TECHNOLOGY OF BELLOWS MANUFACTURING AND THE APPLICATON OF HYDROFORMING

TEHNOLOGIJA IZRADE KOMPENZATORA I PRIMJENA POSTUPKA HIDROOBLIKOVANJA

Ivan SEUČEK [1)], **Marin KUFRIN** [2)], **Branko GRIZELJ** [3)], **Ivan SAMARDŽIĆ** [3)], **Josip CUMIN** [3)], **Josip PAVIĆ** [4)], **Štefanija KLARIĆ** [3)], **Branimir VUJČIĆ** [5)]

Ključne riječi: kompenzator, hidrooblikovanje, TIG zavarivanje, nehrđajući čelik

Key words: bellow, hydroforming, TIG welding, stainless steel

Sažetak: Ovaj članak se bavi mogućnostima primjene tehnologija izrade kompenzatora. Proizvodni postupci su opisani, opisane su mogućnosti izrade i mogućnosti primjene hidro postupka oblikovanja. Dane su smjernice za tehnologično rješenje, i za optimalno planiranje procesa proizvodnje.

Abstract: This paper deals with possibilities and technologies of a bellows manufacturing process. Manufacturing technologies are described, possibilities of hydroforming process application are shown. Instructions for technological solution are given, for optimal process planning.

[1)] Faculty of Mechanical Engineering and Naval Architecture - FSB, I. Lucica 5, 10000 Zagreb
[2)] Plinara Zagreb
[3)] Mechanical Engineering Faculty - SFSB, Trg I. Brlic Mazuranic 2, 35000 Slavonski Brod
[4)] ĐĐ Kompenzatori d.o.o., Dr. M. Budaka 1, 35000 Slavonski Brod
[5)] Veleučilište u Slavonskom Brodu, Dr. M. Budaka 1, 35000 Slavonski Brod

1. INTRODUCTION

Bellows are special elements of pipelines, designed to withstand high temperature and pressure of the fluid, but with lower thickness than the rest of the pipeline. Bellow has one or more wave segments made by plastic deformation of metal pipe. These convolutions, serve for compensation of elongation of the pipeline, caused by temperature or pressure changes in the pipeline. Convolutions of a bellow are shown in Figure 1. Convolutions have three dimensions, inside and outside diameter, and convoluted length. Neck is used for connection to the pipes.

Bellows are used in various engineering machines and power plants. For example most widely used application of bellows is in the petrochemical plants, ventilation systems, on ships, in the airplane fuel supply lines and air conditioning pipelines, in car industry, nuclear power plants, heat exchangers and condensers.

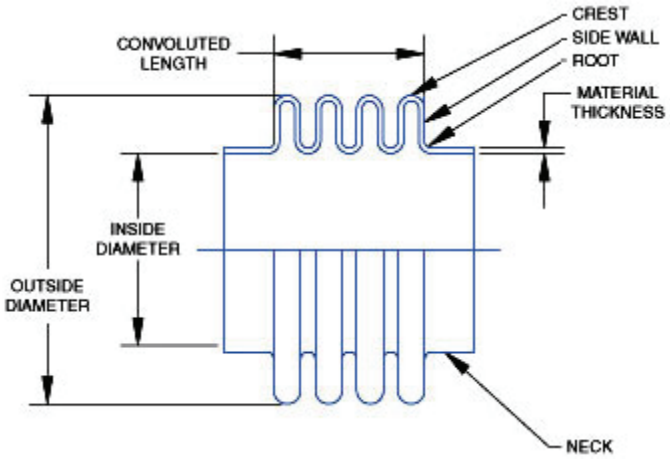

Figure 1. Axial cylindrical bellow with described parts.

2. BELLOWS TECHNOLOGY OF MANUFACTURE

Bellows are made by metal forming procedure applied on the thin walled pipes. Metal forming of the tube can be done either by rolling (Figure 2), or by hydroforming. Metal tubes are made out of pre-cut sheet metal plates, which are then bended and welded together with TIG welding process. By using TIG as a welding process, it is assured that welded joint is strong as the base material.

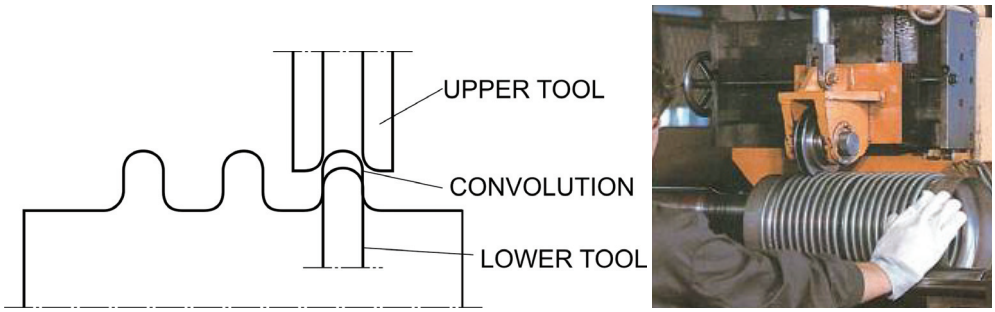

Figure 2. Metal forming of convolution on the thin metal tube [1]

Quality of the weld joint is very important for the working lifetime of a bellow.
Rolling of the convolutions is done by two tools, which are discs with a specified profile

on the perimeter. Depending on the dimensions of the wave sections, pipe diameter, and material strength, this operation of wave forming is often done in several passes. The rolling of convolutions is shown in Figure 2.

For the production of the bellows for high pressure, it is better to use several layers of thin metal plates, instead of one thick metal plate/pipe.

It is also possible to produce bellows wave sections with the process of hydroforming. In this process, pre-bended and pre-welded metal pipes are used. Pipe is placed in the tool die. Ends of the pipe are closed, and metal pipe is filled with the high pressurized fluid, which expands pipe until it makes contact with die surface. Depending on the deformation of material, hydroforming can be done in several passes.

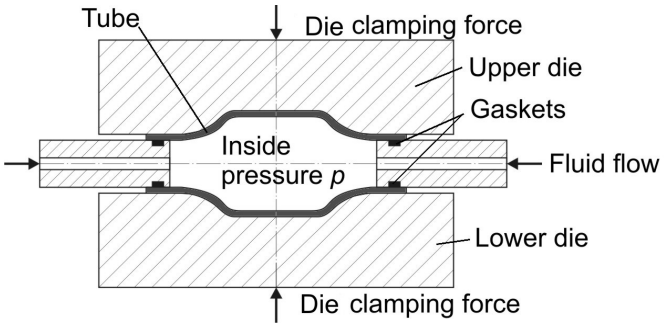

Figure 3. Hydroforming of the metal tube without axial feeding.

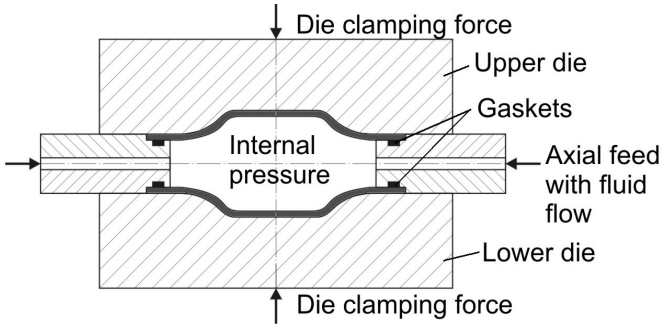

Figure 4. Hydroforming of the metal tube with axial feeding.

The process of hydroforming is shown in Figures 3 and 4. The hydroforming process can be done without axial feeding, which means that only internal pressure forms pipe to die surface – shown in Figure 3. It is necessary to provide extra length of the tube, due to the tube shortening. It is important to provide quality sealing between tube and axial connectors. Second way of hydroforming is with using appropriate axial feeding. Axial connectors move with the edges of pipe, and it is necessary to control this movement. By controlling axial feeding, the thickness of the tube in the formed sections can be influenced – shown in Figure 4. Special kind of a bellow is a square bellow. It is made by cutting sheet metal plates and forming the waves on the bending machine. Figure 5 shows convolutions formed by bending of sheet metal plate. Then these four sections are welded together in order to form a square bellow. They can be placed and welded in two different ways.

Formed sheet metal plates can be positioned and welded together in two ways. One way is called "camera fold", and it provides less k spring rate factor, and more elongation.

The other way of connecting of a bellow sheet metal plates is used more often, because it provides stiffer bellow, with high k spring rate, and it is more rigid. It is shown in Figures 6 and 7.

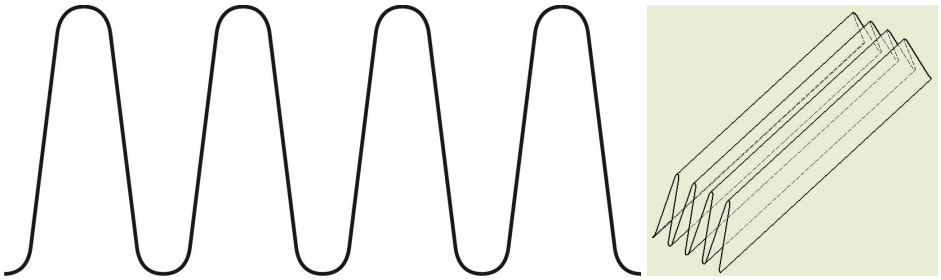

Figure 5. Convolutions made on the sheet metal plate for rectangular bellow.

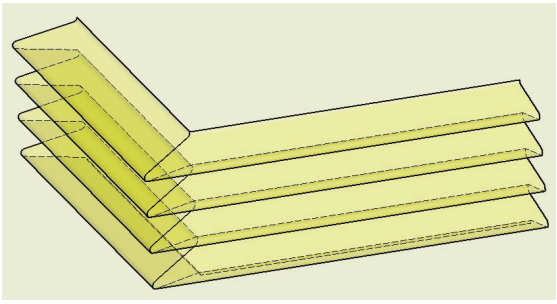

Figure 6. Conventional way of positioning sheet metal plates (Single miter corner).

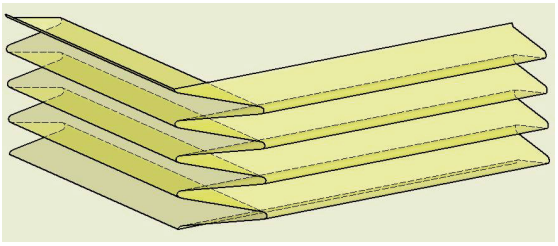

Figure 7. "Camera fold" way of positioning.

Big rectangular bellows for ships are made by welding together pre-formed sheet metal plates with cut parts of a circular bellow, which is cut in four pieces.

This type of bellow can only withstand small loads, and inner pressures. It is usually applied for air conditioning systems in ships, or in movable sections of the doors, passages etc.

They are usually made out of very thin sheet metal plates, which are welded by TIG procedure either by manual or automated process, shown in Figure 8.

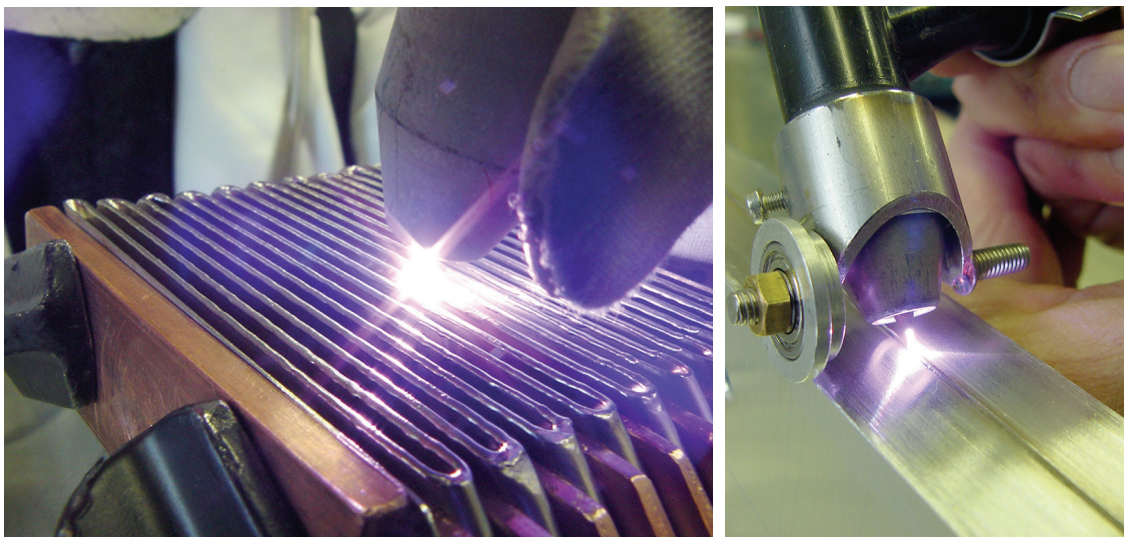

Figure 8. TIG welding of pre-formed metal sheets. [2]

3. BELLOWS HYDROFORMING PROCESS

Bellows can be made by the process of hydroforming. This process requires die for each shape and dimension of the bellow. It also requires special plant for the production of high pressure for fluid which forms thin metal pipe.

The process of hydroforming can be done on the classical hydraulic presses, where hydraulic press ram force is used only for the closing of the die. This can be technological solution only for small series production. This is not the case for mass production.

For the purpose of mass productions, hydraulic presses have a bit different configuration. They have high speed upper hydraulic cylinder, which has purpose of only high speed closing of the die. The lower hydraulic cylinder is made with bigger diameter, therefore it produces high die closing force, but it has low speed. Lower hydraulic cylinder also compensates press frame elongation under loading. In this configuration it is assured that minimal time wasting operations are used, and the production of parts per hour is bigger then with the use of conventional hydraulic presses.

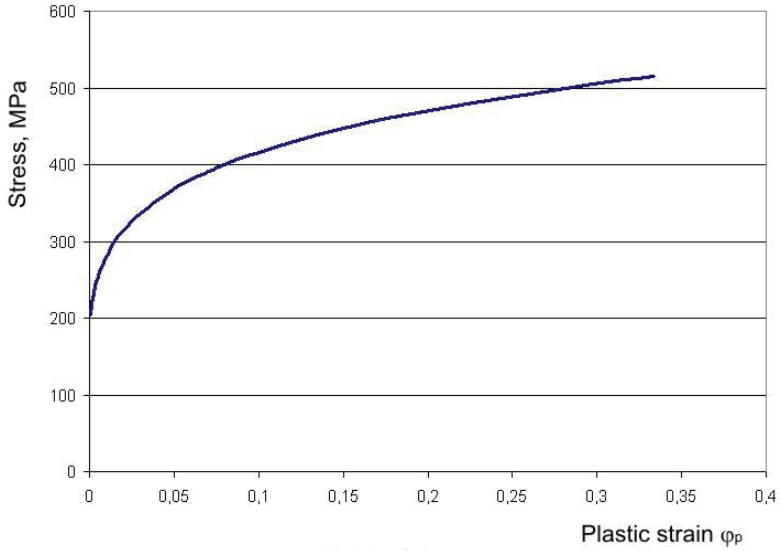

Figure 9. Stress – plastic strain of bellow material.

For numerical simulation, material Č4752 (X6CrNiTi 18 10) was chosen, according to European standard EN 1.4541.

Material properties are:

- yield strength R_{p02} = 205 MPa;
- tensile strength R_m = 515 MPa
- minimum elongation A_{min} = 40 %

Strain hardening can be described with function $k_f = 626{,}6 \cdot \varphi^{0{,}3365}$. Plastic portion of strain is calculated by expression $\varepsilon_p = \varphi - \frac{k_f}{E}$. Strain hardening is shown in Figure 9.

Figures 10 and 11, represent 3D model of the tool which is used in numerical simulation. Figure 10, shows tool geometry with respective dimensions. This tool is used for the numerical simulation of hydroforming of one convolution on circular bellow. Figure 11 shows geometry and respective dimensions of the tool, for the numerical simulation of hydroforming one convolution on the rectangular pipe.

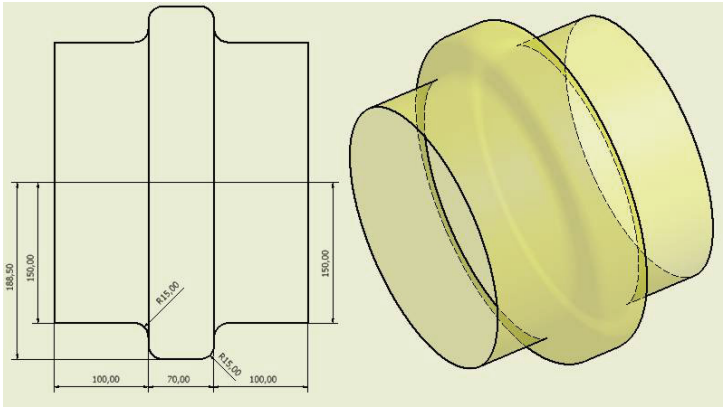

Figure 10. Geometry for round bellow hydroformed section.

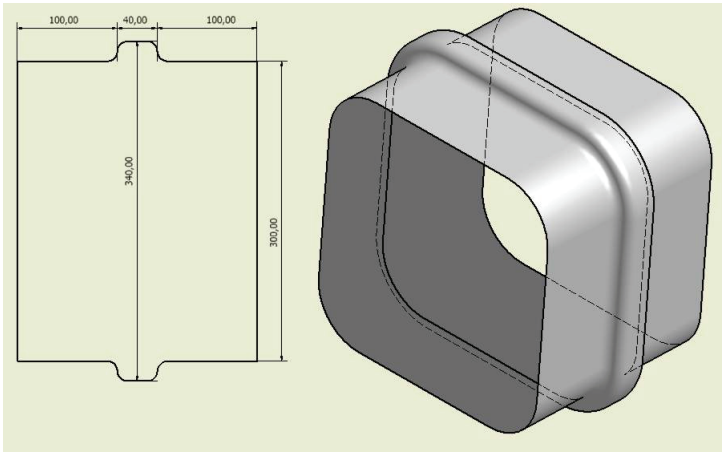

Figure 11. Geometry for rectangular bellow hydroformed section.

According to [3-6], theory knowledge of the process of hydroforming for T-shapes can be used to show stresses and strains in various places on the surface of the sheet metal tube. Figure 12, shows various elements of a T-shape, with respective stresses and strains drawn on each element. Analyzing stress - strain states in a T-shape – one can see four characteristic zones, shown in Figure 12. [3-6]: I - zone of the main tube, II - zone of tube translating into drainage, III - drainage zone and IV - drainage peak zone. Zones I, II and III appear in the hydroforming of a metal tube for the bellow. According to [3-6] pressure needed for the process of hydroforming of metal tube can be calculated as:

$$p = \frac{\beta \cdot k \cdot s \left(\frac{1 - \frac{R_0}{\rho}}{R_\rho} + \frac{1}{R_0} \right) - \frac{s \cdot R_0 \cdot F_A}{R_\rho \cdot \rho \cdot A}}{1 + \frac{s}{R_\rho}\left(1 + \frac{R_\rho}{\rho}\right) + \frac{s}{R_\Theta}} \tag{3.1}$$

where:
s - metal tube thickness, mm
R_0 - the middle radius of tube, mm

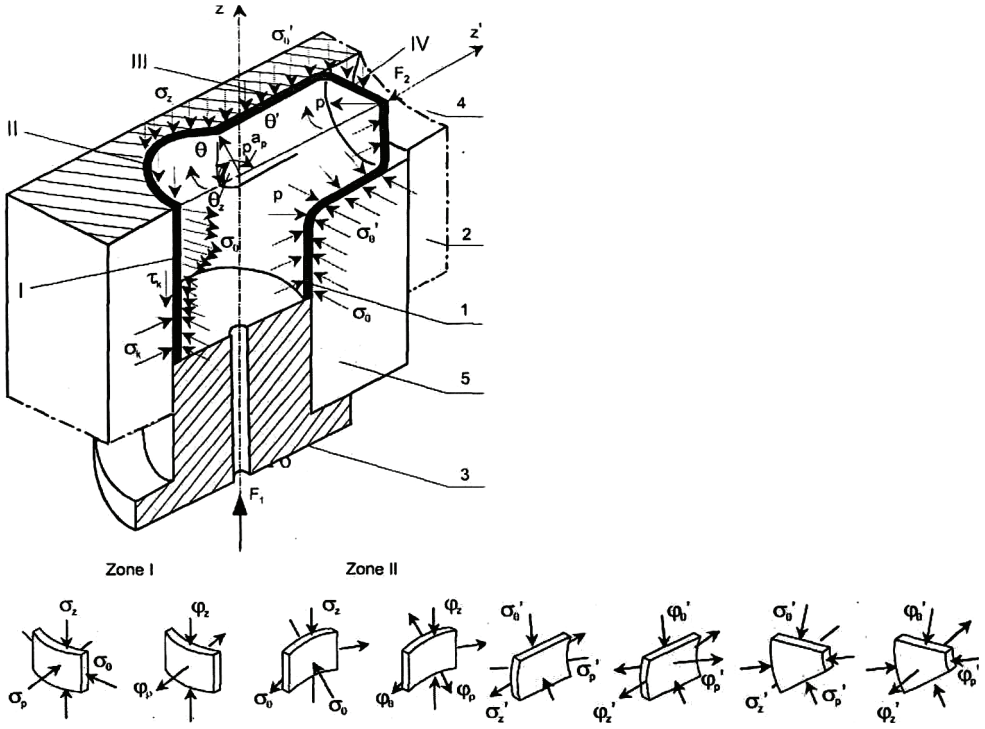

Figure 12. Stress strain states at various elements in a hydroformed T-shape. [3-6]

R_p - radius of free bending, mm
R_Θ - radius, mm

$$R_\Theta = \frac{\rho}{\cos \alpha_i} \tag{3.3}$$

F_A - axial force, N
α_1 - angle of scope of tube about profile ring,
A - tube cross sectional area, mm^2
P - bending radius, $\rho > R_0$, mm
d, d_u - inside and outside tube cross sectional area, mm.

From the expression (3.1) one can see that with increasing of the force F_A , there is decrease of the fluid pressure p needed for the tube hydro forming. This is logical, because with axial feeding of the tube there is no need for high fluid pressure – axial cylinders push the ends of the tube inside the die, and fluid only shapes the tube against the tool cavity. Without axial force F_A fluid pressure forms tube against the tool cavity, and also draws ends of the tube inside tool cavity. Necessary fluid pressure p increases with increased tube thickness, and material hardness.

According to [3-6] if during the forming process the fluid pressure p = const, and for the beginning value:

$$R_0 = \rho;\ R_\rho = \infty;\ R_\Theta = \ R_\Theta = \frac{\rho}{\cos \Theta} = R_0,$$

expression for pressure gets the form of [3-6]:

$$p = \beta \cdot k \frac{s}{R_0 + s} \tag{3.4}$$

Axial force [3-6]:

$$F_A = F_{pd} + F_{pf} \tag{3.5}$$

where are:
F_{pd} - force for plastic forming of tube material, N
F_{pf} - force for pressure fluid in tube acted by presses, N

$$F_{pd} = \frac{\pi}{4}\left(d^2 - d_u^2\right)\left(\frac{\beta \cdot k}{2} - p\right) \tag{3.6}$$

$$F_{pf} = p\frac{\pi \cdot d_u^2}{4} \tag{3.7}$$

According to needed calculated pressure for the hydroforming of a bellow, the hydraulic pressure ram force for die closing can be calculated, by multiplying fluid pressure in the hydroformed tube with the projection of die cavity on the die division line.

Figure 13 shows the results of a numerical simulation for two different types of the tubes – circular and rectangular one. Tool models shown in Figures 10 and 11, are used in this numerical simulation. Tube is approximated with finite number of elements, and tool is defined as a rigid body. Pressure is applied inside the tubes on each finite element, and configured to follow element movement.

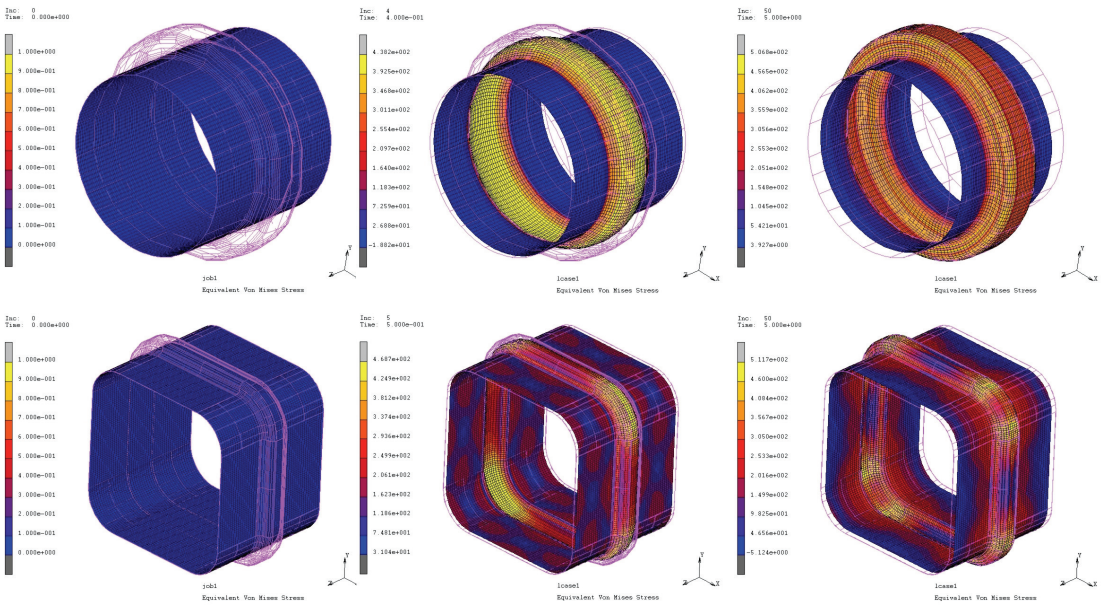

Figure 13. Phases of deformation of circular and rectangular tubes.

Figure 14 shows resultant element thickness along the tube length (arc length). One can see that on the outer parts of a tube there is no element thickness reduction. Central elements

which approximate tool cavity show thickness reduction because of strains achieved during hydroforming process. Maximal reduction of tube thickness is at the radiuses from neck to convolution.

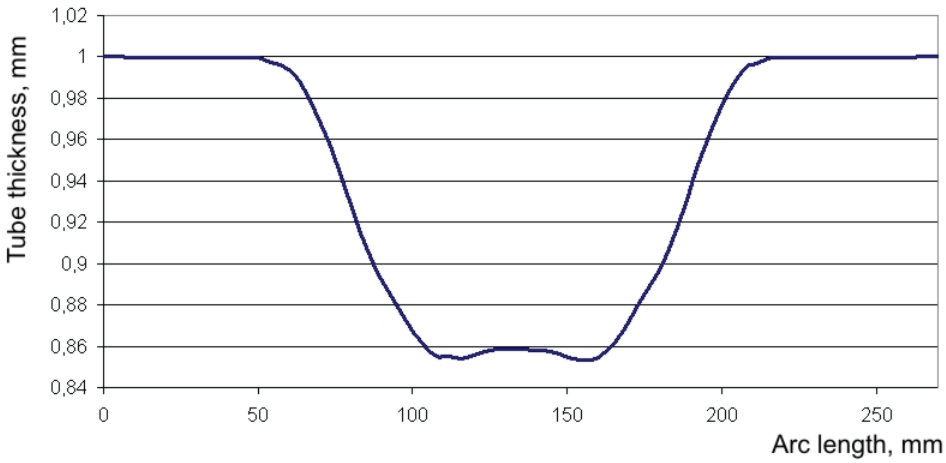

Figure 14. FEM calculated circular tube thickness at the end of the hydroforming process.

Figure 15 also shows element thickness along the tube arc length, but for a rectangular tube. One can see that tube thickness change is maximal at the corners where tube neck forms into convolution.

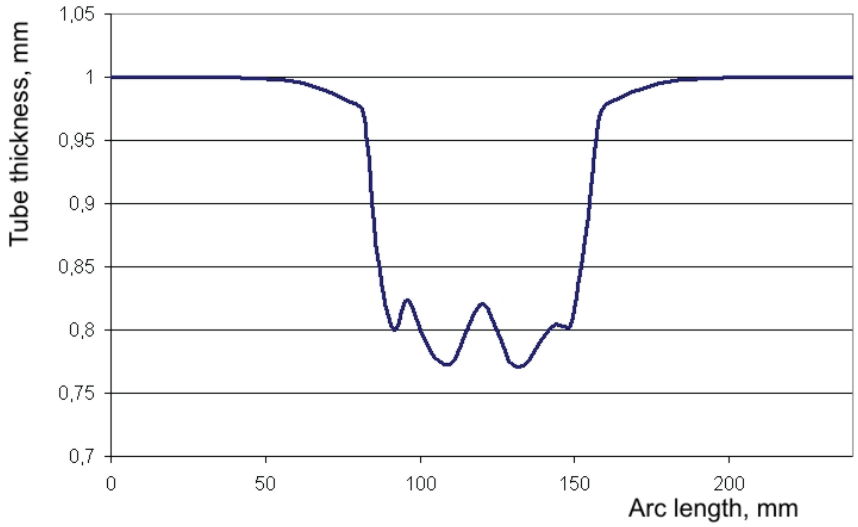

Figure 15. FEM calculated rectangular tube thickness at the end of the hydroforming process.

4. CONCLUSION

Bellows are important elements in the manufacturing industry. They are irreplaceable constructional elements. Since bellows can withstand high temperature and pressure, with thin bellow wall, materials for the production of a bellows have excellent mechanical properties. It is shown that bellows are made from pre-bended, and pre-welded metal pipes by deformation, either by mechanical rolling, or hydroforming procedure. Which technology should be applied, depends on the number of bellows which needs to be manufactured. Hydroforming process is

quicker than mechanical rolling process, but costs are several times greater. For the process of the hydroforming it is necessary to invest substantial resources in the expensive hydraulic presses, dies with desired geometry of the die cavity, plant for the production of the pressure which acts on the fluid etc.

For small series of production it is not efficient to use hydroforming process, because of high manufacturing costs.

5. LITERATURE

[1] Kompenzatori, "Manufacture and testing", URL: http://www.kompenzatori.hr/Default.aspx?lang=eng&control=manufacture, (25.6.2009.).
[2] National intituut voor subatomaire fysica, "Prototype work – rectangular bellow",
[3] URL:http://www.nikhef.nl/pub/departments/mt/projects/lhcbvertex/prototypes/rec_bellow/ (25.6.2009.).
[4] M. Jurković, I. Mamuzić, E. Karabegović; "The sheet metal forming with hydraulic fluid pressure", Metalurgija 43 (2004) 4, pp 315-322.
[5] B. Rančić, "Sila zatvaranja alata pri oblikovanju nestišljivim fluidom delova sa bočnim odvodima", 22. jugoslavensko savjetovanje za proizvodno mašinstvo, Ohrid 2009.
[6] B. Rančić, "Određivanje radnog pritiska I sila pri oblikovanju T-račve sa sužavanjem odvoda", 22. jugoslavensko savjetovanje za proizvodno mašinstvo, Ogrid, 1989.
[7] V. Stojiljković, "Reverzibilno izvlačenje cilindričnih elemenata nestišljivim fluidom", Zbornik radova: Obrada deformisanjem u mašinstvu, Novi Sad, 1984, str. 173-185.