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3D Geometrical Solutions for Toroidal LPG Fuel Tanks Used in Automotive Industry

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***Abstract*—This study aims to investigate various geometrical solutions of toroidal LPG (Liquefied Petroleum Gas) fuel tanks used in automotive industry, using CAD parametric modeling. The CAD modeling has a potential impact required to develop and to implement new mathematical models on the engineering design process of toroidal LPG fuel tanks.**

***Keywords*—automotive industry; geometrical models; industrial engineering design; optimization methods; toroidal LPG fuel tank**

I. INTRODUCTION

During the last few decades, in parallel to the formation of global market structures, the business strategies in automotive industry imposed global-scale patterns of integration, but it has also developed strong regional-scale patterns of integration improving vehicle design/engineering [1-4].

Key structural features of both car production and sales differ for every vehicle model and require particularization because of the high level of inter-relationships in the performance characteristics of components [4].

On the other hand, in automotive sector, instruments of regional industrial policy, standards and industry regulations, necessitate local adaptations, local models, local production, and local innovation activities to satisfy local needs [2-4].

Significant contributions has been made in automotive industry by vehicle architects, design engineers and project managers in terms of technology, techniques and material to improve many aspects such as safety, reliability and technology of car at a high level to meet the customer needs and expectations [1, 2].

In order to achieve these targets (the customer attributes and technical specification) the designed vehicles are adapted for local markets, and there are used various practices in design and manufacturing for increased productivity, low design cost, low production cost and improved quality control [2-4].

The first CAD systems began to appear out of research and into commercial use in automotive industry in the 1980s [5-9].

CAD systems (with the use of parametric modeling) improve the quality of design (conceptual, embodiement and detail design), increase the productivity of the designer, reduce time-consuming build-test-redesign iterations, improve communications between all phases through documentation, and create a database for manufacturing [5-9].

In modern CAD sophisticated software's (combining 3D surface/solid computer modeling, animation and powerful computers) for creating complex computer adaptable models of the car concept or detailed geometrical design [10, 11], algorithms act in complex patterns and automated programmable interfaces that have demonstrated to be vital in vehicle manufacturing process [12-17].

3D-CAD models include product-specific features and flexible tools that link a library of 3D shapes, the geometry of parts, additional constraint information, with their functions in diagrammatic visualization of qualitative information necessary for various simulation, verification and validation processes [5-9].

Storage fuel tanks used in automotive industry contain technologically advanced components [18-21] and their design takes into account the supershapes design variables [22-24], specific structural parameters [25-27], precise geometrical conditions of linkage structural parameters [28, 29], computer tools [5-9], numerical computational algorithms and methods [30-32], visualization techniques [33-39], generative design and verification conditions [40, 41].

Liquefied petroleum gas (LPG) describes flammable hydrocarbon gases including propane, butane and mixtures of these gases used as fuel in vehicles [42].

In comparison with to fuels like petrol and diesel, LPG has its advantages and disadvantages in next aspects: environmental impact; efficiency and performance; availability; safety; and financial requirements and costs [43].

LPG is considered clean, safe and cheap, offering a viable alternative to conventional fuels [44].

A toroidal storage tank is a complex geometrical product that can be considered as a shell in the form of the surface of revolution with the wall thickness very small in comparison with its other dimensions [45].

The most important mechanical properties toroidal LPG tanks in designing process are the following: the static behavior under internal pressure, the vibration characteristics, the

buckling and collapse loads, and the properties under impact loading arising from accident conditions [45].

The toroidal LPG fuel tanks (usually made of thick steel) can be placed in various locations in function of amount of space available, vertically or horizontally. The majority of vehicles have the tank installed in place of the spare tyre, and can be mounted (as shown in figure 1) [46-48].

a) LPG installed instead of spare wheel inside

b) LPG installed outside

b) LPG installed in left side

FIGURE I. EXAMPLE OF TOROIDAL LPG FUEL TANK INSTALLATION

In this study, various CAD solutions of toroidal LPG fuel tanks (figure 2) used in automotive industry are proposed.

FIGURE II. STANDARD SHAPE OF TOROIDAL LPG FUEL TANK

II. DESIGN METHODOLOGY

The toroidal surfaces are graphically represented in figure 3 by applying parametric 3D modeling using different mathematical equations.

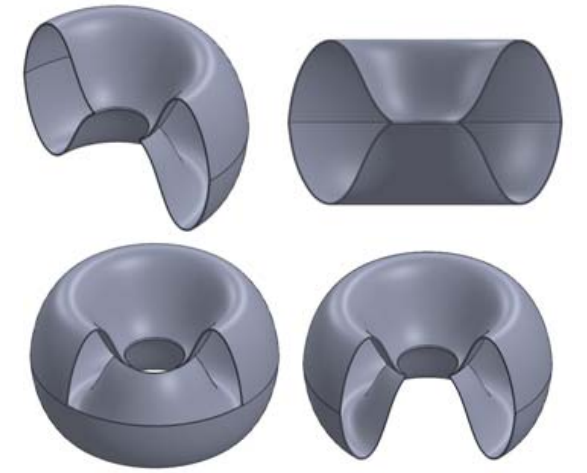
A. *Piriform Curve*

The Piriform curve (figure 3a) is given by the Cartesian equation [49]:

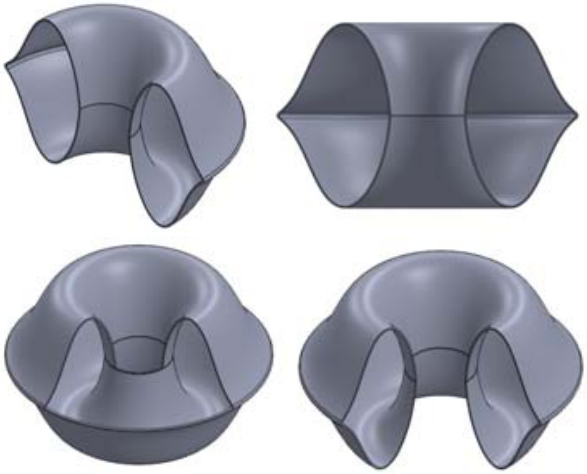
$$a^4 y^2 = b^2 x^3 (2a - x) \tag{1}$$

The area of the piriform curve is:

$$A = \pi ab. \tag{2}$$



a1)



a2)

B. *Burnside curve*

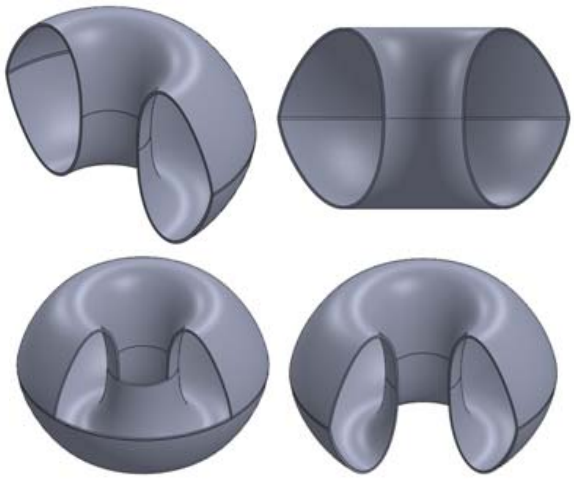
The Burnside curve (figure 3b) is given by the Cartesian equation [49]:

$$y^2 - x\left(x^4 - 1\right) = 0. \tag{3}$$

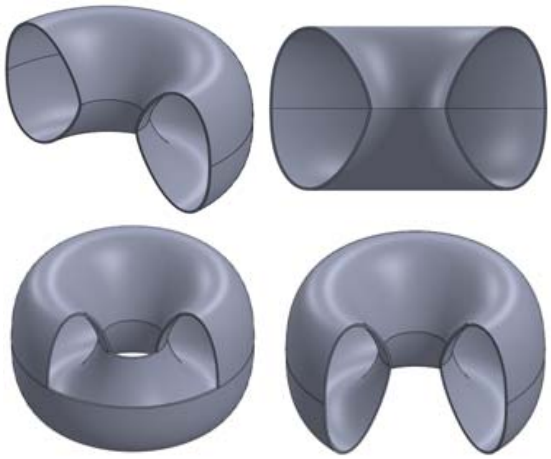
The closed portion of the curve has area:

$$A = \frac{\sqrt{\pi}\,\Gamma\left(\frac{3}{8}\right)}{4\,\Gamma\left(\frac{15}{8}\right)} \tag{4}$$

where Γ(z) is a gamma function.



b1)

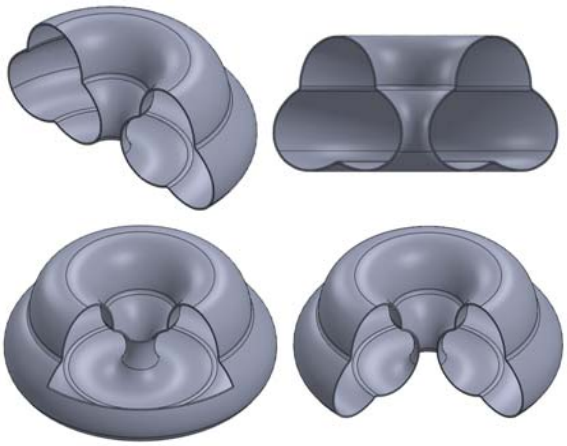


b2)

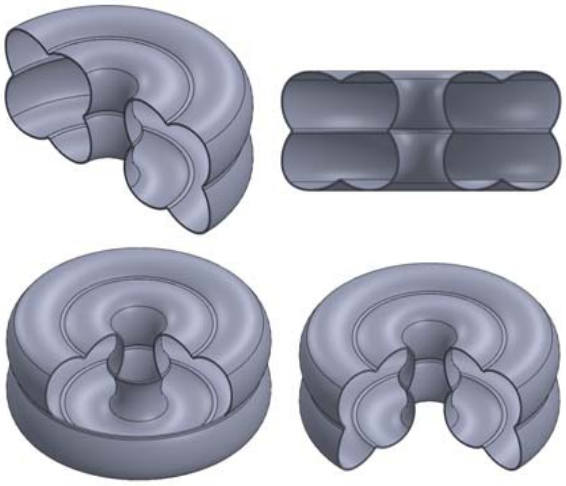
C. Curve of Degree 6

The epicycloid (figure 3c) is given by the parametric equations [49]:

$$x = (a+b)\cos\phi - b\cos\left(\frac{a+b}{b}\phi\right)$$
$$y = (a+b)\sin\phi - b\sin\left(\frac{a+b}{b}\phi\right). \tag{5}$$



c1)



c2)

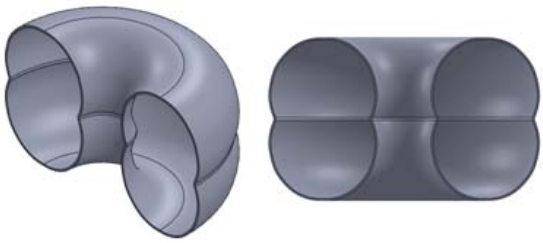
D. Nephroid

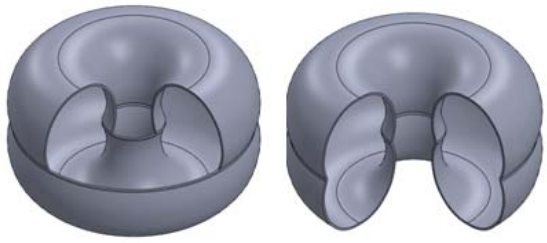
The nephroid (figure 3d) is a 2-cusped epicycloid given by Cartesian equation [49]:

$$\left(x^2 + y^2 - 4a^2\right)^3 = 108\,a^4\,y^2. \tag{6}$$

The nephroid has area:

$$A = 12\pi a^2 \tag{7}$$



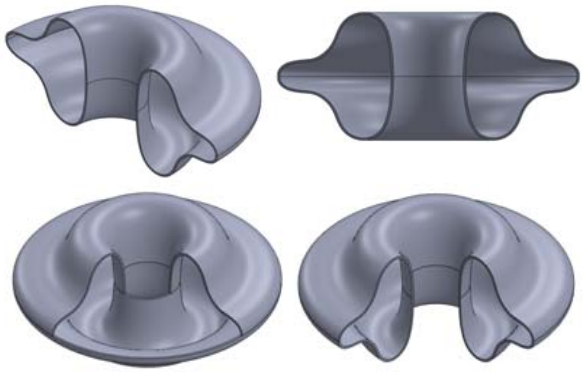


d)

E. Pear Curve

The pear curve (figure 3e) in Cartesian coordinates with a constant r is given by the equation [49]:

$$r^2 = (x^2+y^2)(1+2x+5x^2+6x^3+6x^4+4x^5+x^6-3y^2-2xy^2+ \\ +8x^2y^2+8x^3y^2+3\ x^4y^2+2y^4+4xy^4+3x^2y^4+y^6). \quad (8)$$



e)

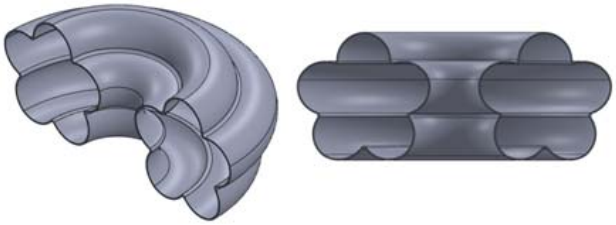
F. Ranunculoid Curve

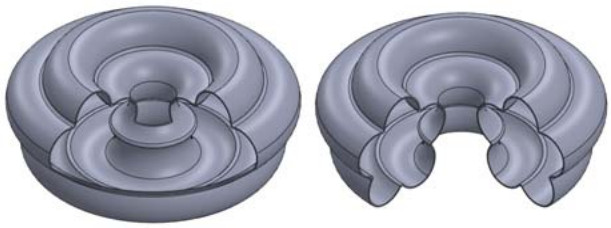
The Ranunculoid curve (figure 3f) is given by the parametric equations [49]:

$$x = a\,[6\cos t - \cos(6t)] \\ y = a\,[6\sin t - \sin(6t)]. \quad (9)$$

The area is given by relation:

$$A = 42\pi a^2. \quad (10)$$





f)

FIGURE III. EXAMPLE OF 3D MODELING OF THE PARTICULAR TOROIDAL SURFACES

III. CONCLUSIONS

In this study the 3-D solid modeling were applied to find different solutions of toroidal LPG fuel tanks used in automotive industry.

3D geometric models, that include geometric conventional shapes as well as other less traditional shapes, can be used in geometric design for more comprehensive design and analysis.

The specific shape of these 3D models of toroidal LPG fuel tank can provides different opportunities and advantages and can be used for optimal engineering design process in various applications by engineers and researchers.

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