Title:
Design, Optimization and Production of Aluminum Alloy Rim for the Vehicle Prototype IDRAkronos

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Keywords:
Topology optimization, optimal design, low-consumption vehicle, wheel rim, mass reduction.

DOI: 10.14733/cadconfP.2018.112-116

Introduction:
This study describes the design of a new aluminum alloy rim for the IDRAkronos vehicle prototype (Fig. 1), designed to race at the Shell Eco-marathon (SEM) from 2016 (SEM2016), a low consumption competition, where the mass reduction is an important goal [1-4].
The study started from the vehicle dynamics multibody model, evaluating constraints (tire, 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 has to present characteristics of low mass and inertia, ensuring the structural strength required both in terms of stress and in terms of stiffness.

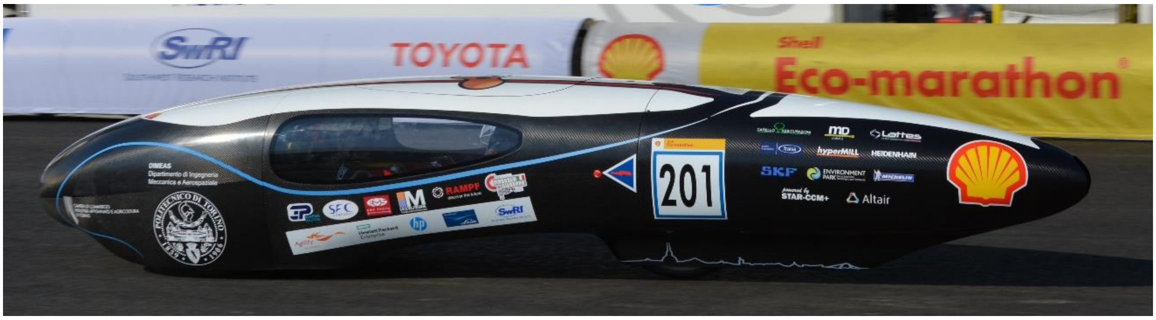

Fig. 1: The vehicle prototype IDRAkronos at Shell Eco-marathon.

Topological analysis:
Regarding the wheel in particular the design constraints are:
- Dimensions: 16"
- Duct dimensions: Michelin tire especially made for the competition
- Hub and upright, linked to the attachment points of the steering arms
- Caster, Toe-in, King-ping angle equal to zero.

The analysis will then be described referring to a "neutral" rim, also if in the final model of the two wheels (front and rear), however, there will be slight differences due to the fact that the rear is directly fixed to the transmission gear. The forces related to the tracks are reported in Tab. 1.

Year	*Track*	*Radial Force [N]*	*Axial Force [N]*
2015	Rotterdam	500	250
2016	London	650	350
		+30%	+40%

Tab. 1: Force values for different tracks.

The design optimization process was performed using the Altair HyperWorks software and especially the linear solver Optistruct. The topology analysis allowed understanding the optimal distribution of material in relation to the type and extent of the applied loads, through an iterative calculation process that requires the constraints and loads, imposed by the designer, as input. The results of optimization have been reprocessed through a phase of post-processing which has led to the definition of the CAD model of the rim. Then it was possible to add the non-structural construction details (support for the transmission crown, hole for the tire valve).
The starting design was obtained by the revolution of the channel and the hub (Fig. 2(a)). Importing the CAD into FEA (Finite Element Analysis) environment, a two-dimensional mesh was generated on the section keeping divided the channel and the hub (Fig. 2(b)). By revolution, this was transformed into a 3D mesh of tetra elements.

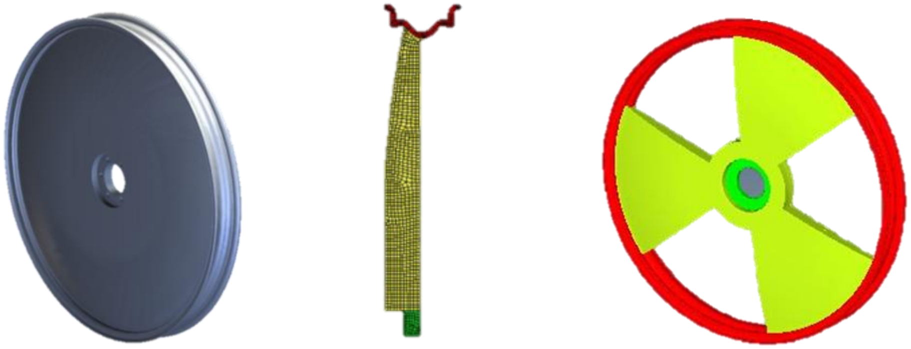

Fig. 2: The first design of the rim and the channel.

The channel (purple) and the hub (green) are defined according to the characteristics of Michelin tire and the wheel hub geometry. In the central region (yellow) were obtained 3 races subjects of the topological optimization through the design variables (DESVAR).
The solution required 33 iterations before going to convergence with the following results:
- Displacement: maximum value of 0.5 mm.
- Mass: the goal of the optimization.

OptiStruct solved the topological optimization problems using the density method, also known as SIMP method [6]. A value of the material density is assigned to each element between 0 (blue) and 1 (red) based on the fact that element is void or solid. Elements with values close to zero may be removed In order to reduce the mass of the final component.
Through a filter, it was possible to remove the elements under a predetermined value. The results obtained for a filter value of 0.9 and 0.5 are shown in Fig. 3(a) and Fig. 3(b), it is possible to see that the area around the hub requires a reinforcement, in particular of three structures in the shape of an "H". The areas in blue can be lightened to reduce volume and therefore the mass of the component.

Fig. 3: Topological optimization by SIMP method: (a) filter value 0.9, (b) filter value 0.5.

<u>FEM Analysis:</u>
The structural strength of the 2015 rim release was verified applying the radial load in two cases:

- case 1: Y Configuration with the radial force discharged on a single race;
- case 2: Δ Configuration with the radial force discharged on two races.

The structural verification of the 2016 rim release carried out linking the hub and applying forces on the channel, considering the non-deformable tire and an estimated contact area between rim and tire. The estimated maximum displacements are still considered acceptable for this kind of application and they are localized in the outer zone near the hub for both configurations. The maximum stress does not exceed 30 MPa in case 1 and 60 MPa in case 2.
For the 2016 Release wheel rim, the results of the linear static FEM analysis shown in Fig. 4, indicate a maximum displacement of 2.56 mm of the channel and a maximum stress of 100 MPa near the hub.

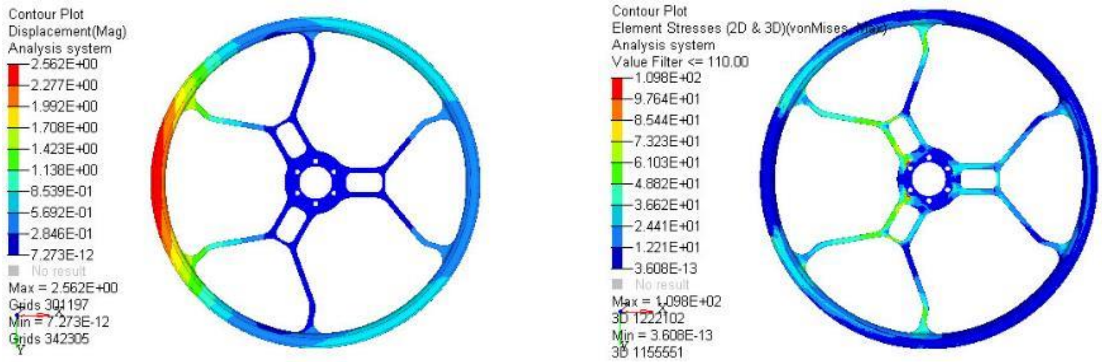

Fig. 4: FEM results – 2016 Release.

The results of FEM analysis and the delta parameter, calculated with the London track new forces, are reported in Tab. 2.

Release	*Mass [g]*	*Max displacement [mm]*	*Max Stress [MPa]*	*Delta [g*mm]*
2015	1150	0,223	59	256
2015_Review	1170	0,267	86	312
2016	**1160**	**0,184**	**30**	**213**
	+10g	-17%	-50%	-17%

Tab. 2: Delta parameter for the FEM analysis evaluations for different release of the wheel rim.

Construction and Verification:
An important aspect is the construction phase of the wheel rim (Fig. 5).

Fig. 5: Tolerance verification of the rim.

The study of [5] was taken into account for the experienced loss in the tubeless rim made in composite material. The chosen material is Aluminum alloy AL7075-T6, able to ensure high yield stress (520 MPa) and good workability. It was starting from a mass full disk of 23 kg, removing material up to 1.160 kg mass component. To preserve the performance of the finished component, the reduction of the residual stresses and strains after the milling phase was obtained with a relaxation of the material for few days before following operations. Following the realization of the rim a metrology measure carried out to verify that tolerances correspond to those required. This verification was successful, the rim was positioned on a test hub and during the rotation the oscillation of the channel was lower than 0.03 mm.

Conclusions:
The setting of topological optimization analysis has enabled the following improvement between the 2015 and 2016 releases of the rim:

- a mass increase of just 10 g;
- a reduction of the thickness of the hub area to minimize packaging of the assembly;
- a reduction of delta parameter equal to 17%;
- a reduction of displacements and stresses, respectively of 17% and 50%.

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 without increasing appreciably the mass.
The experience gained during this work allowed to "drive" the solver optimization towards the desired result, increasing the number of constraints and defining the parameters related to the topological variable. The performances of the component have been appreciated during the Shell Eco-marathon in London in July 2016, where the vehicle IDRAkronos won the competition in the hydrogen category reaching the 1st place and won the design award. The race performance showed effective stiffness of the vehicle on the race track and during the race conditions.

Acknowledgements:
The authors would like to thanks: Altair Italia for the software license and for the technical support, the “Commissione contributi e progettualità studentesca” of Politecnico of Turin which supports the study and all the students of Team H2politO.

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