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STRUCTURAL DEFORMATION CAUSED BY AERODYNAMIC EXCITATIONS DURING THE PASSING OF MAGLEV VEHICLES

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1 INTRODUCTION

Magnetically levitated vehicles (Maglev vehicles) have no wheels, axles, transmissions, or pantographs. Instead of wheels and rails, they use non-contact electromagnetic levitation, guidance, and propulsion systems — wear-free electronics instead of mechanical components. In this paper, the carriage body of the Maglev vehicle Transrapid is investigated. The Transrapid is the first fundamental innovation in railroad engineering since construction of the first railroads. It is the world's only commercially-available high-speed Maglev technology. As a result of over 25 years of continuous design, testing and refinement, the Transrapid Maglev technology is the first such transportation system approved for public use. Achieving operating speeds of up to 500 kilometres per hour vehicles travel along a fixed dual track guideway as shown in Fig. 1. The relative speed between two passing vehicles therefore reaches up to 1000 kilometres per hour.

As the vehicles pass each other in close proximity, their aerodynamic forces react with each other. These interactions can produce significant loads on the vehicles or a fixed object, as shown by Peters [3]. A pressure pulse is generated on the side of the considered vehicle firstly by the bow and secondarily by the tail of the oncoming vehicle. The magnitude of the load on one vehicle depends on the velocity of the oncoming vehicle, the geometry of the bow-part of the oncoming vehicle and the distance between the two tracks. The time behaviour is given by the relative velocity between the two vehicles. This load has an important effect on the safety and especially on the ride comfort as explained by Tielkes [5]. For the considered vehicle this load represents a travelling wave which passes the lightweight carriage body according to the relative speed between the two vehicles.

Fig. 1: Maglev vehicle Transrapid in Shanghai: Two vehicles passing each other at a relative speed up to 1000 km/h (image: Transrapid International)

This lightweight carriage body consists of three main components, bow, carriage body cell and sub-floor structure, as shown by Lobach [1]. The carriage body is manufactured in hybrid-building-method. The sub-floor structure supports the carriage body cell and houses the sub-floor facilities as well as signal and power cables. In this part of the train the distinctive elements of a maglev vehicles are housed: the electrical components for the control of the magnets and the power supply. An important aspect of the design of the Transrapid is the lightweight construction principle. The entire structure has to be as light as possible but at the same time stiff enough to support the loads acting on the structure by high-speed travelling. The lightness is fundamental for a high-speed transportation system because the necessary propulsion power is proportional to the weight. In order to reach a low weight the whole body consists of aluminium profiles and composite sandwich structures.

The travelling pressure wave excites structural vibrations of the carriage side wall. The amplitudes of the structural vibrations can be several times larger than the static deformations if the velocity of the pressure wave corresponds to an Eigenmode of the carriage body. Structural stresses and a decreased life time of the structure could be a consequence.

2 METHOD OF ANALYSIS

In order to analyse the dependency of the structural deformations on the parameters of the vehicle and its operation, transient FE-computations are conducted within the work of a Master Thesis [2]. These computations yield the deformations of the carriage body caused by loads generated by passing maglev trains in relationship with their relative speed. The pressure loads were verified by measurements at the Transrapid vehicle TR08 in Shanghai during test runs and are applied as external forces.

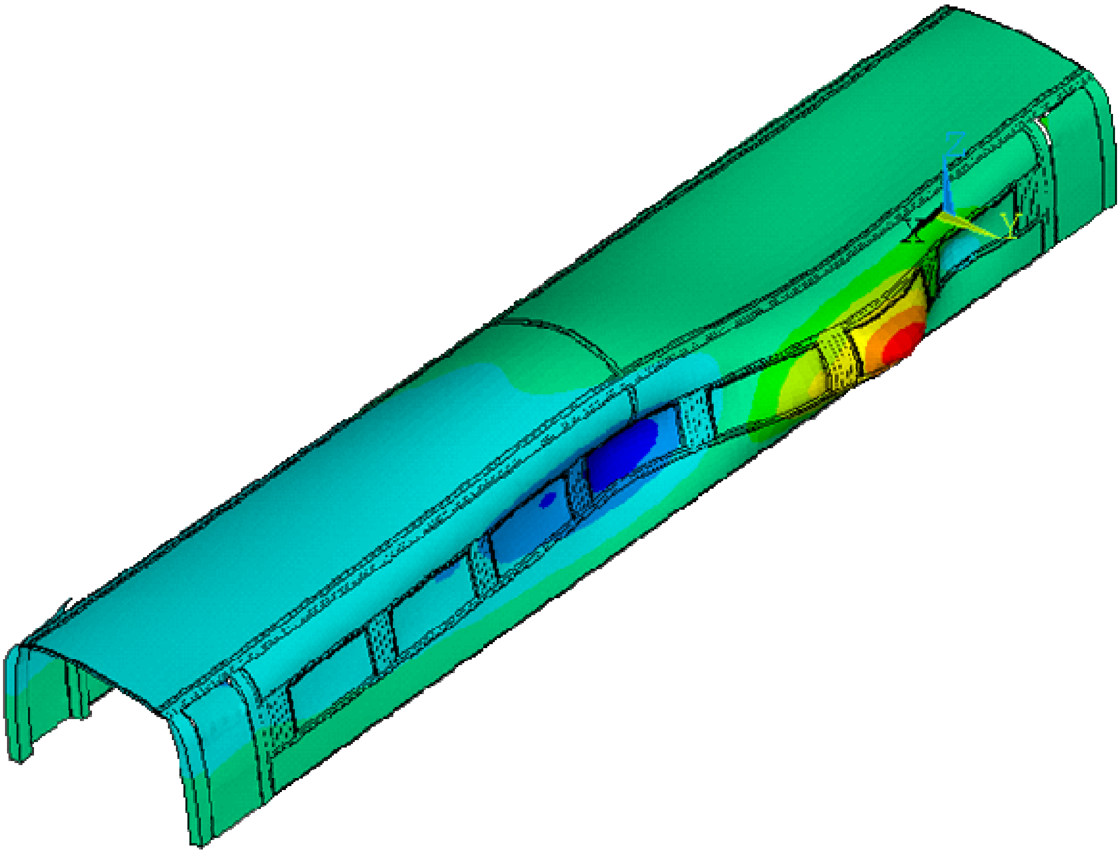

Fig. 2: FE-model of the carriage body. Deformation (shown exaggerated) caused by the pressure wave at one instance of the transient analysis

Since the geometry of the carriage body is characterised by thin sandwich walls with large surfaces an important aspect of the presented work is the creation of an efficient FE-Model which allows the computation of dynamic transient calculations, see Fig. 2. A combination of shell elements with layered 3D volume elements was developed in order to use the advantages of 2D-modelling of thin sheets with 3D-structural properties of sandwich structures and aluminium profiles. To obtain an efficient and at the same time accurate FE-Model a detailed analysis of each single part and module was executed. The overall model allows a full transient analysis of a complete carriage body loaded by the pressure wave within one hour of computation time using a PC with dual Pentium D, 3 GHz processor. As an example, the deformation at a specific time point is shown together with the FE-model in Fig. 2.

3 RESULTS

The model is verified by a comparison with several measurements under given operating conditions. The results show that the amplitudes are largest at a specific relative velocity, which corresponds to the propagation speed of a global Eigenmode of the carriage body that possesses nearly the same wavelength as the pressure wave. As the amplitude increases with the propagation of the excitation along the side wall, it is largest towards the end of each carriage. In relationship with the static displacement it is possible to get a dynamic intensification factor for the deformation. The results can be used to calculate the life time of the carriage structure in dependency on the operating conditions and in order to optimise the architecture of the carriage body. Summarised, the mechanical load on the carriage body depends mainly on

i) the amplitude of the pressure wave, given by
  - the velocity of the oncoming vehicle
  - the bow-shape of the oncoming vehicle
  - the distance between the two tracks

ii) the relation between the propagation speed of the structural Eigenmode with the corresponding wavelength and the relative velocity between the two vehicles

iii) the load at a specific point of the structure depends on its location within the carriage body, but not on the overall length of the vehicles or the position of the carriage body within the vehicle set.

Another fundamental result of the presented work is that the developed FE-modelling technique for the carriage body — using a combination of shell elements with layered 3D elements — has clear advantages over conventional models using either 2D shell or traditional volume elements only. This technique can be applied to other high-speed rail vehicles with similar carriage cells. Such allowing a transient analysis of thin side walls with large surfaces consisting of profiles and/or sandwich structures.

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