material flow from the flange area into the actual tool die is required.

![Figure 1.6: Process principle for parallel plate Hydroforming.](image-url)
As mentioned above, parallel plate hydroforming, in contrast to tubular hydroforming, offers the possibility of producing different sheet metal thicknesses and materials in one forming step without relevant additional costs. However, in varying the plate thicknesses, it is necessary to take into consideration the flow start and instability limit for the various plates, to obtain perfect forming results.

In spite of several advantages in comparison to deep drawing and to tubular hydroforming, it is necessary to consider the process limits, regarding particularly the components design. In fact, since the upper and lower plates are already welded to one another at the circumference at the beginning of the process, part flanges positioned on top of one another are pulled together into the die. At various drawing depths or extensions of the upper and lower component shells, the flange of the part with less depth therefore has a braking effect on the flange of the deeper part. On the other hand, the flange of the deeper part attempts to pull the flange of the less deep part into the die with itself. This can result in the deeper half shell tearing and/or formation of creases in the less deep half shell (fig. 1.9).

As a matter of principle, the same extended dimensions should be attempted for the upper and lower shell; deviations in the developed dimensions in the upper and lower shell in the magnitude between 5% and 10-15% are permissible, depending on the material.

Moreover, in designing component corners, particular attention must be paid to the dimensioning of the corner radii: while convex component radii are completely formed when the ram enters the tool during deep drawing, formation of such radii during hydroforming is accomplished within the scope of calibration phase at the end of the forming process. This has permanent effects on the producibility particularly of small component corner radii with simultaneously deep part geometries.

Due to the higher normal contact stresses and the resulting friction forces, the material flow from the areas of the parts adjacent to the corners into the corner area is impeded during hydroforming; therefore final forming of the corners is accomplished almost exclusively at the cost of the wall thickness in the corner area, particularly at the end of the calibration operation at extremely high internal pressures. This can lead to critical thinning followed by bursting particularly for small corner radii before the corner area is completely formed.

![Figure 1.7: example for producible and non-producible cross section geometries.](image)

**Tube Hydroforming (THF)**

Tube Hydroforming (THF) has been called with many other names depending on the time and country it was used and investigated. The first industrial applications for this process, namely the production of T-shaped joints, were published in papers in the 1960s; the use of these processes increased rapidly when in 1980s the automotive industry turned its attention to this process and, more importantly, to the possibilities for
lightweight constructions. Throughout this paper, THF will be used to describe the metal forming process whereby tubes are formed into complex shapes with a die cavity using internal pressure, which is usually obtained by various means such as hydraulic, viscous medium, elastomers, polyurethane, etc., and axial compressive forces simultaneously.

Figure 1.10 shows the process principles for tube hydroforming. A tube is placed in the tool cavity, whereby the geometry of the die corresponds to the external geometry of the produced part. These tools, in most cases separated in longitudinal direction, are closed by the ram movement of a press, and the tube ends are loaded by two punches moving along the tube axis. Each of the loads applied to the tube ends for sealing the tube’s interior must be at least equal to the force calculated from the product of the tube’s internal area and the tube’s internal pressure. However, the axial forces may be increased to a higher value if the forming job requires it. Then additional tube wall material is brought into the tool cavity. During the process the internal pressure is increased until the expanding tube wall comes into contact with the inner surface of the die cavity. This process principle may be used for hydroforming both straight and pre-bent tubes.

As shown in figure 1.9, the applicability of the process implies that failures caused by plastic instabilities such as buckling, folding and bursting can be excluded. The risk of buckling is posed at the start of the process by too high axial loads on the initial tube, and it is also present for the entire starting phase. So that this risk of buckling can be avoided by compensation the unsupported tube length with increasing in the section modulus of the tube cross section through the simultaneous expansion of the tube wall.

In the intake zone of the expansion shape, a formation of folds cannot be avoided; these folds, which are symmetrical to the longitudinal axis, can be reversed by an increase in internal pressure during the final phase of the expansion process. However further folds can occur at the centre of longer expansion forms as a result of too high axial forces: these can be avoided with a proper process controller.

The risk of bursting is a result of too high internal pressure and is initiated by a local neck in the tube wall, whereby the onset of this local necking significantly depends on the initial tube wall thickness. To prevent this risk it must be ensured that the tube wall briefly comes into contact with the wall of the tool at the latest before the onset of necking.
Workpiece forming in the hydroforming process takes place through the internal pressure $P_i$ inside the component and the axial load $F_a$ exerted on its ends. With some processes, additional external loads are exerted, which cause stresses in the workpiece wall (fig.1.10); in case of thin-walled components these stresses can be referred to as plain stress. It can be described by a stress acting in circumferential direction $s_\gamma$ and a transverse so called axial stress $s_z$. Expansion of the workpiece is ensured under the made assumptions when the comparison stress $\sigma_v = \sqrt{\sigma_\gamma^2 + \sigma_z^2 - \sigma_\gamma \sigma_z}$ corresponds to the local yield stress of the workpiece material and the exerted loads do not give rise to necking. The stress acting in circumferential direction $s_\gamma$ is normally located in the area of tension and the stress acting along the length of the component $s_z$ can be located in the area of compression or tension.

By considering this values the maximal pressure attainable in the forming tube can be calculated. The maximum values for $P_i$ and consequently for $F_a$ normally occur at the end of the forming process, when the workpiece is calibrated through an increase in the internal pressure.

Decisive for the necessary calibration pressure are the size of the component radii to be formed, the wall thickness in these areas and the yield stress, according to equation 2.

$$P_{i\, \text{max}} = \frac{2}{\sqrt{3}} \sigma_y \left( \ln \frac{R_c}{R_c - t} \right).$$