Parameter Optimization of Tube Hydroforming

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Abstract:
Tube hydroforming is mostly applied in automotive industry. In this respect, necessity for the procedure improvement of fluid forming is constant. One of the reasons of its improvement is the procedure performance in optimal conditions. The process parameters have the direct influence on quality and optimal of forming procedure. This paper provides an example of the fluid pressure optimization in T-shape tube hydroforming. Three types of material have been analysed, with three wall thickness and three course levels of axial printers. For the optimization, the evolutional method with applied genetic algorithm (GA) was utilized. The application of GA is significant in solving of many problems in engineering practice. The simplicity and adaptability of the genetic algorithm to the engineering problem results with the increasing volume of applications in a research work. In this paper we investigated interactions of the internal parameters of the T tube hydroforming process, towards achieving the GA model for the optimal internal pressure, necessary for hydroforming.

Keywords: Hydroforming, tube, modelling, optimization, parameter,genetic algorithm, T-shape,

1. Introduction

A significant development of unconventional procedure processing has brought up by the market demands for the rapid part changes in automotive industry, whereas economic and market demands couldn't be satisfied with the conventional method of automotive part manufacturing. The demand that lays for nowadays products is a very high level of quality which implies product manufacturing, with lesser number of constituent elements and lesser quantity of materials (thin-walled elements). The automotive manufacturers are faced with this problem, where apart from functional, the securing and ergonomic product demands lays. It justifies the increasing application of hydroforming in automotive and aviation industry. Hydroforming in that area has showed as satisfying, as besides technological process advantages (possibilities for amplification, narrowing, tube calibration), their advantage is significant in different material application, large dimension parts and complex shape. One of the procedure improving methods is the parameter optimization of the tube hydroforming process. From previous researches, it is observed that the parameter process analyses of element tube hydroforming have been carried out by many other researchers. Investigations were related on modelling and the parameter optimization and considered as the most effective on element tube forming. For modelling and optimization, there are applied analytic methods, numerical methods, evolutional methods, artificial neural networks, finite neural method and alike. A group of researchers, Giuseppe Ingaro and the others (2009) have been investigating and optimizing the internal pressure functioning and printer-counter in Y string hydroforming process in the surging zone, considering the tube wall thickness change. The applied methods are numerical and experimental. Researchers Nader Abedrabo and the others (2009) are analysing and optimizing the internal fluid pressure and axial shift in symmetrical tube amplification, using the finite element method and genetic algorithm. Researchers Zhan Yong and the others (2009) apply FE simulation and GS method for the internal pressure optimization and axial shift in element tube hydroforming. The results of all investigations have influence on the improvement and development of the hydroforming process. This paper provides an example of the internal fluid pressure optimisation in T-shape tube hydroforming, with three wall thickness levels (s=1-2-3mm), three materials ($\sigma_{0.2}$= 164-290-412 N/mm^2) and three axial shifts (10-15-20mm). The genetic algorithm method has been applied (1-3,10 - 15).

2. Tube Hydroforming Process

Almost all recent technological processes are based on utilization of the unconventional procedure of metal processing with plastic forming. It is significant that about 10% of manufacturing in automotive industry includes fluid plastic forming of a tube. The demands are corresponding to the techno-economic justification and hydroforming process utilization. Some of the reasons of the utilization: (4, 7, 8, 10):satisfactory quality of the obtained tube elements,a single tube part fabrication, the welding utilization reducing, possibility of different shape tube forming and wall thickness,abrication possibility of the high repetition percentage products.

Some of the examples of element tube forming are given in Figure 1.

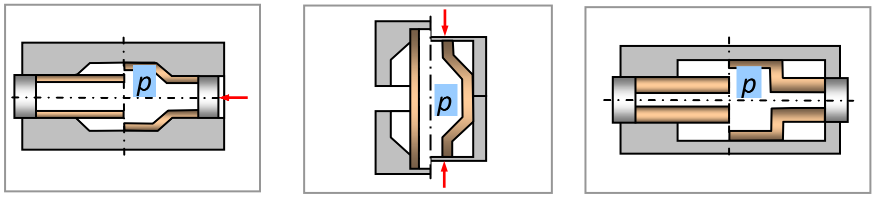


Figure 1: Tube elements obtained by hydroforming

2. 1. T tube Hydroforming

In T tube forming, without drain narrowing, the deformation of the drain terminate in the initial forming stage, while rising of the drain height is obtained by plastic tube deformation, i.e. material inflow from the tube to the drain.

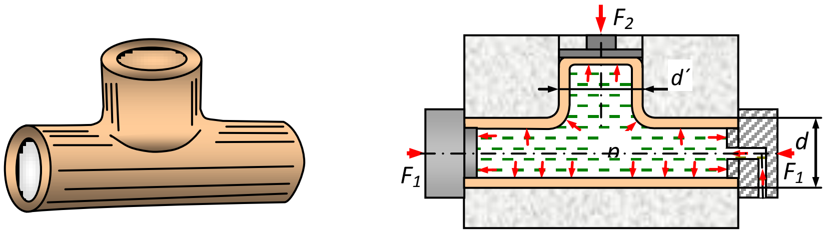
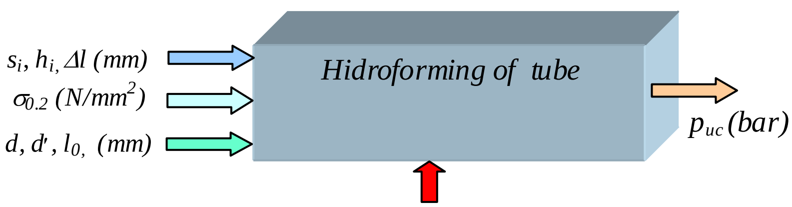


Figure 2: T –shape hydroforming tube

A successful tube forming doesn't depend only on dimensions and contact stress distribution, i.e. the stress-strain states in certain zones of plastic forming part. It also depends on the requisite forces for the operation achievement and the other parameters like: material characteristics, tribological conditions and geometry setup. With defining of the block scheme in process of the input/output sizes, the mutual dependence of the influential parameters of the hydroforming process is recognized (4, 7, 8. 10).



Legend:

- pressure of the cylinder, p_c (N/mm^2)
- stress of the flow, $\sigma_{0.2}$ (N/mm^2)
- diameter of the tube, d_i *(mm)*
- diameter of the bulge, *d ′ (mm)*
- height of the bulge, h_1*(mm)*
- wall thickness, s_i *(mm)*
- the shift, Δl *(mm)*
- length of the tube, l_0 *(mm)*

C = const.

- a device(machine tool)
- a tool,
- the fluid,
- the outer diameter d_v=*const*.
- an abrasion.

Figure 3: Inner/outer scheme block of tube hydroforming process sizes

The internal fluid tube pressure (p_{uc}) via T-shape tube is obtained and represents a cost function for modelling and optimisation of parameter forming process.

2. 2. Tube hydroforming device

Researches of tube hydroforming have been done on the tube hydroforming machine in the laboratory of the Faculty of Technical Engineering of Bihać, Figure 4.

Figure 4: Experimental analysis device of tube hydroforming process

The working pressure, obtained during the forming process has reached the valuation to 3200 (bar).

2. 3. Measuring equipment for the internal fluid pressure

The measuring amplifier device, Spider 8 from Hottinger Saldwin Messtechnick (HBM), Germany (10), has been utilized for the internal fluid pressure measurement of T-shape tube hydroforming.

Figure 5: Measuring amplifier device, Spider 8, P3MB – Fluid pressure sensor in the tube

The device contains eight independent measuring channels, where various sensors can be connected, based on principle of the electronic dimension change. The fluid pressure sensor P3MB, differs with small dimensions, and has been fitted at the fluid output of the multiplier (10).

2.4. Hydroforming tubes

For the analysis there has been used tubes made of three types of material (aluminium alloy, brass and steel), with the outer diameter d_v=20 (*mm*) and length *lo*= 80 (*mm*).

Figure 6: Initial tube shapes for the aluminium alloy, brass and steel

In Table 1 there are the basic material characteristics of which the initial tube shapes have been made.

Table 1. Properties of Materials

TYPES OF MATERIALS								
Aluminium alloy AlMgSi0.5			*Brass Cu63Zn*			*Steel Ck10 (soft annealed)*		
Mechanical Properties		*Chemical properties*	*Mechanical properties*		*Chemical properties*	*Mechanical Properties*		*Chemical properties*
$\sigma_{0.2}$	σ_m	*Al 98.5%*	$\sigma_{0.2}$	σ_m	*Cu 63%*	$\sigma_{0.2}$	σ_m	*C=0.10%*
164 N/mm^2	175 N/mm^2	*Mg≤1 Si=0.5*	164 N/mm^2	164 N/mm^2	*Zn 37%*	164 N/mm^2	164 N/mm^2	*Si≤0.10% Mn≤0.30% P≤0.035% S≤0.035%*

2. 5. Genetic algorithm modelling

Modelling represents a mathematical law description of the parameter process change in certain time and space. In engineering practice problem solving, the genetic algorithm, with its simplicity and repeatability has given solutions for better problem solving. The genetic algorithm (GA) is adjusted to the evolutional organism previsions, and as a modelling shape is necessary for solution improving of cost functions. The classic GA works with the coded variables. The GA seeks the solution by the dot population (not only by one dot). The linear model has been utilized for the modelling of the first line (general shape) for the triple-factor interaction:

$$y = b_0 + b_1 s_0 + b_2 \sigma_{0.2} + b_3 \Delta l + b_4 s_0 \sigma_{0.2} + b_5 \sigma_{0.2} \Delta l + b_6 s_0 \Delta l + b_7 s_0 \sigma_{0.2} \Delta l \quad (1)$$

The modelling aim is to optimize coefficients b_0, b1, ...,b7, in the equation 1.
A single organism coding has been derived (9):

$$\left(\left(\overbrace{b_0, b_1, \ldots b_7}^{O_1} \right), \left(\overbrace{b_0, b_1, \ldots b_7}^{O_2} \right), \ldots, \overbrace{b_0, b_1, \ldots b_7}^{O_m} \right) \quad (2)$$

The population P(t) in a generating time t (Figure 5), is an organism set (O_1, O_2,…, O_m), and the single organism is the dot (solution) in a multidimensional area. A single gene is a coordinate of the dot (3, 5, 6, 9). The initial stochastic generated population in our concrete example consists of the m organisms. Each organism is made of eight genes (see equation 1):

$$O_i = b_0, b_1, \ldots, b_7, \quad (3)$$

Where (i) is a single organism index, i.e. the mathematical model considering the equation 1. The coefficient evolution of the model from equation 1, i.e. overall mode, is carried out in a way given in the pseudocode, Figure 7.

```
Evolutionary algorithm
        t := 0
        Generate the initial random population of the solution P(t)
        evaluate P(t)
        repet
               edit P(t) → P(t+1)
               evaluate P(t+1)
               t := t + 1
Till the criteria for the evaluation abruption is not achieved
```

Figure 7: Pseudo code evolutionary algorithm

In the evaluation phase of population $P_{(t)}$, in the generation time t, an absolute deviation $D_{(i,t)}$ of the individual model (organism) i for all measurements has to be calculated:

$$D_{(i,t)} = \sum_{j=1}^{n} \left| E_{(j)} - P_{(i,j)} \right| \quad (4)$$

Where:

- $E_{(j)}$-experimental values for j measuring
- $P_{(i,j)}$ prediction value of individual model i, for j measuring
- n- a maximum number of measurements

The equation (4) is a raw adaptive measure. The aim of the optimization by GA is to achieve the equation solution (4) with the lack of deviation. But the smallest given absolute solution value doesn't indicate that the smallest percentage model deviation is achieved. Therefore, the average percentage deviation, for all measurements and for individual model i was introduced:

$$\Delta(i) = \frac{D(i,t)}{\left| E_{(f)} \right| n} \cdot 100\% \quad (5)$$

The equation (5) was not utilized as an adequate measure for the evaluation population, but is utilized in order to obtain the best organism in the population after the settled optimisation.

3. The Measurement Results

3. 1. Experimental results

The table shows the values of obtained experimental results of the internal fluid pressure (p_{uc}) in the tube, upon T-string hydroforming.

Table 2: Experimental measurement results of the internal fluid pressure

Number of exp. Nj	*Input values of parameters*			*Output values*
	s_0	$\sigma_{0.2}$	Δl	p_{uc}
	mm	*N/mm²*	*mm*	*bar*
1	1	164	10	432
2	3	164	10	1220
3	1	412	10	1120
4	3	412	10	2940
5	1	164	20	477
6	3	164	20	1298
7	1	412	20	1210
8	3	412	20	3090
9	2	290	15	1603.75

The diagram of experimental values for the fluid pressure of T tube forming, made of steel, wall thickness s_0=2 mm, obtained by measuring on Spider 8 device.

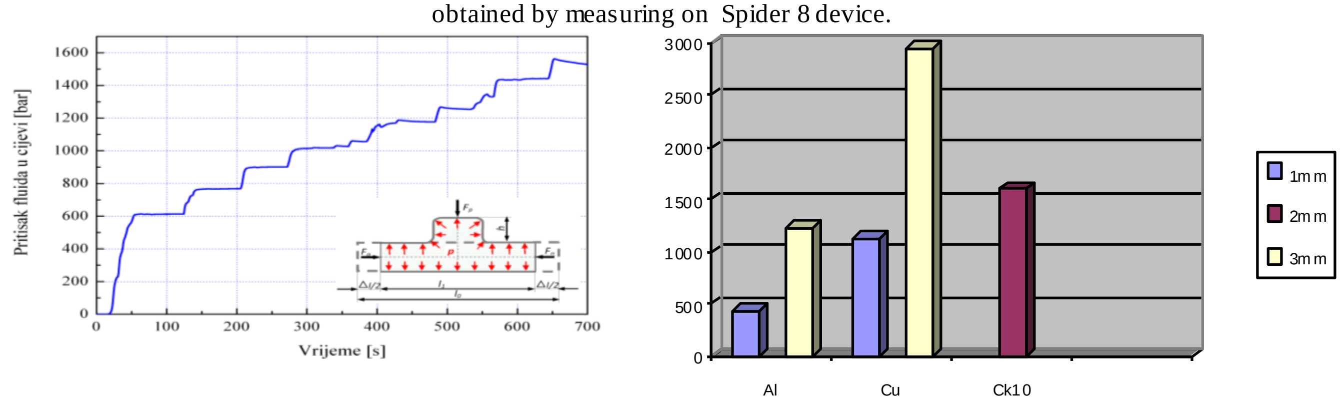


Figure 8: Fluid pressure in the tube by experimental measurement,fluid pressure in the tube

The fluid pressure in the tube for three types of material has been given in Figure 8.

3. 2. GA model of fluid pressure in the tube

The analysis of the experimental values of the fluid pressure in the tube, with the GA application has been obtained. The population carried the 100 organisms, and the number of the system motions for GA was 10. The maximum number of the generations was 1000.

The best mathematical model obtained by GA for the fluid pressure in the tube has a shape:

$$p_{uc} = -81,1683 + 43,9205 s_0 + 0,559208 \sigma_{0.2} + 0,59908 \Delta l + 2,02987 s_0 \sigma_{0.2}$$
$$+ 0,0132628 \sigma_{0.2} \Delta l + 0,860965 s_0 \Delta l + 0,00514024 s_0 \sigma_{0.2} \Delta l \quad (6)$$

The figure 9 shows the best evolution solution (i.e. the best mathematical model for the fluid pressure in the tube), over the generations. The solution improvement in the initial phase was rapidly, and after the generation of 100, relatively small solution improving has been perceived.

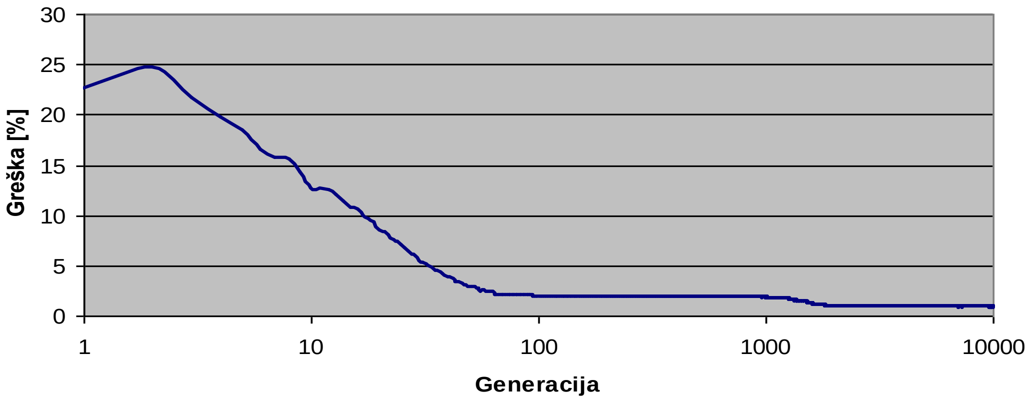


Figure 9: Improvement of the best generation solutions

3. 3. Comparative results of the experimental values by the GA model

Experimental researches of the T tube hydroforming process parameters, the values for the defined outer parameter are obtained, i.e. tube fluid pressure (p_{uc}). These values are compared with the values (p_{uc}) obtained by the GA model, Table 3.

Table 3: Comparative data of the experimental and obtained GA model values

Number of exp. Nj	*Input values of parameters*			*Output values*	*GA model*
	s_0	$\sigma_{2,0}$	Δl	p_{uc}	p_{uc}
	mm	*N/mm²*	*mm*	*bar*	*bar*
1	1	164	10	432	432,1424
2	3	164	10	1220	1219,8601
3	1	412	10	1120	1119,8733
4	3	412	10	2940	2939,9021
5	1	164	20	477	476,9239
6	3	164	20	1298	1298,7208
7	1	412	20	1210	1210,2943
8	3	412	20	3090	3089,8979
9	2	290	15	1603.750	1483,3960

The mean percentage deviation within experimental and prediction values, obtained by the GA model is Δi = 0.85148%.

4. Conclusion

Plastic forming with the fluid application has been known since the last century, and researches in this area are significant for the process improvement. With the process parameter optimization of the plastic forming, the techno-economic justification of the process is achieved.With the mathematical modelling and optimization of the experimental values for the fluid pressure in the tube, with the applied genetic algorithm (GA), the mathematical model equation is obtained, with the percentage deviation Δi = 0.85148%. The mathematical model for the fluid pressure in the tube refers to the optimal work area, describing the solution regression for the derived experiment. The solutions in this area ensure the forming efficacy, with the optimal internal pressure for the generated dimension lines: $s_0 = 1mm \div 3mm$, $\sigma_{0.2} = 164 \div 412 \quad N/mm^2$ i $\Delta l = 10mm \div 20mm$.

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