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SHAPE OPTIMIZATION OF A THOROIDAL METHANE GAS TANK FOR AUTOMOTIVE INDUSTRY

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Abstract: *The aim of this study is to present a methodology for optimal shape design of the thoroidal gas tank used in the automotive industry for storage of the methane gas based on the application of the Finite Element Method (FEM). The engineering design of the thoroidal gas tank is performed using a specialized database of 3D parameterized shapes.*

Keywords: *engineering design, thoroidal methane gas tank, optimization, Finite Element Method*

INTRODUCTION

This paper presents a methodology for optimal shape design of the thoroidal methane gas tank for automotive industry using the FEM and based on a specialized database of 3D parameterized shapes.

The thoroidal methane gas tank is designated to be installed in car's trunk, where the optimal capacity dimensions are determined by the user.

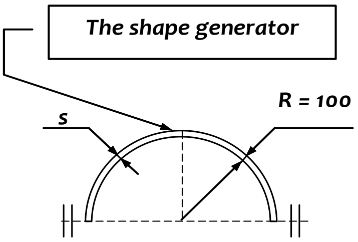

Figure 1. The shape generator

The mechanical simulation, numerical calculations and geometrical modeling are a complex task, especially for the three-dimensional complex models [1-20].

THE PROPOSED METHOD FOR OPTIMIZATION

The optimization method includes the following steps:

- ☐ *the shape of the thoroidal gas tank is chosen from a specialized database of 3D parameterized shapes;*
- ☐ *the material selected for the construction of the thoroidal gas tank is chosen;*
- ☐ *the shape and dimensions of the thoroidal gas tank are modeled and optimized using the FEM;*
- ☐ *the real dimensions of the thoroidal gas tank are rounded to the nearest representable values;*
- ☐ *the 3D parameterized real model of the thoroidal gas tank is modeled and assembled;*
- ☐ *a study of efforts and deformation states is performed using the 3D real assembly model.*

This thoroidal gas tank has a particular shape that is generated by the movement of a ring section (Figure 1), alongside of a guiding curve with axial symmetry, as it is shown in Figure 2.

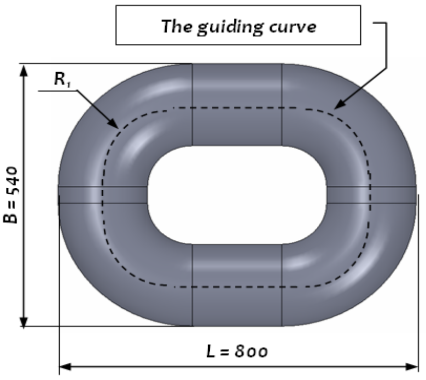

Figure 2. The 3D thoroidal model

The constructive dimensions of the shape generator are shown in Figure 1, and the dimensions of external size imposed to the toroidal shape are as follows: Length, L = 800 mm, Width, B = 560 mm and Height, H = 200 mm.

In engineering design, the optimized dimensions are afterwards rounded up to real values.

DIMENSIONAL OPTIMIZATION OF THE THOROIDAL GAS TANK USING THE FEM

The optimum design through the Finite Elements Method can significantly reduce the weight, the cost of manufacturing and increase security and even the reliability of the thoroidal gas tank [21].

The proposed method is applied to determine the optimal shape of a thoroidal gas tank for automotive industry, designated to storage CH_4 gas, made from high tensile steel.

For mathematical calculations, we use next input data:

- ☐ *the maximal inner pressure of CH_4: $p = 30\ N/mm^2$;*
- ☐ *the external pressure is equal with the atmospheric pressure;*
- ☐ *the normal range of working temperature: $T = -20\ ^oC,..., +60\ ^oC$;*

Table1: The typical material properties of AISI 4340

Characteristics	Symbol	Units of measurement	Value
Longitudinal modulus of elasticity	E	[N/mm^2]	205000
Shear Modulus		[N/mm^2]	8000
Density	ρ	[kg/m^3]	7850
Elongation unit load	σ_t	[N/mm^2]	1110
Admissible unit load	σ_a	[N/mm^2]	710
Coefficient of linear thermal expansion	α	[/°K]	$1.23{\cdot}10^{-5}$
Coefficient of thermal conductivity	λ	[W/(m·K)]	44.5
Specific heat capacity	c_p	[J/(kg·K)]	475

- ☐ *the material: high tensile steel AISI 4340 with the typical properties shown in Table 1. It offers a very good balance of strength, toughness and wear-resistance. The typical chemical analysis for AISI 4340 is: Carbon 0.40 %; Silicon 0.25 %; Manganese 0.70 %; Nickel 1.85 %; Chromium 0.80 % and Molybdenum 0.25 %.*

The optimization can be done on a 1/4 part of the initial model (Figure 2), to which are applied accordingly: the distributed force loads, the local material connections and the conditions of symmetry on the contour.

The 3D modeling and the finite element analysis is obtained by applying the SolidWorks 2011 software [22]. The discretization in finite elements of the shape was made by next settings: Mesh density:/ fine/; Mesh parametric:/ curvature bashed mesh/; 2mm/2 mm/3 /1.1 /; Advanced mesh/ Jacobian points/29 points.

The variables within the optimization process are: the cover thickness s and radius $R_{1.}$

Applying the SolidWorks 2011 software to the 3D model, it results an optimal wall thickness s_o = 6.48 mm and a radius R_1 = 199.82 mm. Consequently, the resultant effort von Mises is σ_o = 709.87 N/mm^2, corresponding for a temperature T = -20 °C.

Table 2: The results obtained by applying the SolidWorks 2011 software to the 3D model

No.	T [°C]	σ_r [N/mm^2]	u_r [mm]
1	-20	709.126	0.36755
2	-10	689.677	0.37084
3	0	670.619	0.37421
4	10	651.842	0.37767
5	20	633.483	0.38127
6	30	629.871	0.38498
7	40	636.507	0.38882
8	50	643.988	0.39272
9	60	657.141	0.39689

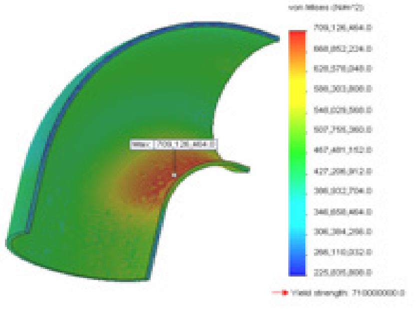

Figure 3. The spatial von Mises distribution

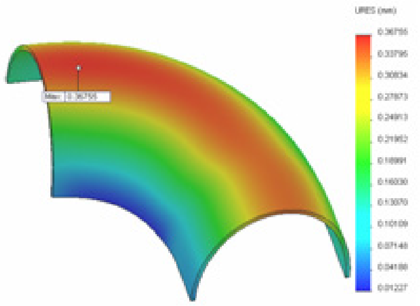

Figure 4. The spatial linear deformation distribution

The real wall thickness s_r = 6.5 mm and radius R_1 = 200 mm are rounded to the nearest representable values. The spatial von Mises distribution (Figure 3) and the spatial linear deformation distribution (Figure 4), as functions of temperature field, are based on values from Table 2.

The variation laws of $\sigma_r(T)$ and $u_r(T)$, as functions of temperature, are obtained by interpolation with the least-squares method, as:

$$\sigma_r(T)=667.8765-1.879566\cdot T+0.0171747\cdot T^2+0.00001963198\cdot T^3 \qquad (1)$$

$$u_r(T)=0.37421+3.423\cdot 10^{-4}\cdot T+0.495418\cdot 10^{-6}\cdot T^2+0.158249\cdot 10^{-8}\cdot T^3 \qquad (2)$$

with the corresponding graphical representations from Figure 5 and Figure 6.

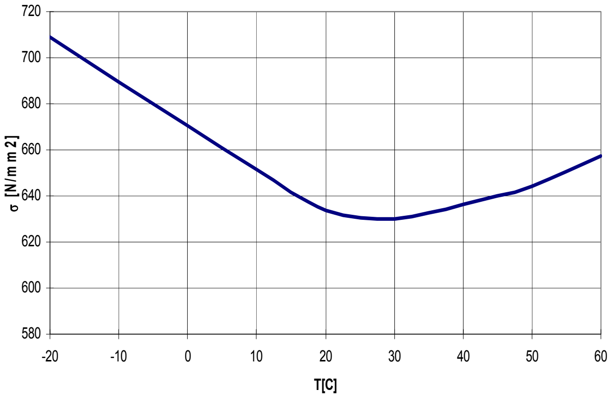

Figure 5. $\sigma_r(T)$

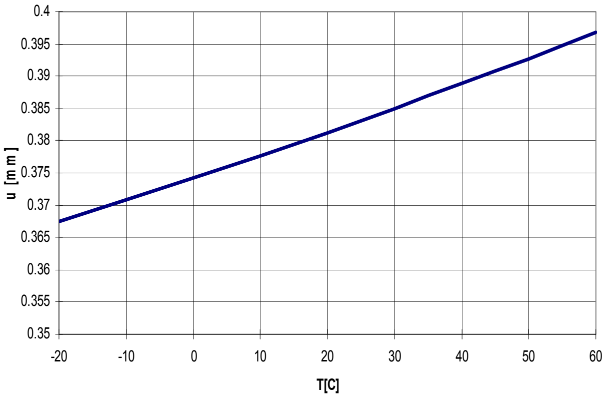

Figure 6. $u_r(T)$

CONCLUSIONS

For the real model of the thoroidal gas tank corresponding to the optimized solution, subjected of a inner pressure $p = 30$ N/mm^2, *with a thickness increased by* $\Delta s = 0.3$ % *comparative with the optimal thickness, the finite element analysis shows a maximum resultant effort von Mises of* $\sigma_r = 709.126$ N/mm^2 *for the minimum temperature* $T = -20$ °C.

On the other hand, $\sigma_r = 709.126$ N/mm^2 $\leq \sigma_a = 710$ N/mm^2, *as it was required by the design condition. The resultant linear deformation has the maximum value* $u_{r\,max} = 0.39689$ *mm on* $T = 60$ °C.

The minimum resultant effort von Mises of $\sigma_{r\ min} = 629.871$ N/mm^2 *corresponding for the temperature* $T = 30$ °C *is lower with* $\Delta\sigma = 11.3$ % *than the admissible value* $\sigma_a = 710$ N/mm^2.

The results of optimization demonstrates that the dimensional optimization method applied to the 3D parameterized thoroidal tank model is correct and efficient.

The following acceptance tests were performed prior to delivery for methane gas tank: a) preliminary examination; b) pre-proof volumetric capacity; c) ambient proof pressure; d) post-proof volumetric capacity; e) external leakage; f) final examination; g) cleanliness measurement.

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