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THEORETICAL ANALYSIS OF THE TUBE HYDROFORMING PROCESS PARAMETERS AND A SUGGESTION FOR EXPERIMENTAL EQUIPMENT

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ABSTRACT
The paper deals with gives a theoretical analysis of the tube hydroforming process parameters (typical T-shape): axial forces, internal pressure, the diameter of tubes at the beginning and end of stage, the forces of friction and so on. The solution which is gained analytically is close and it is a good idea to check them experimentally. In addition to the work there is an explained procedure for the calculation of forces and experimental apparature for the testing tube hydroforming process.
Key words: hydroforming, tube, forming forces, pressure, experimental apparature.

1. INTRODUCTION
When it comes to the technological process of hydroforming of tubes it is necessary to analyze and calculate the parameters of process and to make an adequate die. The starting data for the technological analysis is a drawing of the final tube and its geometry, dimension and material. On the basis of this data the calculation of dimensions of the initial shape of the tube, analysis of stress and strain, the calculation of the fluid pressure and forces with main aim to recommend optimal die shape. Every more complex forming process requires experimental testing of process and confirmation of the workpiece quality. After the conclusion that the final product quality is satisfied (geometry and dimension) one can begin the production. Such a procedure is determined for the production of tubes elements by hydroforming [1-7].

2. THE CALCULATION OF THE INITIAL TUBE DIMENSION
The final tube is shown in figure 1a. and the initial tube on figure 1b.

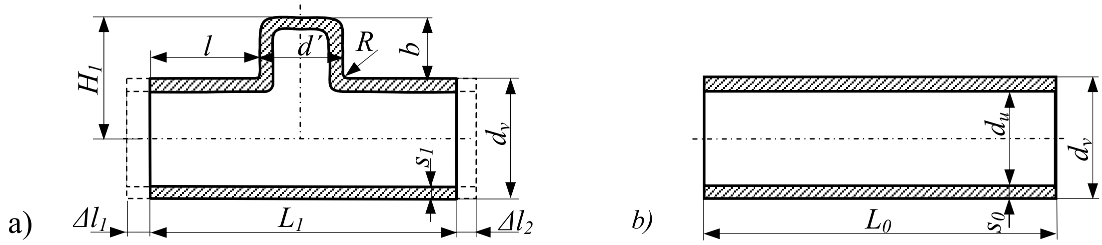


Figure 1. Tube workpiece (a) and initial piece (b)

The protrusion height:

$$b = H_1 - \frac{d_v}{2} + (2 \div 2{,}5)s_0 \tag{1}$$

the difference between the length of the initial piece L_o and work piece L_1, comes to $\Delta L = L_o - L_1$, which proportionally depends on the protrusion height of the figure 1b. The relation between ΔL i b

depends on the shape and dimension of protrusion and is marked as a coefficient of proportionality (figure 2). The length of the initial piece is determined by:

$$L_0 = n \cdot d' + \frac{mb}{k} + (L_1 - nd')\frac{(d_v - s_1)s_1}{(d_v - s_0)s_0} \qquad (2)$$

where :

- d_v, outer diameter of the initial tube,
- d', outer diameter of protrusion,
- s_0 and s_1, the wall thickness of the initial tube shape and T-shape workpiece respectively,
- *m,* coefficient of the proportions between ΔL and the protrusion height *b*,
- *k,* correction coefficient and *n,* empirical coefficient.

Experimental dependence of the correction coefficient *k* according to the relation d'/d_v shown in figure 2 [4].

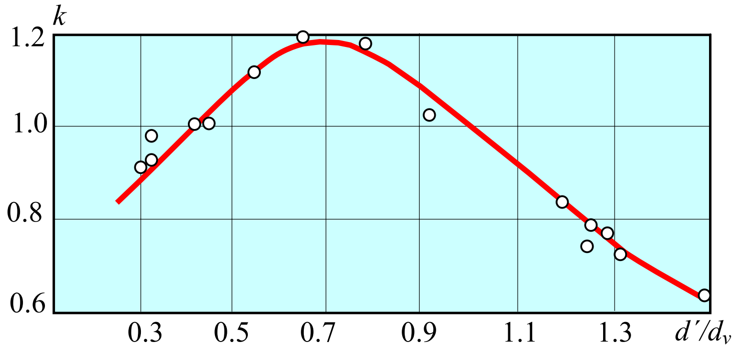


Figure 2. Correction coefficient depends on the relation between the diameter k - f(d′/d$_v$)

The value of the correction coefficient *k* decrease with increasing the relation of the diameter *(d'/d_v)*.

3. HYDROFORMING FORCES PARAMETERS

Defining the technological process of plastic forming it is necessary to exactly determine the forces needed for hydroforming. The optimal parameters of the forces of hydroforming give a quality production of a tube workpiece. The basic parameters of the process: the internal pressure of the fluid in the tube *p*, axial force when it comes to the shortening of the tube F_a and counter force F_d.

3.1. The internal fluid pressure

From plastic deformation terms $\sigma_{\theta'} = \sigma_s$ and the solution of the equation static equilibrium of forces we gain an expression for the minimal internal pressure :

$$p_{min} = \frac{\sigma_s \cdot s_i}{R} \qquad (3)$$

for the round protrusion:

$$p \geq \frac{2\sigma_s \cdot s_1}{d' - s_i} \qquad (4)$$

Where is:

d' – the outer protrusion diameter,
s_i – wall thickness of the protrusion after pressing,
σ_s – flow stress of the tube material,
R – the lowest radius of the protrusion curve,
$\sigma_s=\sigma_{0,2}+3,4(100\ e_i)^{0,60}$ for the low carbon construction steel and
e_i – final deformation.

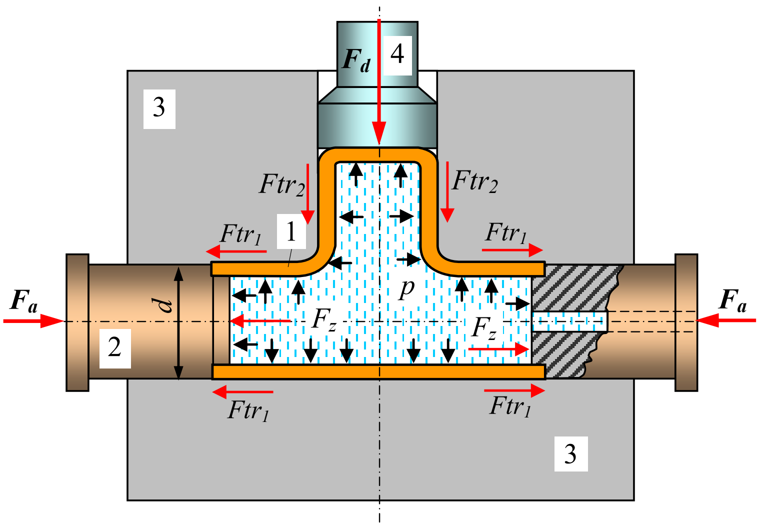


Figure 3. Schema of hydroforming process T-shape and forces

3.2. Axial forces

The total force which affects in the axis of the tube (1) consists of:

$$Fa = F_{pd} + F_{tr} + F_z \qquad (5)$$

where:
F_{pd} – the force of plastic deformation of the work piece,
F_{tr} – forces of friction,
F_z – the effect of the fluid pressure on the surface of axial punch (2) (sealing force).

$$F_{pd} = \pi\left\{ p\frac{d_v^2 - (d_v - 2s_i)^2}{4} + \beta\cdot\sigma_s\left[\frac{3}{4}(d_v - s_i)s_i + \frac{d_v^2}{8}\ln\frac{d_v}{d_v - 2s_i}\right]\right\} \tag{6}$$

d_v – the initial diameter of the tube $\beta = 1,155$.

$$F_{tr} = \mu\cdot\pi\cdot d_v\left(p + \frac{\beta\cdot\sigma_s}{d_v - 2s_i}\right)\left(\frac{L_i\cdot d'}{2}\right)d_v \tag{7}$$

L_i – variability of the length of the workpiece

$$F_z = p\pi\frac{(d_v - 2s_i)^2}{4} \tag{8}$$

On the basis of the equation (5), (6), (7) and (8) the total axial force is:

$$F_a = \pi\left\{ p\frac{d_v^2}{4} + \beta\sigma_s\left[0,75(d_v - s_i)s_i + \frac{d_v^2}{8}\ln\frac{d_v}{d_v - 2s_i}\right] + 0,5\mu d_v(L_1 - d')\left(p + \beta\sigma_s\frac{s_i}{d_V - 2s_i}\right)\right\} \tag{9}$$

s_i – the final wall thickness.

3.3. Counter force

With the lack of counter force F_d (4), the protrusion wall thickness is under pressure and thence which brings us to a thinner wall tube or to tearing of the same.

$$F_d = p\frac{\pi(d' - 2s_0)^2}{4} - (0.6 - 0.7)\sigma_v\pi(d' - s_0)s_0 \tag{10}$$

p – internal pressure,
s_0 – thickness of the initial tube,
σ_v – the resistance of material at stretching.
Technical conditions allow for a thinner wall thickness by 15-20%.

3.4. The force of assembling and disassembling of a die

Hydraulic forming of hollow elements with protrusion from tube it is possible to gain in a die cavity that is set apart (3). The force of the assembling, disassembling of the die has the following shape:

$$F = \left(p + \frac{\beta\sigma_s s_i}{d_v - 2s_i}\right)d_v(L_i - d') + pd'(d_v + n\cdot b_i) \tag{11}$$

d_v, d' – the outer diameter of the tube and protrusion, L_i – the length of the shaped workpiece,
b_i – the height of the protrusion, n – the number of protrusion in an alignment by separating die.

3.5. Diagram of hydroforming forces

Figure 4. shows the graphic changes of the parameters of force F during a forming T – tube from initial diameter of 25 mm made from steel.

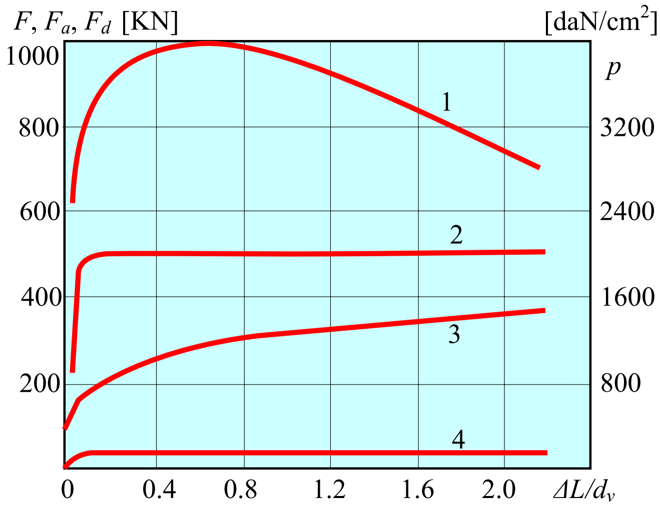
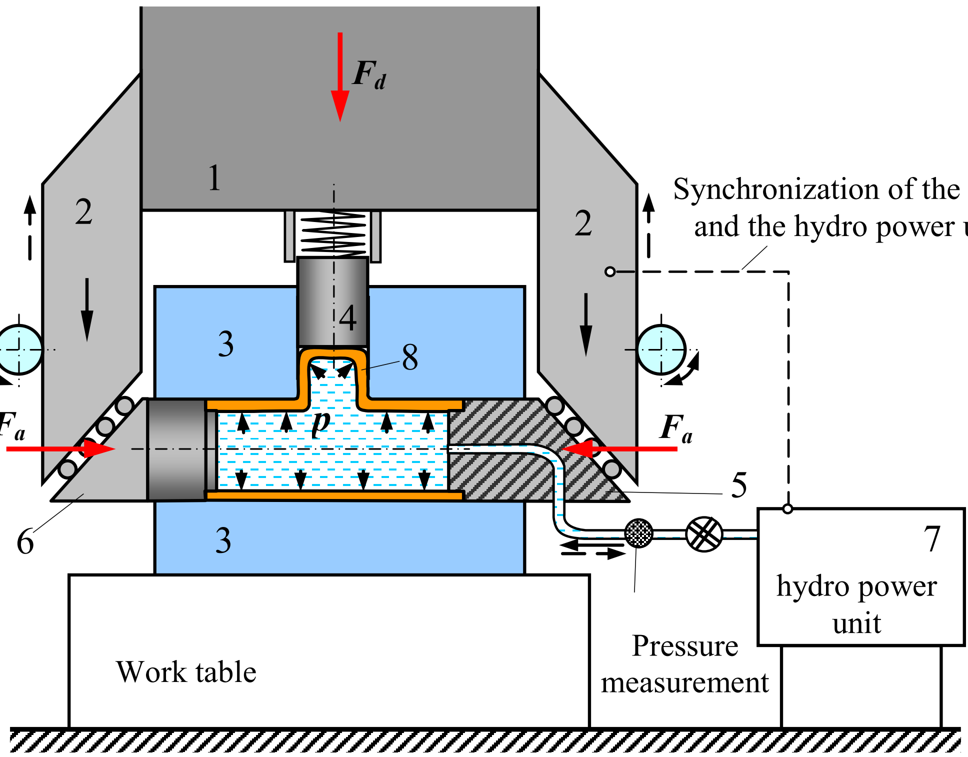


Figure 4. The change of force Fi in the hydroforming process of T shape tube, ϕ 25 mm from steel: 1 –the force needed for the open of the die F lock-up die force, 2 – the internal pressure of the fluid, p 3 – the force on the axial punch F_a, 4 – counter force F_d

4. THE SUGGESTION OF THE EXPERIMENTAL EQUIPMENT
4.1. Scheme of the mechanical adjustment of forces and feed ΔL



1- Punch 2- Built in additional sliders. 3- Die. 4- Counter punch. 5- Multiplication of pressure (punch of axial hollow for the intake of fluids). 6- Piston – axial punch. 7- Hydro power unit with all needed elements (measuring, safety, regulation). 8- Forming of tubes under pressure p.

Figure 5. Scheme of the press with the apparatus for hydroforming of T-shape tube

4. CONCLUSION
A concluded theoretical analysis shows that in the designing process of tube hydroforming they should be exactly defined dimensions of the initial tube piece, and the internal pressure of the fluid p, axial force F_a and counter force F_d.

Suggested experimental equipment with pneumatic adjustments of the feed of axial punch and the built in sensors for force stroke enables a better testing quality of hydroforming process of tube than mechanical equipment could.

The tool design demands high level of accuracy considering the value of the toleration of the initial tube and high level of accuracy in clamp die force. The force which closes the tool has to be grater than the force that opens the tool, which means it should have higher level of construction when it comes to safety.

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