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DESIGN OF AN EXPERIMENTAL DEVICE FOR TUBE HYDROFORMING TECHNOLOGY

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ABSTRACT

Hydroforming technology is a comparatively new technology in its application in the different manufacturing sectors.
An analysis of the general material demands and of the technological methods for obtaining hydroformed tubes is presented. Based on some design guidance, it was design an experimental device for tube hydroforming. The testing results show that the device, with some future improvements, is able to produce sounds hydroformed product. Future investigations will be made for process analysis and process control.

***Key words:** tube hydroforming, hydroforming, process design*

1. INTRODUCTION

Hydroforming (HPH) is a comparatively new technology in its application in the automotive and the aircraft industries as well as in the manufacturing of components for sanitary use.

Automotive applications can be found in exhaust parts, camshafts, radiator frames, front and rear axles, engine cradles, crankshafts, seat frames, body parts and space frame. Some well known applications /6/ are BMW-rear axle of 500 series, Mercedes Benz-exhaust manifolds, Buick Park Avenue-roof rail inner and engine cradle, Corvette-lower rails, roof bow and instrument panel beam. Some typical parts are presented in figure 1.

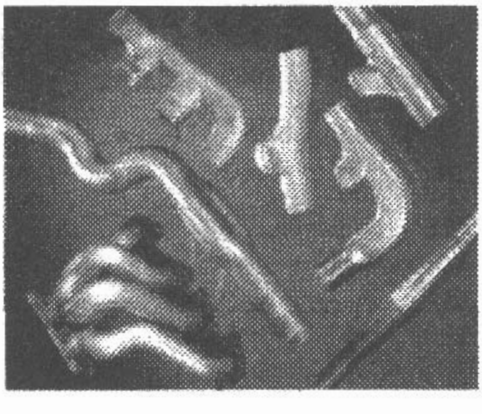


Fig. 1. Examples produced by Hydroforming (*Schuler Hydroforming*)

In HPH the tube typically is designed to be 5 to 10 percent smaller than the die cavity periphery. The starting round tube must stretch into the final cross-sectional shape after the die is closed. The stretching pattern varies depending on the part shape, its position within the final form cavity; material type and properties; as well as lubrication, surface finish, and several other factors that can reduce wall thinning concentration.

HPH because of expansion requires materials with higher elongation and n values to form a given part, even YS tends to decrease. This is a process benefit because it reduces the pressure needed to form the part, but the end result may not be consistent with the part's functional needs.

For HPH, YS increases as the part progresses toward full formation by stretching, which is concentrated in cross-section corners. This increase requires that internal pressure be elevated accordingly to continue forming to completion.

With steel, as YS increases, elongation decreases, and the amount of deformation that the material can withstand before necking and rupturing is reduced substantially.

N value is the work-hardening exponent that expresses material behaviour as it is plastically deformed. Higher n values indicate that as stretching commences, a particular element stretches to the point where it gets too strong. Any continuing strain is shared with elements surrounding it that are not as strong. Spreading strain more effectively allows larger expansion, and thus this property describes a material's ability to balloon. In lower-n-value material, stretching concentrates locally and the material bursts more easily.

N-value always is important in HPH because all parts are expanded, whether to prevent pinching, to vary the periphery, or to form larger expansions. N value also plays a role in how quickly a part can be formed. Higher values indicate that faster forming is possible, while lower values dictate a longer cycle time to avoid rupture.

R value quantifies material drawability and is applicable to large expanded sections, normally achievable only at the part end where end feeding is most effective. Attention to maintaining a specified range of values is necessary for some applications, particularly for HPH.

2. PROCEES PRINCIPLE AND DIE DESIGN

The process of tube hydroforming can very considerably depending on the part and the equipment used. Basically, the tube blank is placed into a half of a die in split construction (Figure 2). The die cavity corresponds to the final shape of the component.

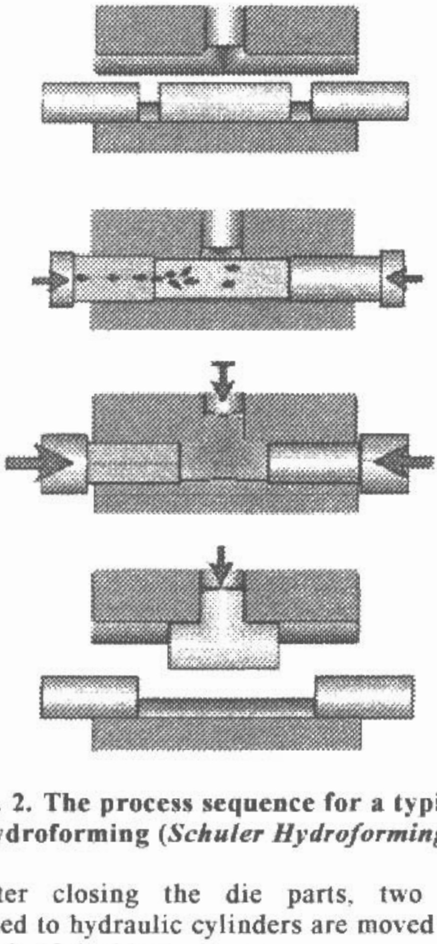
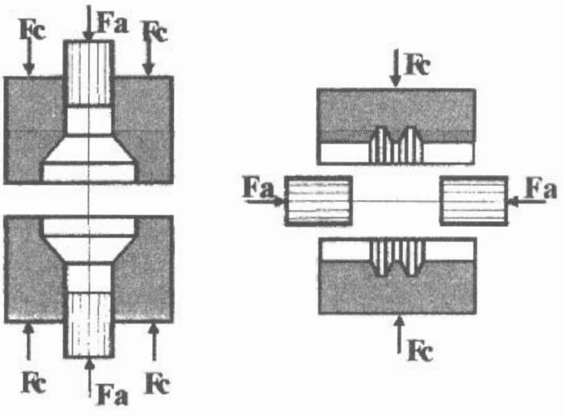


Fig. 2. The process sequence for a typical hydroforming (*Schuler Hydroforming)*

After closing the die parts, two rams attached to hydraulic cylinders are moved in on the ends of the blank. At this stage, the rams do not yet seal the blank completely. Subsequently, the high pressure medium is introduced into the interior of the blank, with the help of a pump. When filling is completed, the rams make a perfect seal and internal pressure build-up starts. By the combined action of the internal pressure and the rams the part geometry is generated. After the forming process, the internal pressure is reduced to zero and the rams retract to their initial position. By opening the two die parts, the component can be removed.

Dies in tube hydroforming are divided in either a lengthwise or crosswise direction (Figure 3).

Crosswise split dies are cheaper to produce compared to lengthwise split dies. They also have the advantage that predefined diameter dimensions can be better controlled. Moreover, closing forces are also smaller.



Crosswise die **Lenghtwise die**

Fig.3. Dies for tube hydroforming

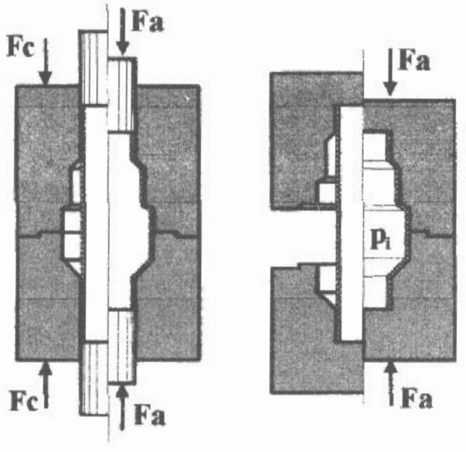
However, lengthwise split dies must be used, if the workpiece has bends or subsidiary shapes perpendicular to the main axis of the tubular preform. This is the case, for example, in parts having multiple junctions at varying angles.

Generally, crosswise divided dies are preferred whenever possible. Using crosswise dies there are possible two deformation methods.

In the closed die case (Figure 4), the forming die, which is divided laterally, is closed prior to the start of the shaping process. There are guides for holding the tubular blank at each end. The blank is pushed by means of punches throughout the forming process. By using the closed die, the free length of the tube can be limited to a minimum, ensuring a good tube guidance. Hence, the danger of buckling is reduced.

In the open die case (Figure 4), the die is open at the beginning of the forming process.

The distance of the opening corresponds to the difference in the length of the tubular blank and the final workpiece. As the process progresses, the die walls are closed and the expanded tube comes into contact with the die surface.



Closed die **Open die**

Fig. 4. Types of crosswise die

Using the open die, there will be very little or no friction between the tube wall and the die. The drawback is the greater danger of buckling compared to forming with a closed tool. Buckling basically limits the forming potential of this method.

3. DESIGN GUIDELINES FOR EXPANSION WITH AXIAL FEEDING

During the hydroforming process, only a limited amount of material can be pushed into the die cavity. There is a point along the component at which the total resistance force is equal to the compressive or buckling limit of the blank. Beyond this point, no more material can be fed.

It could be established some relations between the maximum compressive force (*Fa*), the frictional force (*Ff*), the coefficient of friction between the tube and die surface (μ) and the length of the tube (*L*).

Maximum compressive force (*Fa*) is found with the relation:

$$Fa = \pi\,(D-g)\,g\,Rm \qquad (1)$$

where: *D* is the tube diameter; *g* – thickness; *Rm* – material ultimate tensile strength.

Frictional force (*Ff*) from internal feed pressure is gave by the relation:

$$Ff = \pi\,(D-2g)\,L\,\mu\,p_a \qquad (2)$$

where: p_a – internal pressure.

By equating these two equations, the value for tube length (L) beyond which material cannot be fed can be found:

$$L = g\,Rm\left(1-\frac{g}{D}\right)\Big/\left[\left(1-\frac{2g}{D}\right)\mu\,p_a\right] \qquad (3)$$

From the equation (3), it follows that the maximum value of L beyond which material cannot be fed to expand the section without thinning can be increased only by lowering the coefficient of friction (μ) and by keeping the internal pressure (p_a) as low as possible to prevent material wrinkling and excessive thickening near the ends.

During the axial feeding stage the internal pressure for round sections is approximated by the following equation:

$$p_a = \frac{2\,g\,(0{,}85\,Rm)}{D-2g} \qquad (4)$$

For large D/g ratios, (D-2g) approximates to D; (1-g/D)/(1-2g/D) approximates to 1; therefore, equations (3) and (4) can be simplified to the following relation:

$$L = \frac{D}{1{,}7\,\mu} \qquad (5)$$

The maximum length to which material can be fed is approximately: L = 12 D for a coefficient of friction μ = 0,05 and L = 6 D for a coefficient of friction μ = 0,10.

The amount of feed is approximated by equating the material volume of the hydroformed component to the material volume of the tubular blank. For simple component shapes, the volume can be approximated by hand calculations; for complex shapes, the component volume can be derived from a CAD model. In these calculations—if constant thickness profile is assumed—the calculated feed will be a little conservative but provides a good starting point number that can be optimised through detailed process simulation and at prototype tryout.

For tube blank diameter (D), thickness (g), and blank length (L), and for component material volume (Vc) and component length (C), the axial feed length (F) can be calculated as follows:

$$Vc = \pi\,D\,g\,L \qquad (6)$$

$$F = L - C \tag{7}$$

Maximum expanded diameter:

$$De = 1.8\ D \tag{8}$$

Expanded shape corner radius:

$$r_c = 6\ g \tag{9}$$

4. THE DEVICE AND ITS OPERATION

Based on the design guidelines presented in the former paragraph of the actual paper and on the dates presented in /10/, it was projected the device showed in fig. 5.

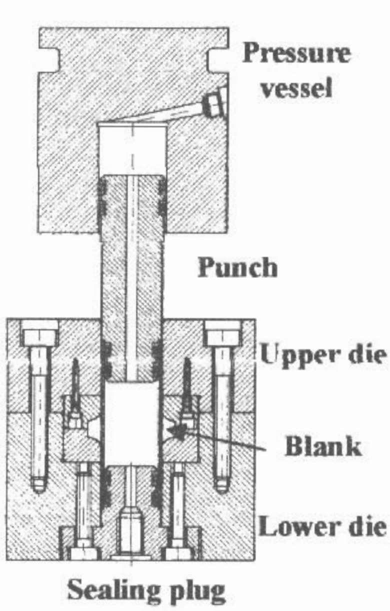


Fig. 5. The sketch of the device for hydroforming

The assembly of the tooling is used for bulging tubes of 45 mm outside diameter with an axial compressive load proportional to the pressure. By varying the geometrical forms of the active elements could be obtained different types of parts.

The two parts of the die are screwed on together by cap screws and a sealing plug inserted in the bore of the die at the bottom. Then the tubular blank (that is to be bulged) is inserted from the top of the die bore until it is seated on the sealing plug. This ensures sealing of the inside of the tube at the bottom. Then oil is poured into the tube to a level of about 4 mm below the top of the tube.

The pressure vessel is attached to the press ram and aligned with the die. Then the differential piston with O ring seals, as shown in figure 5, is inserted into the die to rest against the top of the tube. The press ram is then lowered so that the big end of the differential piston enters of about 40 mm in the bore of the pressure vessel.

Oil is then pumped manually in pressure vessel.

Then the press ram is brought down with uniform speed. The increase in the hydraulic pressure in the tooling could be registered by a pressure gauge. An ink mark on the small diameter of the differential piston (near the top) enables detection of any downward axial movement of the tube. Downward movement of the press ram will not show this axial movement of the tube, as there can be relative displacement between the pressure vessel and the differential piston.

As the tube bulges into the die cavity, oil will flow with the tube into the die cavity. To compensate for this, the vessel has to move down relative to the differential piston thereby reducing the volume of oil in the pressure vessel.

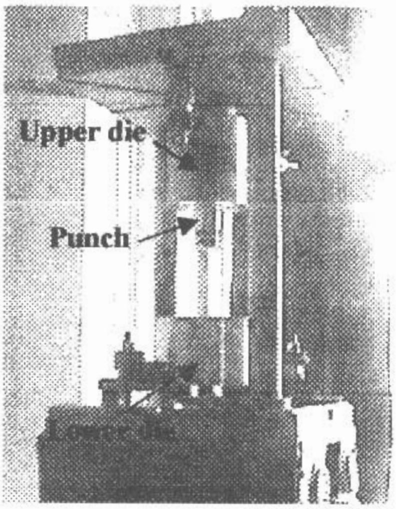


Fig. 6. The device for hydroforming

Once the bulging is complete the press ram is retracted, the pressure drops to zero and the oil will be eliminated from the product using the bore from the sealing plug. Finally the product will be removed by opening the die into parts.

5. TESTING RESULTS

The device was equipped for obtaining the part presented in figure 7. A 20 t hydraulic press is used.

The initial tube was cut 127 mm long from a body spray, is made from aluminium alloy, and it was obtained by extrusion. The tube wasn't annealed. The material thickness was 0.5 mm.

Photograph of one the bulge tube is showed in figure 8. The maximum circumferential expansion is in this case to a diameter of 54 mm.

By increasing the axial displacement of the ram the inside tub pressure increased. The result was tube fracture (Figure 9).

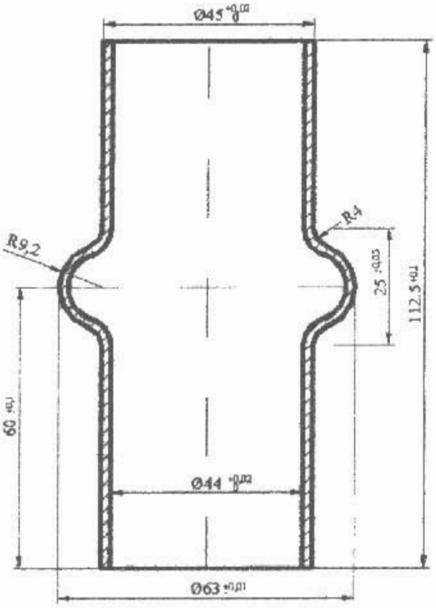


Fig. 7. The part dimensions

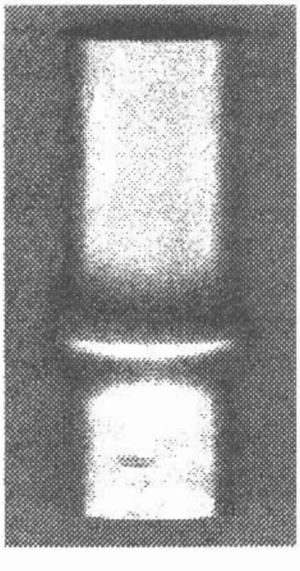


Fig.8. A sound tube obtained by hydroforming

The projected outer diameter of the tube using such type of extruded tube wasn't attained.

During the experiments appeared some problems that will necessitate the design solution improvement.

One of this is the axial tube deformation when the punch is inserting in the pressure vessel within the specific length. For this a precisely clearance must be set up between the punch and the pressure vessel. This clearance must assure both axial moving and sealing of the two elements in contact.

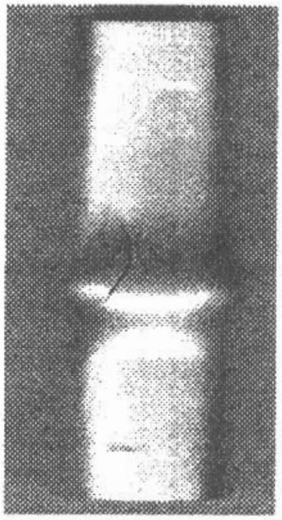


Fig. 9. Fracture of tube during hydroforming

6. CONCLUSIONS

An analysis of the general material demands and of the technological methods for obtaining hydroformed tubes is presented.

Based on some design guidance, it was design an experimental device for tube hydroforming. The device combines the axial compressive force with the internal hydraulic pressure. The testing results showed that the device is able to produce sounds hydroformed product.

Future investigations will be made for process analysis and process control.

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PROIECTAREA UNUI ECHIPAMENT PENTRU TEHNOLOGIA HIDROFORMĂRII TUBURILOR

Rezumat

Hidroformarea tuburilor este o metodă relativ nouă de fabricare, redescoperită datorită aplicaţiilor din diferitele sectoare industriale. În lucrare se prezintă o caracterizare a proprietăţilor materialelor destinate hidroformării şi metodele tehnologice de obţinere a tuburilor hidroformate. Pe baza unor date de proiectare, s-a proiectat şi executat un stand experimental pentru fabricarea tuburilor hidroformate. Încercările preliminare au arătat că echipamentul poate fi folosit, cu unele îmbunătăţiri, pentru obţinerea unor produse corespunzătoare. Vor fi intreprinse încontinuare investigaţii experimentale pentru analiza procesului de hidroformare a tuburilor şi a controlului acestuia.

DESIGN EINER EXPERIMENTELLEN VORRICHTUNG FÜR INNENHOCHDRUCKUMFORMEN TECHNOLOGIE

Zusammenfassung

Innenhochdruckumformen ist eine verhältnismässig neue Technologie in seiner Anwendung in den unterschiedlichen Herstellung Sektoren. Eine Analyse der allgemeinen Material und der technologischen Methoden für das Innenhochdruckumformen wird dargestellt. Gegründet auf etwas Designanleitungen, war es Design ein experimentelle Vorrichtung für Innenhochdruckumformen. Die Testergebnisse zeigen, daß die Vorrichtung, mit etwas zukünftigen Verbesserungen, köne zu produzieren hydroformed Produkt. Zukünftige Untersuchungen werden für Prozeßanalyse und Prozeßsteuerung gebildet.