Next Generation Train - The Revolution

The DLR (Deutsches Zentrum für Luft- und Raumfahrt) is widely known as a governmental German aerospace research organisation with a workforce of about 7,000 - most of them scientists. Over the past ten years security, energy and transport research areas have been added to DLR’s range of activities. From 2007 transport research for rail vehicles has engaged the capabilities of several DLR institutes in one theme - the Next Generation Train (NGT). 18 departments of nine institutes are involved in this DLR project until end of 2013. A prolongation until 2018 is being prepared, and depends upon the approval of the Helmholz Society, which supervises German research centres.

As it is not possible to describe the full scope of the NGT project here we refer interested readers to [1]. This research contribution pays attention to the high speed train concept and the construction of lightweight carriages.

From 1991, when the first scheduled electric railway services in Germany started, until today, the railway has been the most environmentally friendly mode of mechanical transport that travels. In 2003 the mechanical transport sector contributed 20 % to the EU's greenhouse gas emissions. Freight transport is responsible for 70.8 % of the total emissions, civil aviation 12.7 %, sea transport 13.5 %, road transport 7.6 %, rail just 0.6 % [8].

The electric railway, usually independent from the national grid, makes use of low-carbon electricity. On top of this the energy consumption, CO₂ and exhaust emissions of rail transport amount to 0.11 kWh/km and 0.06 kWh/km, much lower than road transport, which generates 0.47 kWh/km and 0.47 kWh/km [2].

In terms of land take, a double track railway will have the same traffic capacity as a motorway of up to 16 lanes [3]. Accidental levels are approximately 200 times greater for road than for rail transport [2]. Several objectives of the NGT project are aiming to keep the leading position of the railway as a safe and green one and to make it more comfortable for users.

Energy-Saving Potential For Rail Vehicles

Basic Simulation Conditions

Simulation calculations help determine how much energy can be saved by reducing for example vehicle mass. We used a simple longitudinal dynamic vehicle model for simulation purposes, wherein mass is assumed to be punctiform. Since neither curve resistance nor wind resistance is considered, assuming punctiform mass will not affect the calculated energy requirement [5].

Three vehicle types are considered, each of which represents a particular category of railway carriage:

- High-speed is represented by a Class 420/423 EMU
- Electric suburban and middle-distance services are represented by a Class 422 EMU
- Diesel-powdered suburban and middle-distance train services are represented by a Class 611 EMU

Train power characteristic curves at the wheel describe the vehicle’s drive systems. Traction power and drive power are independent of mass. Traction and braking forces are limited by the frictional connection between the wheel and rail. Frictional connection specifications as laid down in TSI HSC [4] are used here, whereby the proportion of powered axles is described.

The speed-dependent operational deceleration of TSI HSC is used for all braking. Constant efficiency is assumed for the drive systems: Driving resistance is described in the Darseis formula:

\[ F_{\text{dr}} = A + B \cdot v^2 + C \cdot v \]

This is clicked into mass-dependent and mass-independent components. According to Wendez [5], in the Darseis resistance formula coefficient A is in the first approximation directly dependent on mass, while coefficient B and C are independent of mass. Table 1 contains a complex vehicle data used for the simulations. The traction energy requirement is determined using standard profiles published by the UIC for Technical Recommendation 100-001 [6]. These standard profiles describe typical operational scenarios for rail vehicles in suburban, middle-distance, inter-city, and high-speed services. Table 2 contains the most important data of the service profiles. Separate travel times are defined for each vehicle and each service profile. Additionally, a simulation with a vehicle whose mass exceeds the occupied mass was conducted at the highest feasible speed in order to determine the standard travel times between the individual stations. In order to determine the influence of vehicle mass, mass was reduced in the simulations in steps of 5 % until 70 % of the occupied mass was reached.

Results Of Simulation Calculations

The simulations have shown that the potential for savings through reduction of vehicle mass is dominant by the characteristics of the service profile. There is a particularly high potential for savings with service profiles that have short inter-station distances and low maximum speeds. As this maximum speed increases, the proportion of energy needed to overcome aerodynamic resistance also increases and the potential for savings diminishes. The potential for savings with DMUs is up to four times greater than with electrically powered vehicles because the latter can operate on a portion of the kinetic energy during braking. However, if the electric braking power is not adequate to achieve the required deceleration, then the potential for savings also increases with electrically powered vehicles. Table 3 summarises the achievable energy savings, expressed per metric tonne of reduced vehicle mass as a weight reduction of 10 % of the occupied mass.

Costs Of Lightweight Construction

In conclusion, we derive from the calculated energy savings the costs that may arise for eliminating 1 kg of vehicle mass so these costs can be amortised through energy savings over the lifetime of the vehicle. We make the following assumptions for calculating cost savings:

- yearly release according to data in the service profile in Table 2, - vehicle service life of 30 years, - price for electric energy from the ballpark (22.4 ct/kWh in euros), - cost of diesel fuel 1.15 euros/litre corresponding to 11.533 kWh/kWh (in euros).

Interest payments on employed capital and increasing energy costs are not taken into consideration. Table 4 contains the calculated values for each vehicle and service profiles. The listing clearly shows that the expense of reducing weight is amortised faster with DMUs than with electric vehicles.

Train Concept

Derivation And Evaluation Of Rail Vehicle Concepts

To define an optimum solution for a rail vehicle, different train configurations (in individual railroad, an articulated train, and running gear construction and layout), car structures (single deck, double deck, standard and maximum widths and propulsion possibilities (type, layout and power supply) were systematically examined and screened using selected comparison criteria and compared with vehicles already in use [11].
Development

In High Speed Traffic

In rail traffic terms, an operating speed of 200 km/h or more is designated as high speed [12]. As many multi-

ple-unit train sets are running faster than 250 km/h today, we are talking about high speed (differing as between

200 and 300 km/h, very high speed defined as between 300 and 400 km/h and ultra high speed between 400 and

500 km/h).

In recent decades the development of the TGV, the ICE and the Shinkansen trains played a prominent role

in evolving high speed international services. These and other types of rail vehicle are predominantly-employed

and have been further developed in various countries in Europe and Asia. They offer considerable advantages

in design characteristics and also high speeds of up to 400 km/h can be achieved in regular operation in

different ways. The Chinese railways ran their CRH 380 trains for some months in late 2010 and early 2011 at

scheduled speeds of 420 km/h and achieved a record of non-moulded passenger trains at 486 km/h. They

then had to reduce scheduled speeds to 250 km/h and 300 km/h afterwards, to allow the simultaneous operation

of trains with various maximum speeds on

Table 5: Comparison of high-speed trains, data compiled from the following references [22, 16, 17, 18, 13, 14, 20, 21, 23, 24, 25, 26, 27].

<table>
<thead>
<tr>
<th>Vehicle / Class</th>
<th>Year of Building</th>
<th>Start of Operation</th>
<th>Length [m]</th>
<th>Design Speed [km/h]</th>
<th>Traction Power at 25 kV (AC)</th>
<th>Traction Power at 25 kV (DC)</th>
<th>Traction Power at 1.5 kV (DC)</th>
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Fig. 1: Evolution of top speeds for rail vehicles [13].
Horizon

Excerpt high-speed transport

<table>
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<tr>
<th>Speed (km/h)</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
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</table>

- **CGV**
- **ETR**
- **ICE**
- **KTX**
- **Shinkansen**
- **Talgo**
- **TGV-Thalys-Eurostar**
- **Velaro**

**Seat weight [kg/seat]**

- **0.40**
- **0.50**
- **0.60**
- **0.70**
- **0.80**
- **1.00**
- **1.10**
- **1.20**

**Comparison of leading densitites and seating weights of different types of high speed trains.**

**Propulsion And Braking Concept**

The propulsion and braking concept makes a key contribution to achieving the desired technical performance parameters and to determining the energy requirements and therefore the environmental compatibility of each rail vehicle.

The energy supply of the NGET EMU is future-oriented and envisaged to be situated in the track. This means that high maintenance overhead catenary is no longer required. The propulsion concept is envisaged to incorporate a contact-free current collection from the track distributed along the whole length of the track. This means that there is no longer a requirement for deep penetrations, which have a rapid wear rate. Each end car of the train can reach about 95% of the traction power of about 18 MW; the remaining 5% is powered by traction motors of the third single wheel running gears. These motors are located near the window sills. Instead of two-axis bogies, the single wheel bogies are planned, where they allow for paths to pass through the lower deck, and the number of wheelsets is reduced where compared to bogies.

These are high-speed automatic couplings. The electric power is transmitted through the bogies, and therefore it is significantly reduced. The propulsion of this EMU is therefore above average. The double bogie high-speed version will be built for a service speed of 400 km/h, which means that it will be approved for 440 km/h.

**Leading vehicle**

- **radio antenna**
- **dedicated line**
- **computer**
- **trailing vehicle**

Several EMUs can be coupled together by a telecontrolled clutch. Through a geometrical target point, optical sensors observe the state of the train in front. Simultaneously, the train driver control commands, via radio communication, of the propulsion and braking system control the whole train.
Fig. 3: Topological optimisation of a 20 m long double deck bodyshell.

Fig. 5: Construction design of a section of running gear based on a methodological approach.

Fig. 7: Topological optimisation of a 20 m long double deck bodyshell.

Fig. 8: Topological optimisation of a 17 m long double deck bodyshell.

Principle Findings Regarding Force Flow Optimised Bodyshell Structures

Significantly relevant for the concept is the load which results from the compressive force at bunker height combined with payload. The impact of the payload, at a maximum permissible deflection of 1 % of the distance between supports, is within the considered load ranges for the NIG (a maximum of 20 MN loads relevant for dimensioning of a bodyshell, despite the relatively low compressive force (300 kN) at the height of the central, this load case noticeably affects the framework resulting from the topological optimisation. Segments load paths are formed because of the position of the force application at the height of the central. From this it follows that connection paths of these load paths to the rest of the framework are necessary. Also, the main load paths are influenced (Fig. 7). A comparison of the frameworks of the bodyshells of different lengths shows a largely similar structure. This makes a force flow optimised style design possible, which can then be applied to various other bodyshell dimensions. As the length of the bodyshell increases, a requirement for additional stiffening elements is identified, but the main load paths remain the same. This means that when the design is being used for various bodyshell lengths, the same structural elements can be included. Only in localized areas are additional supports needed to match the results of the topological optimisation. As a result of the high number of common parts and segments of the bodyshell structure both the engineering and the production costs can be minimised (Fig. 7, Fig. 8).

Concept of Force Flow Optimised Bodyshell Segment

The concept of a force flow optimised bodyshell structure includes the support structure. A suitable process for optimum selection of the paneling elements according to set static conditions is also necessary.

Concept for Force Flow Optimised Support Structure

Based on the findings of the topological optimisation, a structure concept for the segment over the running gear can be derived. This can be adapted to various bodyshell lengths with only minor changes. On account of the high complexity of the bodyshell segment over the running gear, the potential of the methodology can be well demonstrated.

Taking into consideration the load path and force directions which result from the topologically optimised three-dimensional shaped bulkheads are used for the support structure. The specific awareness of the industrial bulkheads produces ideally a curved shape and a torsion stiff honeycomb tub. The loads and forces acting on the running gear result primarily from the running gear mountings, the cooling forces, the static loads according to static load cases specified, EN 12603, the mass of the rest of the bodyshell and the payload.

If vertically directed forces are absorbed by the bodyshell through the secondary suspension of the running gear. For this reason brackets are included within the aluminium structure for suspension support. Multiple supports ensure a minimum of movements. The supports are integrated into the load bearing structure and need to be continuous as well as into flow optimised. The transmission of the traction forces of the running gear is realised through the tension and compression rods, which engage through eye connections and further distribute the loads into the floor area. The direction of the running gear with the two lateral dampers is provided at the inner cross beams.
A force flow optimised design is realised between the spring brackets and the load bearing floor structure. The connection points for the coupling forming part of the running gear sequence is dimensioned in line with EN 12663, and optimised with regard to force flow and stiffness. The force, acting in a longitudinal direction, according to the EN 12663 standard, distributes themselves over the structure in the subfloor. Similarly these are introduced into the diagonal running members in the homogeneous structure, which thus form a link to the spring connection (Fig. 9).

As a result of aerodynamic op- timisation, a complex external contour of the car is prevailed. This requires the diagonally running beams with a square cross-section to follow a three-dimensional curve, and in addition, they have to be bolted. This can be avoided by using circular cross-section beams in moderately loaded areas. These beams that only have to be curved in one direction. In heavily loaded areas suitable beams are then connected together individually shaped or from one-dimensional curved beams.

Consistent lightweight Construction Of Panelling Elements is contingent on the structural function of as many parts as possible. Depending on the internal panelling, construction using independent beams can be dispersed with, in local areas. The required stiffnesses be suitably determined by the panelling. Given sufficiently high stiffness and panel strength, stiffness can possibly be completely dispensed with at appropriate locations. The car, for example, be achieved with sandwich structures, or the running gear suspension stiffness, by increasing the area moment of inertia.

The principle of sandwich con- struction here corresponds to the behaviour of an beam. Under a bending load the sandwich core is stressed on shear, and the cover layers absorb the tensile and compressive forces, thus the local stiffness. Thus the area moment of inertia and the bending stiffness of the whole structure can be greatly increased (Fig. 15). This also allows it to be shown, that even with a total thickness of 10 mm, the specific bending stiffness, in comparison with solid steel sheet or aluminium sheet, can be increased by over 50 [%].

A systematic process must be used for the optimum selection of possible panelling for structure designs which are easy to bend (Fig. 19). The large number of different material and production combinations of cores and cover layers means that the space, the load- ing, and any other requirements first of all have to be defined. Have, in addition to the mechanical loads, other selection criteria such as thermal properties, che- mical resistance, fire protection, acoustic properties, and possible functional integrations have to be taken into con- sideration. Based on these specific requirements, with the aid of an analy- tical preliminary layout and a database of sandwich materials, the combinations are selected which can be used for the specific application. The analytical preliminary layout involves only a small amount of work, in comparison, for example, with an FEM analysis, since most requirements can, at this early stage, be simplified or abstracted. The optimisation of the component then follows, and the here

**Systematic Process For Construction Of Panelling Elements**

**Definition of design space, loads, ...**

**Preliminary analytical design of sandwich structure**

**Experimental determination of material parameters**

**Establishment of the first component structure (core properties, face properties)**

**Detailed specification of component using local and numerical procedures**

**Specific indication of additional influencing parameters (load transfer, peripheral bending, functional integrations, ...)**

**Optimised sandwich component**

**Fig. 11: Procedure to follow when selecting sandwich components for panelling (based on [21]).**

**Sources**

2. ERMAC, route 2060: The sustainable backbone of the Silesian European Transport Area, FPT.
7. NcT: Grundlagen spurplanerischer Raumbelegung, 2005, Vor- tragsband TU Berlin
9. Lang, Andreas und Horstmann, Bernhard: Neue elektrische Trieb

**Fig. 12: Cross-section of a possible connection of the sandwich with the homogeneous structure profiles in the transverse area.**