[B9.04]

Optimization and design of rail vehicle running gear components under dynamic loading

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Introduction (300 words)

This paper describes the simulation, optimization and design of a low-floor running gear frame for a high speed train's independently rotating wheel single axis running gear.

The running gear is part of the Next Generation Train project (NGT) at the German Aerospace Center (DLR). The NGT High Speed Train (NGT HST) is designed to run at speeds up to 400 km/h. The cars' double-deck design necessitates a low-floor running gear concept.

Travelling at high speeds with rail vehicles leads to high dynamic loads in the running gear. In order for these loads to be considered in the design of the running gear frame, the running gear is analyzed using multi-body simulations (MBS). However, dynamic loads – as they appear in the MBS and real-world applications – are not compatible with static optimization methods, such as topology or gauge optimization. Static loads, as given in various norms, do not offer the same load characteristics and are usually increased for good safety. Considering dynamic loading conditions in the running gear design promises better material utilization. In this paper, the Equivalent Static Load Method (ESLM), as it is integrated in the Altair HyperWorks/OptiStruct software suite, is used to combine static optimizations with dynamic loads derived from multi-body simulations.

First, it will be shown that MBS/ESLM-optimizations promise realistic and useful results in comparison to static topology optimizations using static loads derived from norms. Second, ESLM-based topology and gauge optimizations will be used to optimize vital structural components of the running gear frame in order to further refine its lightweight design.

The optimization results will then be used to redesign core components of the secondary frame of the NGT HST running gear with regard to lightweight design, high stiffness and ease of manufacturability.

Methods (300 words)

Multi-body simulations enable the investigation of dynamics for systems composed of bodies. This involves the bodies' kinematics as well as the forces acting upon and between them. Common optimization solvers, such as Altair OptiStruct, are not able to handle these dynamic forces as optimization input. Instead, static loads are commonly used which no longer contain time information and the corresponding response field. The ESLM can help introduce the effects of dynamic loads to otherwise static structural optimizations. The equivalent static load is defined as the load which creates the same response field as that of the dynamic load at any time during the simulation. This replicates the dynamic behavior of the system in a static environment. The ESLM has the potential to apply more realistic load conditions to structures, thus, improving the structure's lightweight design potential.

In the first part of this paper, simulations are conducted to evaluate the viability of topology optimization results using the ESLM in comparison to static structural topology optimizations run previously at the DLR. For this, topology optimizations on design spaces for an axle bridge, connecting the two single wheels, and an outer secondary frame are conducted (Figure 1). Loads are applied as wheel force curves from previous MBS performed at the DLR.

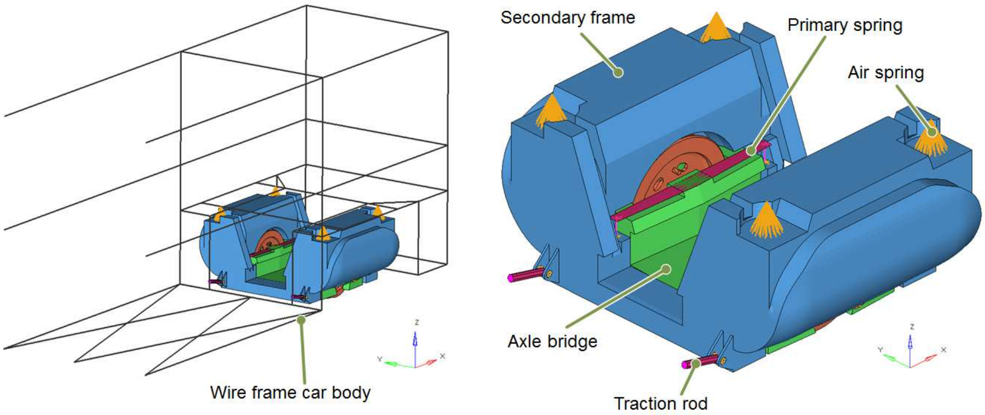

Figure 1 - Design spaces for ESLM evaluation

In the second part, the existing running gear Computer Aided Design (CAD)-model is transferred to HyperMesh (Figure 2). The secondary frame is then subject to topology and gauge optimizations. The optimizations are carried out for two frame versions. One is made of steel, the other of aluminium with local carbon fibre composite reinforcements.

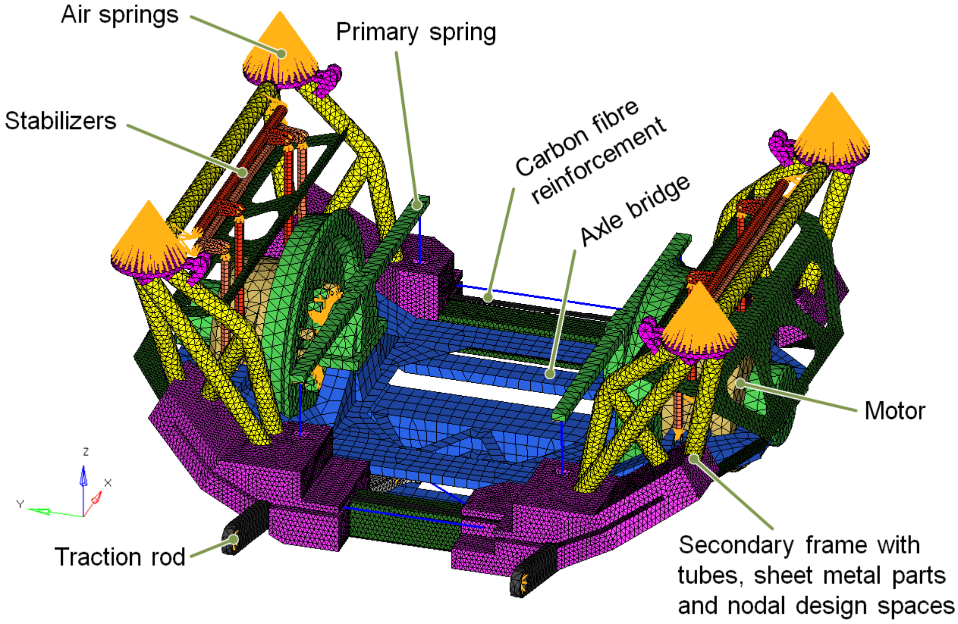

Figure 2 - Running gear model for gauge and topology optimization on the secondary frame

Results (300 words)

The ESLM optimization of the design spaces shows plausible resulting topologies (Figure 3).

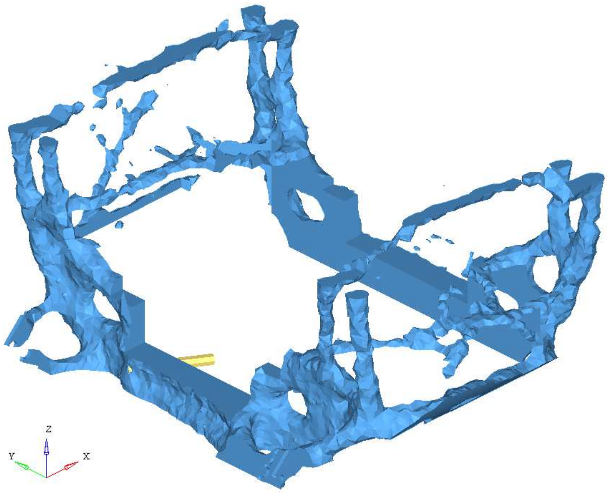

Figure 3 - Topology optimization of the secondary frame using the ESLM

The ESLM-topology optimization features similar principal load paths as previously run static topology optimizations using comparable static forces (Figure 4). Along the sides of the ESLM-optimization there are additional material accumulations. This can be attributed to the greater variety in load directions derived from the MBS-kinematics.

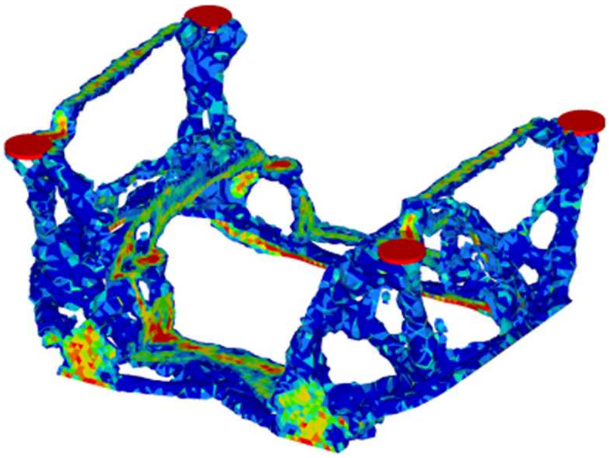

Figure 4 - Topology optimization of the secondary frame using static forces

Having shown that the ESLM is suitable to conduct topology optimizations for rail vehicle running gear, the detailed design of the running gear is subjected to a targeted structural optimization of selected highly stressed components (Figure 5). The optimization is designed to simultaneously deliver information regarding topologies, wall thicknesses, kinematics, displacements and component stresses. From these results, requirements for the structural integrity of the frame are derived. Subsequently, design solutions are found using a methodical product development process which involves morphological and benefit analyses. As a result, a solution option is deemed best in which the frame is made of steel and uses a hybrid design featuring cast parts, structural tubing and bent plate. The other investigated frame version made of aluminium with local carbon fibre reinforcements is discarded due to it being more complicated while not providing significant weight savings.

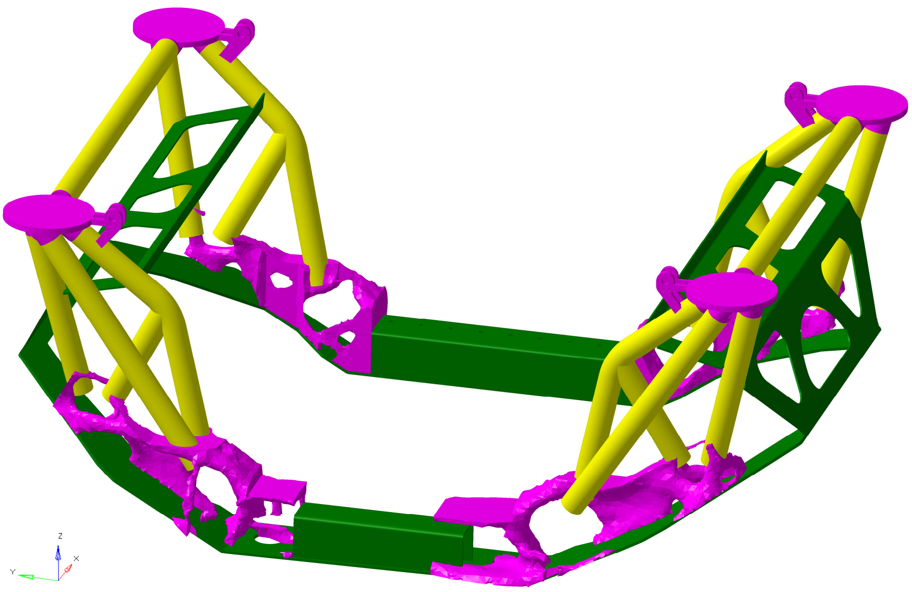

Figure 5 - Topology optimization of the nodal components for the detailed secondary frame

Based on the methodical development process and the optimization results, the running gear frame is then redesigned in CAD. It uses hollow cast structural nodes combined with bent plate so that a lightweight and stiff frame is created while maintaining good manufacturability (Figure 6).

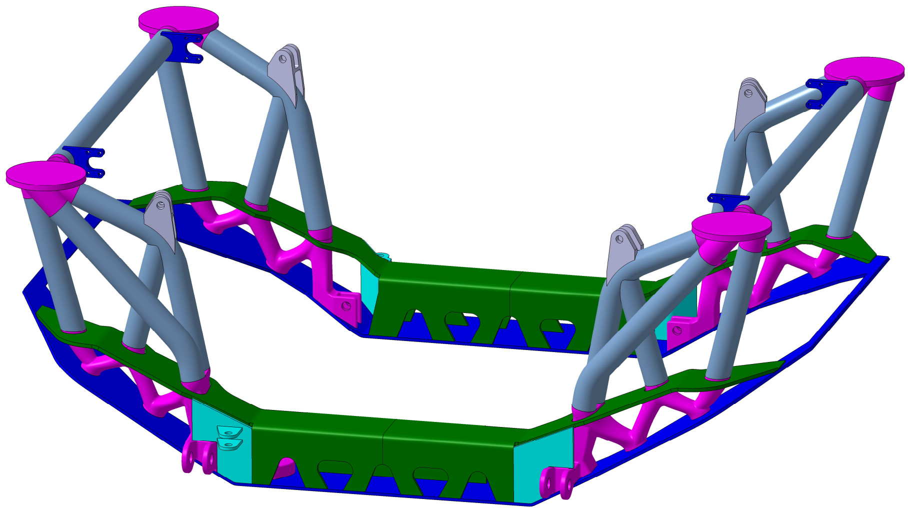

Figure 6 - Redesigned secondary frame with nodal elements (pink) and continuous top flanges (green)

Conclusions and Contributions (300 words)

In this paper, it is shown that the ESLM can be successfully used to optimize a rail vehicle's running gear frame under consideration of the dynamic rolling environment. It enables a unique and comprehensive lightweight design approach while taking realistic load conditions into account.

This finding is applied to a real-world example with the DLR's NGT HST running gear, where topology and gauge optimizations are performed in the secondary frame. From the results, it can be shown that a steel variant possesses the same lightweight design potential as a variant made of aluminium with local carbon fibre reinforcements.

The steel variant of the secondary frame is then further detailed and core parts are redesigned considering state-of-the-art manufacturing methods such as 3D-printing sand preforms for

casting. The design solution was found using a comprehensive methodical approach to find the best suited solution.

Compared to the initial design, the redesigned frame is stiffer as well as cheaper and easier to manufacture. The new design features continuous flanges providing a high stiffness and uninterrupted load paths. They are supported by die-cast hollow nodal elements which connect key structural components and redistribute the forces through short paths.

A 1:5-scale model of the running gear will be built in 2018, as well as a 1:1-scale structural weldment for testing and validation purposes.

Keywords: running gear, multi-body simulation, topology optimization, lightweight design