Design, Optimization and Manufacturing of an Aluminium Wheel Rim for an Urban Vehicle

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Design, Optimization and Manufacturing of an Aluminium Wheel Rim for an Urban Vehicle

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Introduction:

This paper describes the design of a new aluminum alloy rim for the JUNO Urban Concept Vehicle (Fig. 1), designed to race the *Shell Eco-marathon* (SEM) from 2019 (SEM 2019), a low consumption competition, where the mass reduction is an important goal.

Fig. 1: JUNO during SEM Europe 2019.

The study started from the vehicle dynamics multibody model, evaluating constraints (tyre, bearing, hub, etc.) and load case relative to the track. A finite element topological optimization of the rim was required to maximize stiffness and reduce the component mass. In fact, the design of the aluminum alloy rim must present characteristics of low mass and inertia, ensuring the structural strength required both in terms of stress and in terms of stiffness.

Main Idea:

JUNO has four wheels: two front steering wheels and two rear ones, of which one is the driving wheel. The overall mass of the vehicle (including a 70 kg driver) is 200 kg.

The wheel design constraints are:

- Dimensions: 16".

- Duct dimensions and profile: according to ETRTO (European Tyre and Rim Technical Organisation) standards (Fig. 1(a), Fig. 1(b)).
- Tyres: Michelin 90/80 R16, especially designed for the *Solar Challenge* competition.
- Hub and upright, linked to the attachment points of the steering arms.
- Caster angle 2,55°, Toe-in angle 0°, King-ping angle 5,1°.

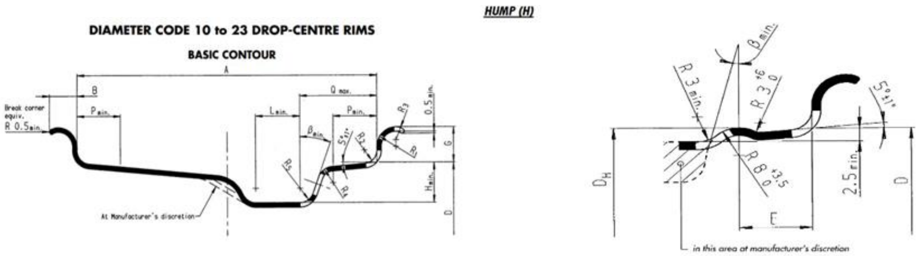

Fig. 2: (a) ETRTO rim channel profile, (b) ETRTO hump detail.

The vehicle dynamics multibody model recognizes the race worst load case for the rim as the vehicle rollover. In this situation the applied forces on the wheel are along the radial, axial and longitudinal direction. The forces were applied directly on the wheel rim, considering the tyre as rigid body, as visible in Fig. 3.

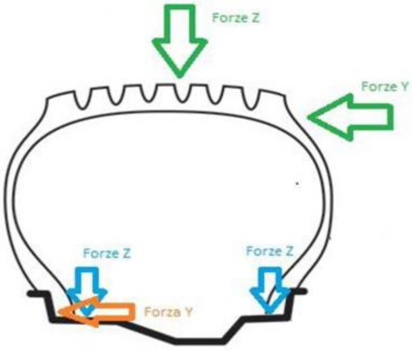

Fig. 3: Forces applied on the wheel.

Furthermore, the inflation pressure effect is also considered: the tyre can be inflated up to 5 bar, but, during summer track tests or bumps against steps pressure can reach 6 bar, so this second value was considered for simulation. The loads applied are reported in Tab. 1. The wheel was then locked fixing the hub hole and four rear small holes, house for the fixing pins.

Loads	*Values*
Axial Forces	1250N
Radial Forces	715N
Longitudinal Forces	590N
Tyre Pressure	6bar

Tab. 1: Loads applied on the wheel rim.

Topological optimization has been recognized a valid approach to guide the design phase for a large part of automotive components and for wheel rims. The presented calculations were performed using *Altair HyperWorks* software and especially *HyperMesh* as preprocessor and *Optistruct* as linear solver. Through topology analysis is possible to predict the optimal distribution of material in relation to the type and extent of the applied loads. The iterative calculation process requires, as input, constraints and loads, imposed by the designer. The optimization results have been evaluating during a post-processing phase, using *HyperView*. These data led to the rim CAD model definition. Then it was possible to add the non-structural construction details, e.g. hole for the tyre valve, support for wheel cover. The starting design was obtained by the revolution of the channel and the hub. Importing the CAD into FEA environment, a two-dimensional mesh was generated on the section keeping divided the channel and the hub. By revolution, this was transformed into a 3D mesh of tetra elements. To obtain a homogeneous FEM model after the step of mirroring, the nodes in the contact parts have been re-indexed to be coincident. Referring to Fig. 4(a) the channel (purple) and the hub (yellow) are already defined: the first according to the ETRTO requirements [4], while the wheel hub follows the geometry of XAM, the Urban Concept vehicle that preceded JUNO. This choice, learnt by previous experiences on the prototype IDRAkronos [2-3], guarantees compatibility between the two vehicles. The central region (green) was the subject of the topological optimization through the design variables (DESVAR function).

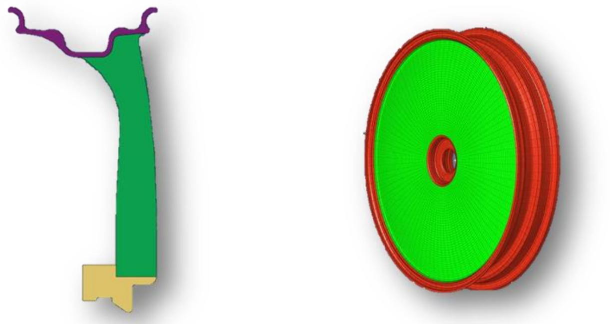

Fig. 4: (a) Wheel section before revolution, (b) Wheel after revolution.

The computational time for the optimization iterative analysis linearly depends on the number of elements, therefore it was necessary to optimize the following parameters:

- *Mindim*: minimum dimension of an element.
- *Cyclic pattern grouping*: request for an axisymmetric distribution.
- *Draw direction*: preferred direction of extrusion (wheel axis) to ensure the machining by milling.

The solution required 65 iterations before going to convergence with the following results:

- *Displacement:* maximum value of 1 mm.
- *Minimize compliance:* goal of the optimization.

OptiStruct solved the topological optimization problems using the density method, also known as SIMP (Solid Isotropic Material with Penalisation) method. A value of the material density is assigned to each element between 0 (blue) and 1 (red) since element is void or solid. Through a filter, it is possible to remove the elements under a predetermined value. The result obtained with the complete filter is shown in Fig. 5(a). To obtain more accurate results the *OSSmooth* function was applied, which re-meshes and optimizes again the first prototype, as shown in Fig. 5(b).

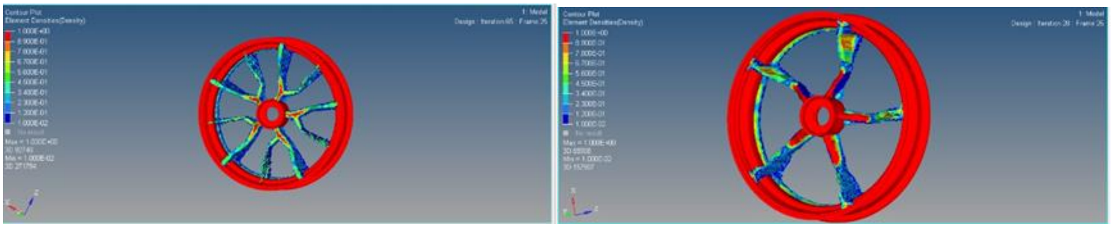

Fig. 5: (a) Optimization outcome, (b) Final result.

For each rim spoke, the material was removed following the guidelines of the topological analysis. Particular attention was given in the interface areas with the hub and the channel. The presence of edges not adequately connected, in fact, constitutes a critical issue to the stress concentration. Each element has a minimum thickness from 3 to 5 mm, to eliminate the harmful effect of vibrations during machining and to prevent deformation cause by residual stresses. Moreover each corner has a connecting radius of 2 mm ore more, to reduce strain as much as possible. The rim, ready for production is visible in Fig. 6(a) and Fig. 6(b).

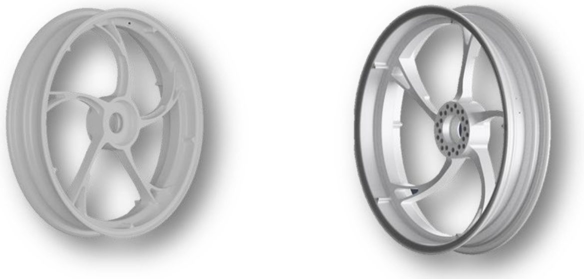

Fig. 6: (a) Wheel CAD front, (b) Wheel CAD rear.

After the CAD modeling was finished, a new FEM analysis on the rim was done to verify the design and the effects of the non-structural construction details, like the hole for the tyre valve. A 2 mm mesh size was chosen to ensure a detailed approximation of each geometry, while loads and constraints have been maintained the same used during topology optimization. The linear static analysis results are plotted in terms of displacements and stresses, respectively in Fig. 7(a) and Fig. 7(b).

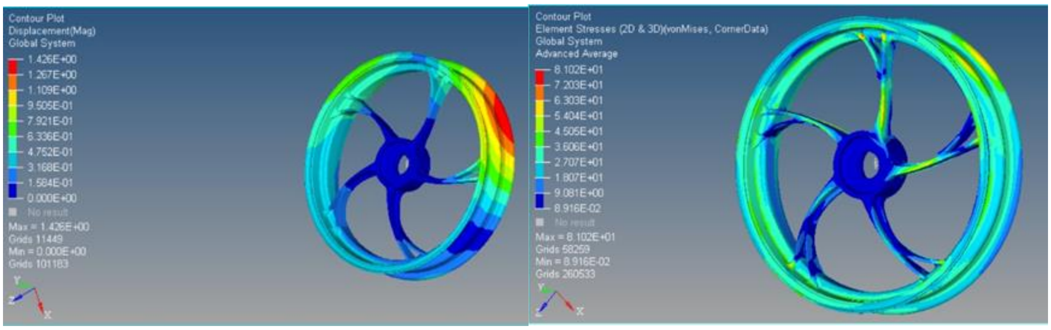

Fig. 7: (a) Wheel rim displacements, (b) Wheel rim stresses.

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The wheel rim construction is an important phase. Considering the impossibility to produce a mold and make the rims through casting process due to high cost, the manufacturing by machining was recognized as the only viable alternative. The chosen material is Aluminum alloy Al6082-T6 from plate, able to ensure a yield stress (277 MPa) and good workability. To preserve the performance of the finished component and to reduce residual stresses and strains, the production was done in different phases: first the plate was machined at the lathe on one side, then after some hours of relaxation, the same process occurred on the other side. The following days the component was machined using a 3-axis CNC machine, to achieve the entire wheel. Following the realization of the rim, a metrology measure carried out to verify that the actual tolerances correspond to those required. Finally, the wheel was painted using two layers of varnish: the first in dark grey, the second translucent. The treatment preservers the wheel from oxidation and external agents, while the weight increment is negligible (approx.70 g). The wheel final mass is 2,9 kg, comprehensive of the valve (Fig. 8).

Fig. 8: The wheel mounted on JUNO.

Conclusions

The paper presents a topological optimization approach that has been studied referring to many literatures works in which the resistance performance was maximized with respect to the geometry and therefore to overall mass of the component. This method has been applied to the design of the wheel rim for the JUNO Urban Concept vehicle. The results obtained with a FEM model, both in terms of displacement and in terms of stresses, widely comply with the specifications of the project.
The topological optimization of the rim carried out the following results:

- a mass of 2,9 kg.
- a maximum displacement of 1,42 mm.
- a maximum stress of 81 MPa, which means a safety factor of 3.5.

Thanks to the experience gained in the topological optimization pointed out on the presented wheel rim, in future the same methodology will be used to design other automotive components.

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