Combining topological optimization and multibody dynamics: application to an innovative railway bogie

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EXTENDED ABSTRACT

1 Introduction with state of art and problem description

Nowadays, rolling stock manufacturers work to reduce the environmental impact of railway vehicles, that are one of the most important solution for mass transport over the world [1], also for emerging countries. Innovation of the structural design and traction source represent the two main points of interest. Focusing on the first one, vehicles lightweight design allows to reduce the energy required during their operation conditions. With the objective to reach this ambitious result, structural optimization process can represent an effective support for the development of innovative components in railway field. However, the current standards for the design of carbody [2] and bogie frame [3], do not defined a role for this type of approach. Available literature illustrates that not many studies about optimization processes, especially applied on railway vehicles bogie frame, have been carried out. Referring to railway sector, a structural optimization approach with dynamic constraints for carbody lightweight design, was proposed in [4]. A size optimization and a material selection method have been combined to test an electrical multiple unit (EMU) carbody [5]. Topology optimization and composite materials have been combined to redesign a railway anchor bracket [6]. Running comfort condition must be carefully evaluated, ensuring the decouplment of the carbody from bogie instability motion, as well as from the suspension frequencies. Bogie is the most critical component of a railway vehicle and over the years it has undergone only minor changes. In order to fill this gap, authors have proposed a first topological optimization approach, combined with the reference European standard for bogie structural requirements. The benchmark aims to reduce the mass structure possibly ensuring the mechanical performance of the system, including static, dynamic and fatigue evaluations. In addition, a multibody analysis was conducted to compare the optimized solution and the original one in terms of running dynamic. The procedure was tested on a bogie frame designed for a light rail vehicle.

2 Methodology

With the objective to innovate a complex component like a railway bogie, at first was fundamental to create an effective digital twin of it. Once known the mechanical and dynamic behaviour of the original system, it can be improved. As stated above, structural optimization processes represent an effective tool to support the design process of complex components. The present activity shows a first optimization approach applied on a railway bogie frame, aiming to reduce the mass of the structure. Starting from the original model tested and verified according to the reference standard EN 13749, it was optimized topologically. Then, resulting geometry was imported and managed in a CAD software to smooth it and obtained a final version. Last version of the innovated frame was tested again with reference load conditions. In addition, the modal behaviour and the response in terms of running dynamic, were evaluated comparing them with the original performance.

3 Discussion and Results

First of all, an evaluation of the structural performance of the original bogie frame was performed, highlighting the most stressed zones that will be carefully monitored. In these terms, utilization factor was calculated for each load condition of both types, static and fatigue one. It was defined by the ratio between the calculated and permissible Von Mises stress values. If it resulted greater than one, a local non-linear analysis would be required to validate the results. This point was not object of the present paper. Static results are included in Table xxx. In terms of modal behaviour, first frequency of vibration was higher than 60 Hz.

Table 1: Utilization factor resulted from static analysis.

Load Case	Utilization Factor [-]
SL1	1.41
SL2	1.42
SL3	0.39
SL4	0.59
SL5	0.54
SL6	0.89
SL7	0.44

The second step consisted in the structural optimization approach. Objective of the simulation was the minimization of the weighted compliance, while it was imposed a constraint condition on the mass fraction of the system. In addition, a condition on the maximum mean stress was included. Figure xxx illustrates the bogie frame built to increase the design volume, excluding all the contact interfaces defined as no-design space. Several runs of numerical simulation have been carried out, including all the load conditions and combining them with different settings to study the impact on the final design. While for the longitudinal parts (along X axis) a common geometry was obtained, for the transversal beam different types of shapes have been observed. Then, according to the requirements, their shape could change. Figure 2(a) illustrates the density distribution resulted from a topology optimization run. Figure 2(b) shows the surface model resulted from a different optimization test.

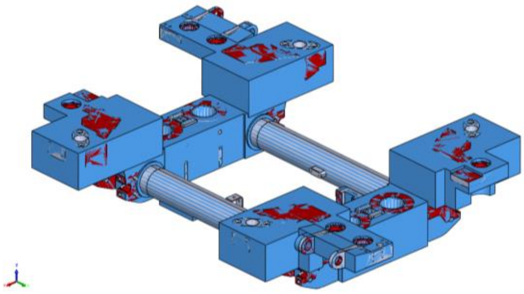
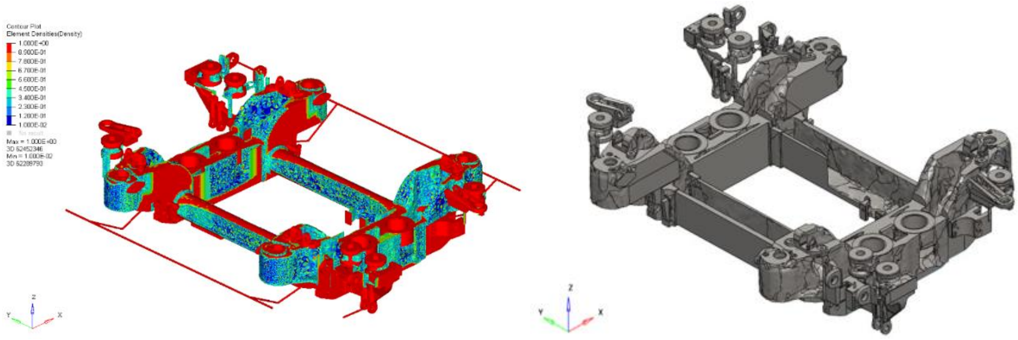


Figure 1: Railway bogie model set for structural optimization process.



(a) (b)

Figure 2: Topology optimization result in terms of (a) element density and (b) surfaces.

Once completed the optimization process, to evaluate the effectiveness of the procedure, resulting surfaces were introduced in a CAD software to build the final geometry. At this point, the optimized bogie frame has been tested according to the reference standard, resulting in similar utilization factors. In terms of modal behaviour, the first vibration frequency resulted in a little decreasing, respecting an acceptable range of values. In addition, the new frame was lighter than the original one, reaching the proposed goal. To conclude, the running dynamic of the innovated system was tested through multibody simulations with rigid bodies and compared with the starting solution, supposing to replace the latter one.

4 Conclusions

During the present activity a topological structural optimization process was applied on a railway bogie frame, to reduce the global mass, maintaining possibly acceptable mechanical performance. Positive results have been obtained from static, dynamic and fatigue point of view. At the same time, the new structure was lighter than the original one. In these terms, the proposed approach is promising, evaluating also the possibility for introducing new constraint conditions to reach new objectives. From running dynamic point of view, in order to increase the modelling level, flexible multibody will be evaluated.

5 References

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