

# The optimization of a hydroformed tube

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## Abstract

The shaping by hydroforming process involves several complex phenomena and presents several types of nonlinearities (geometric, material,...). The development of a hydroforming operation requires a lot of testing to determine with precision the optimum loads of trips and get a room without defects. Advances in digital tools have enabled manufacturers to simulate and optimize their production facilities before launching the production in order to minimize the maximum rate of defective parts.

**Keywords :** tube; hydroforming ; optimization.

## 1. Introduction

Hydroforming is a manufacturing process by deformation; it consists in plastically deforming the thin pieces (sheet, pipes). The final shape of the part is determined by a "shape" called matrix. Unlike swaging, there is no complementary matrix thereof is replaced by a fluid under high pressure which forces the piece to take the shape of the cavity of the die. The use of a pressurized fluid allows applying a force in areas inaccessible by other means.

The shaping by hydroforming process involves several complex phenomena and presents several types of nonlinearities (geometric, material,...). The development of a hydroforming operation requires a lot of testing to determine with precision the optimum loads of trips and get a room without defects. Advances in digital tools have enabled manufacturers to simulate and optimize their production facilities before launching the production in order to minimize the maximum rate of defective parts. Several techniques or deterministic optimization methods have been proposed over the last decade in order to properly conduct a formatting operation. With these means, manufacturers can virtually simulate their processes; allowing responding to some questions mainly on the feasibility of the room and also on the ability of the loading path out form the part. This coupling can often marked improvement. The used methods to develop simple analytical models are based on the theory of plasticity to the membrane tubes, thin and thick. They are useful to optimize key defects, the variation of the axial force based on the internal pressure and the pressure against and wall thinning:

The mechanical process parameters: the initial tube material, friction conditions swelling pressure, stroke, etc. The geometric parameters: radiation tools, dimensions of additional parts, length of the initial tube, etc. The control and optimization of certain operating parameters of the process can improve the formability of the material and the robustness of the process [1].

In this paper, we present the technical hydroforming tubes and one of the optimization

techniques of the different parameters of hydroforming the tube by varying the geometric parameters.

## 2. Problem statement

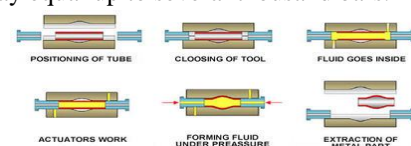
The stamping and fabricating method reduced rigidity at the welded joints, which inherently are more flexible. Also, welding created distortion, which caused a lot of dimensional variation. Although the costs associated with stamping and fabricating parts might have appeared high, this process was the best option at the time. Hydroforming changed the rules of forming structural parts by making it possible to form a tube like structure from a tube rather than stamping and fabricating it from sheet metal. The concept of starting with a straight round tube, bending it, and then forming it to change its cross-sectional shape continuously along its length generated a number of advantages and changed several aspects of design flexibility.

### 2.1-Tube Hydroforming Benefits

In structural design, it is widely accepted that tubes support loads more strongly and efficiently than stamped sheet metal, even when the latter is welded together into a tube like assembly. Concurrently engineers and designers are learning how and where best to apply tube hydroforming, and new capabilities are being developed continually. As design options increase and improve, hydroforming is being used to produce more and more parts. Benefits associated with using this technology also are increasing.

Hydroforming reduces weight; part, tool, and capital costs; dimensional variability; the number of parts; and the number of joints. It also increases or improves structural strength; bending and torsional rigidity; other performance characteristics; certain aspects of design flexibility; and overall part quality.

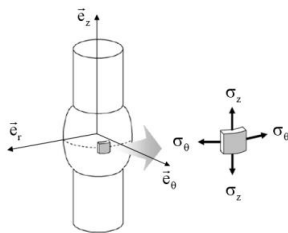
Hydroforming, or internal high pressure forming, is a forming process with an active fluid (often a water-oil emulsion). A hollow part is formed from a tube, any profile or two blanks, by applying internal pressure. The pressure required in this process is largely dependent on the material that is used, the material's thickness and the smallest of rays to be formed. The internal pressure required may equal up to several thousand bars.



**Fig 1:** hydroforming process tubes

## 2.2 - Mechanical characteristic of welded tube behavior

The main difficulty in many hydroforming processes is to find the practical control of the evolution of applied internal pressure and axial forces of the tracks. This prevents the localization of plastic flow leads to buckling or breaking of the tube during the process. In fact, when a metallic material is formed by such processes, it undergoes large plastic deformations, which leads to the formation of high localization of deformation zones and therefore to the appearance of micro-defects or cracks. These initiation and evolution harm results in the loss of the formed part and indicate that the training process itself should be amended to avoid damage appearance. In principle, all materials and alloys used for stamping or embossing can be used for hydroforming applications as well. Taking into account the ratio thickness/diameter of the tube, the radial stress is considerably small compared to the circumferential  $\sigma_\theta$  and longitudinal stresses  $\sigma_z$  (see Fig 2). In addition, the principal axes of the stress tensor and the orthotropic axes are considered coaxial. The transverse anisotropy assumption represented through the yield criterion can be written as:



**Fig 2.** Stress state at bulge tip

$$\bar{\sigma}^2 = F(\sigma_z - \sigma_\theta)^2 + G\sigma_z^2 + H\sigma_\theta^2 \quad (1)$$

With (F,G,H) are the parameters characterizing the current state of anisotropy. If the circumferential direction is taken as a material reference, the anisotropy effect can be characterized by a single coefficient R and the equation (1) becomes:

$$\bar{\sigma}^2 = \frac{1}{1+R} [R(\sigma_z - \sigma_\theta)^2 + \sigma_z^2 + \sigma_\theta^2] \quad (2)$$

The assumptions of normality and consistency lead to the following equations:

$$\begin{cases} d\varepsilon_\theta = \frac{d\bar{\varepsilon}}{\bar{\sigma}} (\sigma_\theta - \frac{R}{1+R} \sigma_z) \\ d\varepsilon_z = \frac{d\bar{\varepsilon}}{\bar{\sigma}} (\sigma_z - \frac{R}{1+R} \sigma_\theta) \end{cases} \quad (3)$$

The knowledge of the two unknown strain  $\varepsilon_\theta$  and stress  $\sigma_\theta$  needs the establishment of the final geometric data linked to the tube (diameter and wall thickness):

$$\varepsilon_\theta = \ln\left(\frac{d}{d_0}\right) \text{ and } \sigma_\theta = \frac{Pd}{2t} \quad (4)$$

Finally, the material characteristics of the tube (base metal) are expressed by the effective stress and effective strain according to the following equation (Swift model):

$$\bar{\sigma} = K(\varepsilon_\theta + \bar{\varepsilon}) \quad (5)$$

## 2.3 Optimization of the tube in hydroforming processes

In a forming process, it is common to want to master the different thickness during the process to avoid sudden failure by thinning. Therefore, the formulation of the objective function in the least squares sense gives the following form:

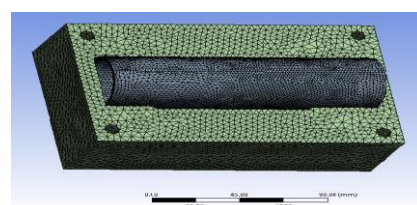
$$\min f(x) = \sqrt{\left(\sum_{i=1}^M \left|\frac{e_i - e_0}{e_0}\right|^2\right)} \quad (6)$$

with  $e_i$  represents the instantaneous thickness.  $e_0$  represents the initial thickness. It is a question of minimizing  $f(x)$ , deducing it for the hydroforming process the vector  $\{x\}$  of the design variables which also define the load path during operation of the process should be:  $\{x\} = \{p_1, p_2, d_1, d_2\}$ ,  $p_i$  symbolizes the forming pressure for  $i=1$  and  $2$   $d_i$  is the driver displacement in meter punches  $i = 1$  and  $2$ .

We have here the couple value  $(p_i, d_i)$  which is equal to 0, which gives us a total of 6 considered system design variables. In our case, the working domain can be outlined according to [2], taking into account several criteria related to the process forming limit prediction. The three development constraints determine the limits of the process states which delimited the feasibility of solutions. Thus, the definition of constraints appears implicitly related to boundary conditions of the process in relation to those previously studied.

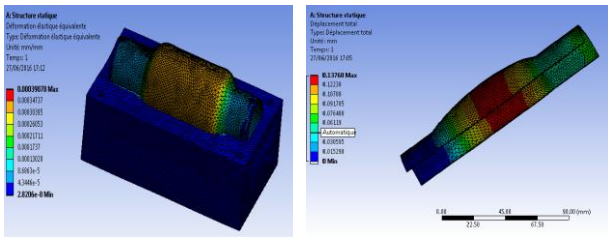
## 3- Numerical results

To study the formability of tubes submitted to the hydroforming process. For this purpose, the tube diameter of 60 mm and 2 mm S250 steel thickness ( $E = 210\,000$  MPa and  $\nu = 0.3$ ) is hydroformed in a die of the desired shape. After that, the finite element model is designed to simulate the process of hydroforming. The influence of some parameters such as the coefficient of friction, Young's modulus, Poisson's ratio, the diameter and thickness of the tube on the formability. The finite element method is used to explore the strain and displacement as well as the influence of work hardening and the anisotropy of the sensitivity of these parameters on the response of the sheet. A three-dimensional model discretized finite element (3D) is then constructed with 15108 nodes and 7187 solids and then solved with the computational code ANSYS (see Fig 3). This is a sheet metal assembly and die dimensions and initial settings.



**Fig 3:** tube meshing

A pressure of 5 MPa is applied to the interior of the tube over time. The tube is inflated in charging does releasing its ends in the direction of the axis of symmetry of the tube. The behavior is formulated in the context of anisotropic elastic-plastic model with isotropic hardening. The tube element is considered a shell member. The choice of parameters for the simulation such as metal-matrix type contact and mesh type assembly (metal - matrix) is paramount to the hydroforming process because it was considered a frictionless contact (tubes - Matrix) and scanning with a shell member for the tube.

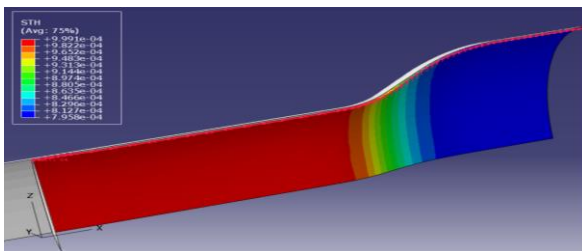


**Fig 4-5:** elastic stress and total displacement

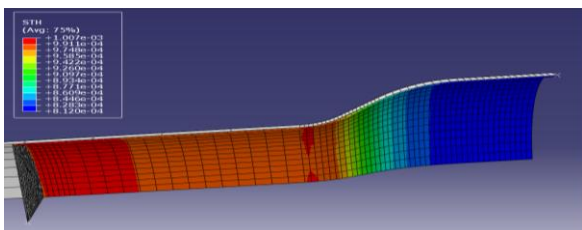
**-The Constraint 1** situates on five geometric control points in sensitive areas to default final forming. (see figure below) These references points validate the dimensional with a global tolerance of 0.15mm after optimization.

The figure above shows the thickness of nuances concerning the simplest form of hydroforming already studied in the previous paragraph. The dimensions are identical [3,4].

First, it is interesting to visualize the effect of design variables on the distribution of thicknesses in the initial state of the elements (Fig 6.) to optimized state (Fig 7).



**Fig 6 :** Report of thicknesses optimization before.



**Fig 7 :**Report thickness after optimization .

**Fig 7** highlights the case optimized with respect to the initial state through a global visualization on 1132 studied

elements. Direct gain is observed on the thinning of almost 2% on the minimum value. This amelioration takes the forming a sensitive area where a crack may occur in the case of excessive thinning [5].

#### 4-CONCLUSION

Modeling hydroforming is still a hot topic and its numerical simulation is a basis for adapting a best practice approach. Based on numerical simulation to adapt a better approach to the contact between the die and the tube (with or without friction), it was found that the choice of contact type proposed by ANSYS has had a good influence on the numerical results just as the choice of the type of finite elements of the tube.

The development of a database to know the dispersion of the input data appears paramount. It is also necessary to change the model to include the specifics of the process.

This section dedicated to the optimization of tube hydroforming process highlights the need to know the limits of feasibility domain. These analytics can be order, geometrical and numerical. The objective must be clearly defined in order to limit the search algorithm complexity chosen. Thus, small changes of the parameters are obtained by finite difference where the disturbance function is adjustable according to the desired precision. From a numerical point of view, the selected mesh must be sensitive enough to return modified values in line with the physical constraints. When the feasibility of field is highly non-linear, there is a risk of saturation of the stresses present, which sometimes the need to try to simplify and reduce the number of constraints. This can be seen when selecting control points geometric optimization of previous single tube [6].

#### Références (12 gras)

- [1] J.F. Barthelemy, « Function approximation, Structural optimization: Status and promise », Ed. Kamat M.P, 1993.
- [2] N. Boudeau, A. Lejeune and J. C. Gelin, “Influence of material and process parameters on the development of necking and bursting in flange and tube hydroforming”, Journal of Materials Processing Technology, Vols. 125-126, 2002, p 849-855.
- [3] M.Koç et O.N.Cora “Hydroforming for Advanced Manufacturing” Elsevier, 25 avr. 2008 - 412 pages.
- [4] Labergère C., Contributions à la modélisation, à l’optimisation et au contrôle des procédés d’hydroformage de tubes et flans, PhD Thesis, Université de Franche-Comté, 2003.
- [5] Gelin, J. C.; Labergère, C. (2001), Modelling, optimization and optimal control for hydro forming process, Proceedings of the 4th international ESAFORM Conference on Material Forming- Volume 1, Liège, Belgium (2001) pp. 377-380.
- [6] Nassraoui. M; Radi. B (24-26 Oct 2016), study of optimizing a tube hydroforming, Proceeding of the 4th IEEE International Colloquium on Information Science and Technology (CiSt), Tangier, Morocco.