tricycle, brake disc, mass optimizing

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MASS OPTIMIZING OF THE BRAKE DISCTOLIGHTTRICYCLE

Abstract

The article presents an optimization process of the brake disc in terms of mass and strength resistance. A model of the disc was made using three-dimensional software – Catia V5 (CAD). Model has been subjected to the parameterization process for the strength calculations. A brake disc was fixed at the location of the mounting screws and subjected to torque resulting from the braking process. As a result of calculations, a set of parameters that meet the established boundary conditions was obtained as shown in the article.

1. INTRODUCTION

Shell Eco Marathon competitions are organized regularly since1985 [1]. The best technical university students from around the world take part in them. Competition is to build a vehicle that will be characterized by a very low energy consumption. The competition Shell Eco Marathon Europe 2015 is to overcome 10 laps of the track, that is specially built for this purpose. The track is located on the streets of Rotterdam, with a total length of the entire distance equal to slightly more than 16km. This distance must be overcome in less than 39 minutes [2]. It is worth mentioning, that it is possible to start in two classes of body styles and several classes of power supply such as diesel, petrol, electric or fuel cell. The vehicle, which consumes the least energy during the trip is the winner in one of the class.

Hydrogreen Pollub [3] as one of two teams from the Lublin University of Technology is involved in the construction of a light vehicle for the Shell Eco Marathon competition. Vehicle design is based on the concept of tricycle

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with two front steering wheels and one rear wheel drive. Figure 1 shows the initial sketches of the vehicle shape and solid models created using three-dimensional printing technique. In order to succeed in competition, the work was focused not only on optimizing the shape of the vehicle [4], but also every aspect of the configuration and all the mechanical components of the vehicle. This publication focuses on the optimization of the mass [5] of the brake disc with achieving adequate, sufficient mechanical properties of this part.

Fig. 1. 3D printed, conceptual models of hydros [source: own study]

This project was mainly made by students from students research circle “Aviation Propulsion Systems”. This organization is an academic organization that belongs to the Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems [6], what allows students belonging to this organization to have the opportunity to use all the tools available in the Department. During the design process of the vehicle, CAD software Dassault Systems – CatiaV5 was used, what allows to make fine-tune solutions to the smallest detail. In the case of geometry optimization of brake disc, Part Design, Generative Structural Analysis and Product Engineering Optimizer modules were used. This article focuses on showing the possibility of a geometric model parameterization process and linked of parametric geometric model with an iterative strength analysis carried out by using Finite Element Method (FEM).

Parameterization setting in Catia V5 software allows to describe the geometric model with the different parameters and equations (Formula) [7] in order to easily modify the model, preparation or use of the model parameters to optimize the geometry. In figure 2 the exemplary view including the optimization tools is shown. If the model will be prepare in adequate way, it will be also possible to build auto generative models, those which are able to intelligently adapt to a pre-existing model geometry.

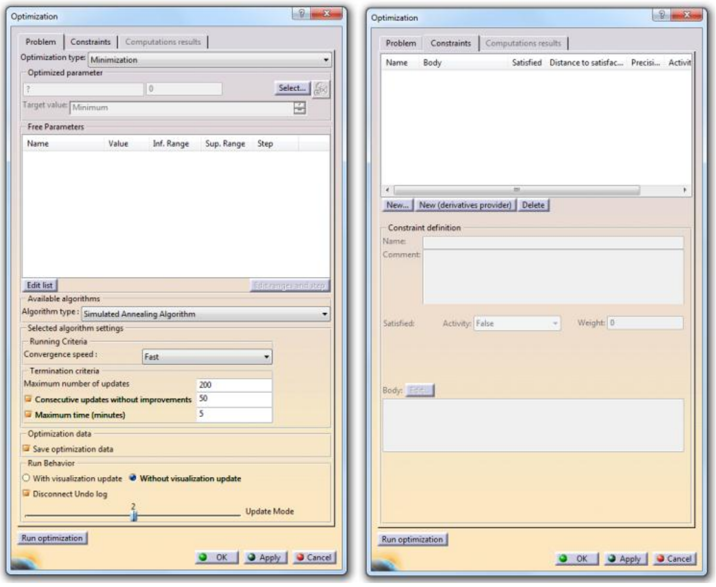

Fig. 2. Dialog boxes from optimization tools in Catia V5 [source: own study]

2. RESEARCH OBJECT

Standard bicycle brake discs of diameter 160 mm, although it meets the strength requirements, at the same time its mass is usually above 0.1 kg. Alligator Windcutter 160 mm brake discs (fig. 3) with a weight of 0.092 kg was acquired, thanks to the cooperation with the bike shop MetroBikes.pl. But during the meetings of the team, it was decided that new brakes discs, which will be at least about 30% lighter than original will be design.

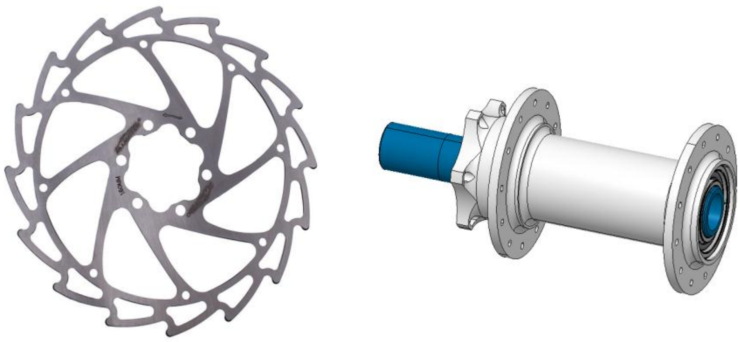

Fig. 3. Alligator Windcutter brake discs and wheel hubs designed by a team of Hydrogreen Pollub [source: own study]

The second purpose to start work on lighter brake discs, were hubs designed by our team (fig. 3), which due to the small size, had changed diameter of brake discs mounting bolts spacing compared to standardized bicycle wheels – from 44 mm to 34 mm.

3. BOUNDARY CONDITIONS OF SIMULATION

The tested brake disc was initially designed in the Catia V5, in Part Design module as part of a solid with a predefined arms distribution and pre-imposed outer diameter, width of the friction surface and bolts spacing distance. In the optimization process, parameters such as arm radius, arm thickness, arm angle, diameter and thickness of the stiffener ring, radius 1 (R1), radius 2 (R2) were taken into account (fig. 4).

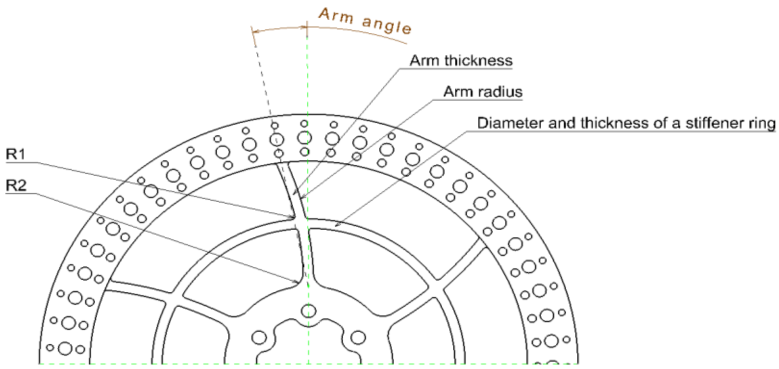

Fig. 4. Description of the parameters on the projection of the 3D model [source: own study]

Thus prepared parametric 3D model was opened in the environment (Workbench) Generative Structural Analysis, where the boundary conditions and load for a preliminary analysis of FEM were given. The holes of the brake disc were virtually connected to each other by means of a Rigid Virtual Parts (fig. 5). Brake disc was fixed in place with a clamp bonds (fig. 6), receiving all degrees of freedom.

Only the torque acting on the brake disc was introduced in the model. In this optimization process, the effects of the axial forces for a brake disc, and thus buckling analysis of the brake disc were not performed. While the value of the torque that has been given to the proposed friction surfaces of the brake disc [8] was calculated from the analysis and design principles that have been adopted.

$$M_s = (F_n \cdot \mu) \cdot [9], \tag{1}$$

where: F_n – force acting on ground,
μ – friction coefficient rubber – asphalt,
R – wheel radius.

$$M_s = (882{,}9 \cdot 0{,}9) \cdot 0{,}239 = 190\ Nm \tag{2}$$

Vehicle with driver weighs about 90 kg, which gives 882.9 N force which acts on the surface by the tire footprint. Multiplying this force by the coefficient of friction for rubber and asphalt equal to 0.9 F_t = 794.61 N is obtain. While stopping the vehicle, the torque equal to 190 Nm (the force F_t multiply by the radius of the tires fitted to the vehicle R = 0.239 m) is acting on the main axle. As a result, there is no need to stop the vehicle by using only one brake (due to the nature of driving during the competition), the torque was divided into individual wheels. It was assumed that 65% of the vehicle mass is acting on the front axle of the vehicle, and therefore, there are two front wheels, so the torque was divided into two. It turned out that the front wheel brake will operate in succession torque 64 Nm [9]. But because of security reasons, the resulting torque has been multiplied by a safety factor x_B = 1.2. Safety factor was obtained to have 20% more strength than needed because of the dynamics load occurred during braking onto rough surface. Finally a load value of the brake disc torque was equal 75 Nm (fig. 7).

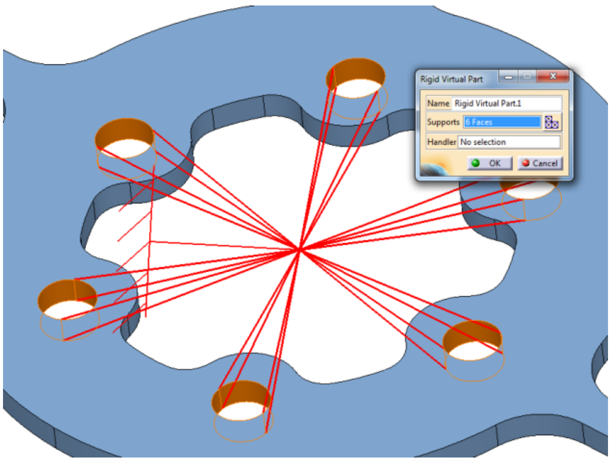

Fig. 5. Binding type of Rigid Virtual Part assigned to the mounting holes [source: own study]

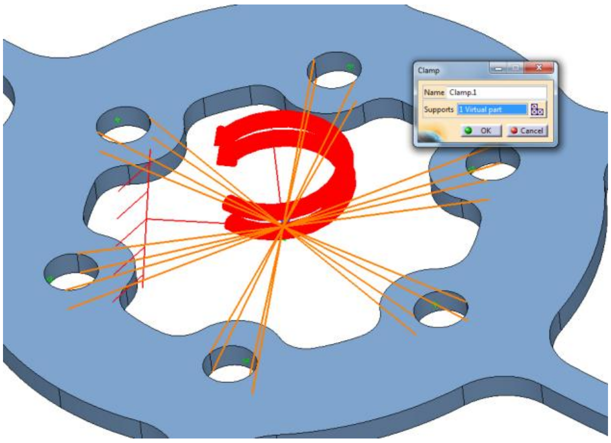

Fig. 6. Fixing of holes in brake disc [source: own study]

After preparing the FEM simulation model new optimization model was developed in Product Engineering Optimizer environment. With this module it is possible to carry out design optimization using several algorithms adapted for this optimization [10]. Constraints for the parameters and boundary conditions have the ability to transmit the conditions criteria (fig. 8).

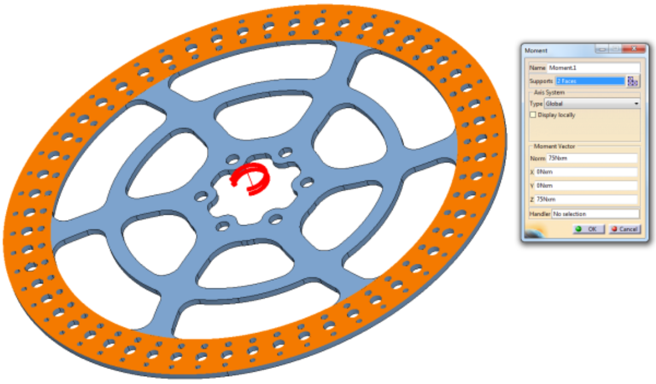

Fig. 7. Load torque of the brake disc [source: own study]

During the simulation the Simulated Annealing Algorithm [11] was used, this is the default algorithm, which operation is based on stochastic search for a set of solutions to meet the job criteria. Optimization process has been set as the minimization. In this way, the process will focus on minimizing the mass having assigned to the function limitation.

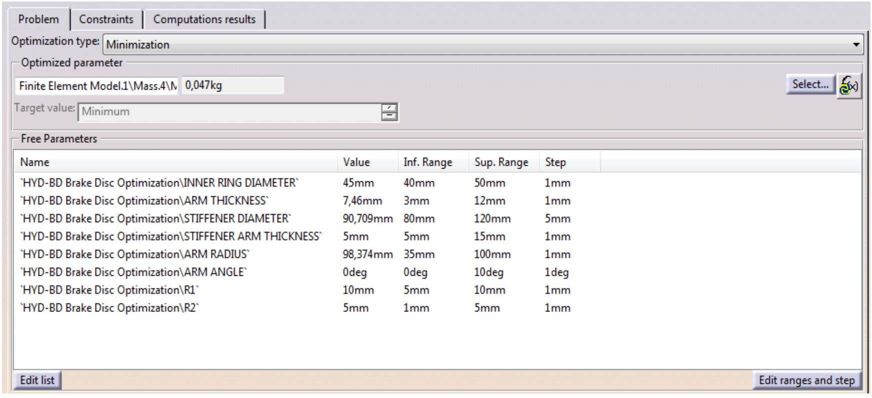

Fig. 8. Parameters and their limitations selected for optimization [source: own study]

After selecting parameters to optimize process, parameters and the imposition of restrictions and iteration with which parameters have to change were created. Additional restrictions on the strength of the structure were also assumed. The maximum von Mises equivalent stresses shall not exceed in the whole model 230 MPa and maximum deformation cannot exceed 0.05 mm.

Tab. 1. The material properties used in the calculation

Young Modulus	70 000 MPa
Poisson Ratio	0.346
Density	2710 kg/m^3
Thermal Expansion	2.36*10^{-6} K^{-1}
Yield Strength	95 MPa

Limitations associated with the maximum stresses are directly related to the material from which the brake discs are made, it is the aluminum alloy 2017A. Thus, the maximum stress in the brake disc with the given boundary conditions cannot exceed the Yield Strength of the material. In Catia V5 software, there is a default library of materials that can be used for numerical analysis. Aluminum material from the library materials without modifying the material properties was used (tab.1).

Tab. 2. Optimization algorithm setting

Algorithm type	Simulated annealing Algorithm
Running Criteria	Medium
Maximum number of updates	100
Consecutive updates without improvements	20
Maximum time (minutes)	60

The optimization algorithm setting are shown in table 2. The maximum time in which the process proceeded, was set to 60 minutes, consecutive updates without improvements to 20 and the maximum number of updates 100. Also the process of data registering that will be generated at the time of analysis was enable.

4. RESULTS

During the iterative optimization of the brake disc geometry, program is changing a set of variable and makes the strength analysis by checking whether the geometry of the model that was created satisfy two strength conditions. During the entire optimization process, 27 iterations were performed. Each of iteration result has been saved in a spread sheet and using the MS Excel it was possible to compare each of the steps. For the purposes of publication, six iterations were choose.

Figure 9 shows the results of simulation of the selected iteration, generated during the optimization process. Results are in the range of 0 to 230 MPa, in order to visualize the iterations in which the maximum stresses exceed the maximum allowable stress resulting from the boundary conditions of analysis. It can be seen that the iteration 0 and 25 have very low mass (respectively 0.047 kg and 0.05 kg), however, for those iterations assumptions concerning strength have not been met. In both iterations, the maximum equivalent stresses were about 1000 MPa, which is several times more than the allowable stress.

In the iteration 11, 17, 23 and 26 boundary conditions for the maximum stress and strain were met. In figure 9, presented iterations have slightly different stress distribution for each of them. The mass of the disc between each iteration is slightly different, the maximum difference is about 0.0014 kg between 26 and 23 iteration. Although the differences between the generated discs in the case of both the mass and stress distribution are hardly visible, but in the case of the disc geometric representation, the differences of these iterations are clearly visible (fig. 12).

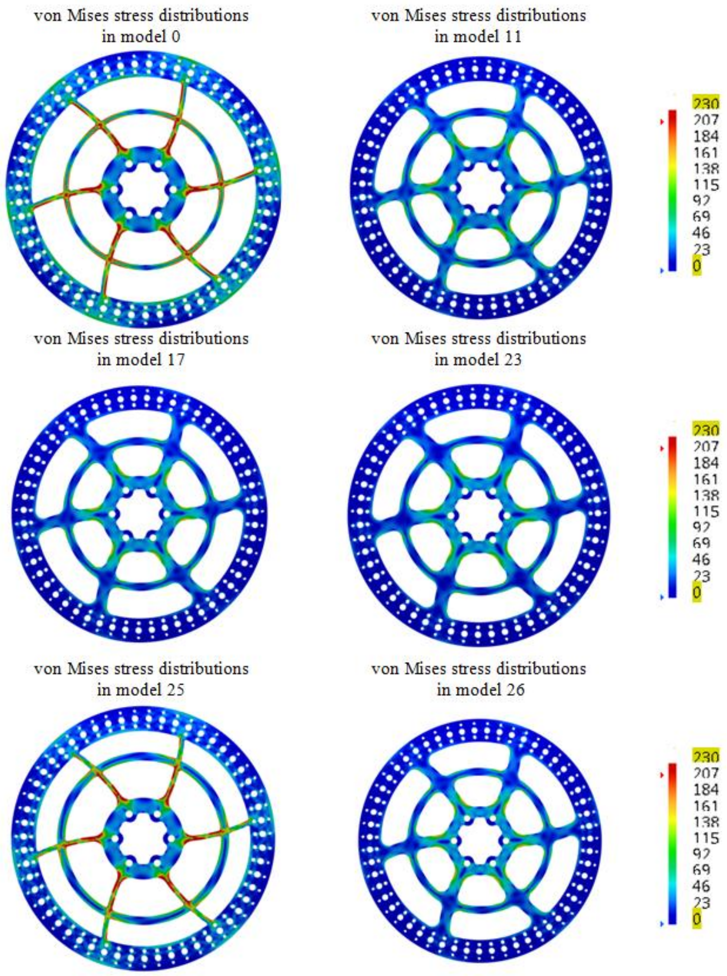

Fig. 9. Summary of simulation results – von Mises stress distributions [source: own study]

Referring intermediate iterations to the final model (model 26) it can be seen that the differences in radius and other geometric parameters are greatly. Significant variations in the diameter of the stiffener ring parameter can be seen in the figure 10. The differences of the other parameters in each iteration are shown in figure 10 and 11.

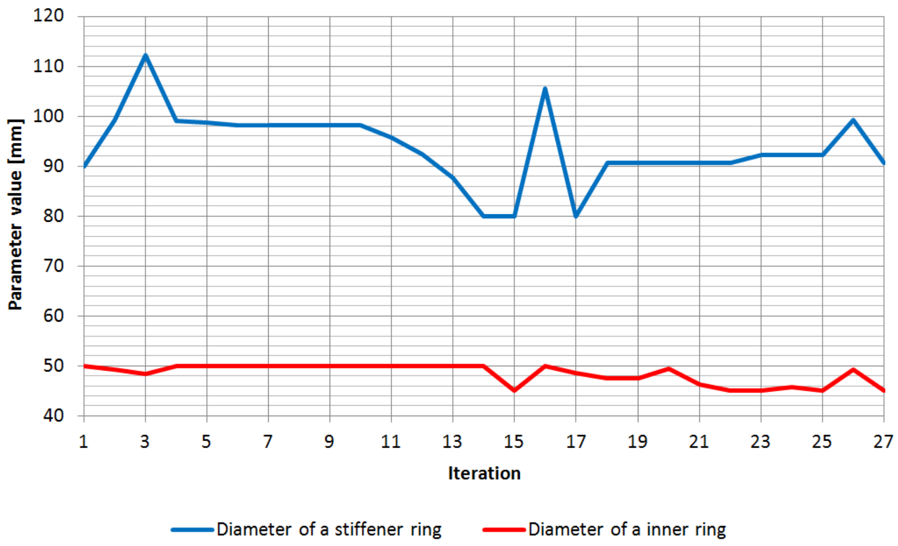

Fig. 10. Differences in diameter of a stiffener ring and inner ring [source: own study]

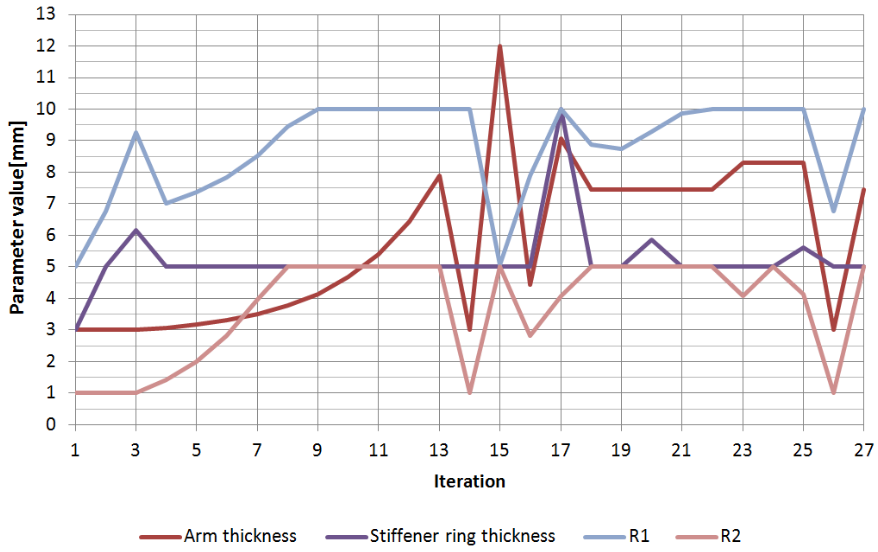

Fig. 11. Differences in other parameters [source: own study]

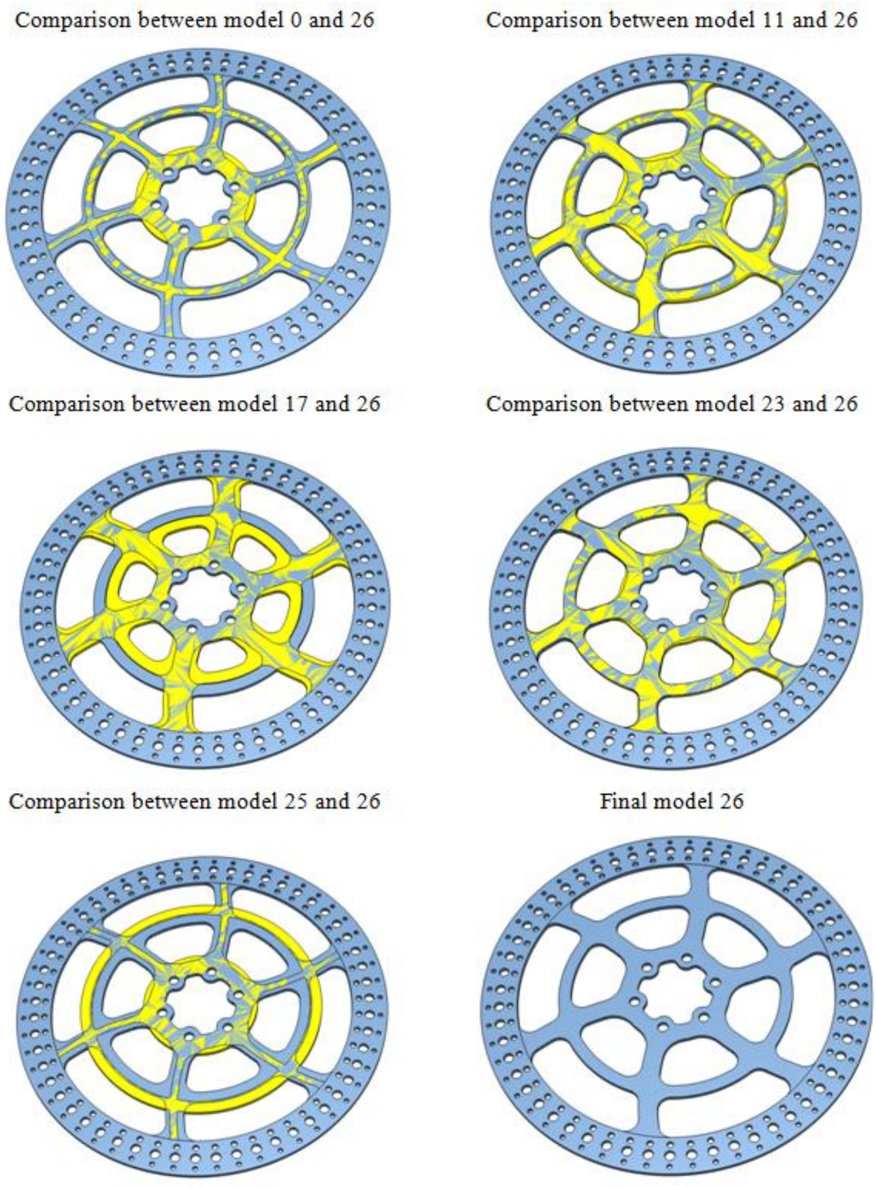

Fig. 12. Summary of simulation results – geometric comparison of the brake disc, yellow color – present model, blue color – final model [source: own study]

5. SUMMARY

As a result of the optimization process, it was possible to meet all the initial design intent. It was possible to get the brake disc mass equal to 0.0549 kg, which means that in comparison to a standard bicycle disc, new disc has about 40% less mass. It was also shown that in the Catia V5 software, iterative process of the optimization is possible. It is possible to prepare the simulation using the parameterization of the model, strength analysis and optimization module. This kind of optimization process can be used in the future for reducing the mass of others mechanical components of the tricycle.

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