SAFETY EVALUATION AND ASSESSMENT OF MATERIALS AND ASSEMBLY TECHNOLOGIES FOR VEHICLE TR 08

Steinert, Winfried; Keller, Uwe
Institute for Software, Electronics, Railroad Technology (ISEB)
TÜV InterTraffic GmbH, Am Grauen Stein, 51105 Cologne, Germany
Phone: +49-221-806-2971, Fax: +49-221-806-2581
Email: steinert@de.tuv.com , http://www.iseb.com

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Abstract

The different materials and assembling technologies used for the structure and claddings of carriage body and Maglev undercarriage of the TR 08 will be presented. Sufficient dimensioning and verification of the mechanical structure elements will also be demonstrated, exemplified taking special consideration of the plastic, adhesive bonding, laser welding and blind joint techniques.

1 Introduction

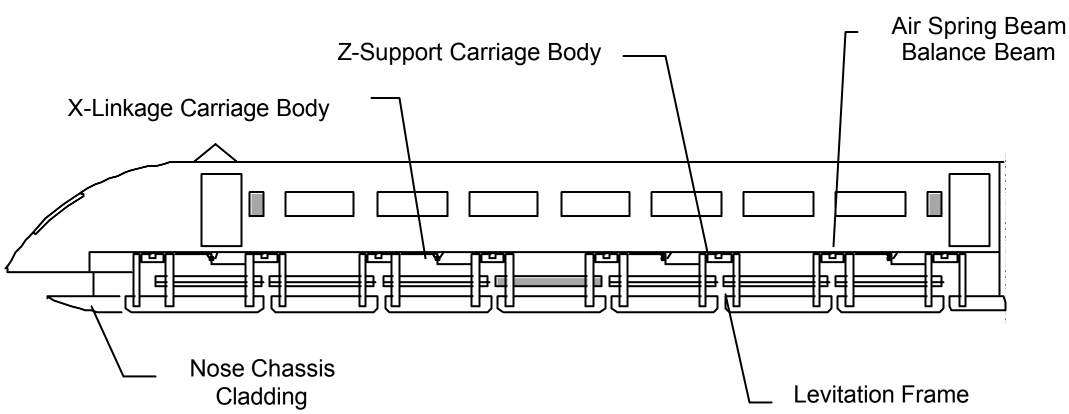
Testing of the 3-section pre-production vehicle TR 08 started in September 1999 at the Transrapid Test Facility (Transrapid Versuchsanlage Emsland, TVE).

This test site operation is one step within the certification process known as vehicle type approval. This process is regulated by the Federal Railway Authority (Eisenbahn-Bundesamt, EBA) together with the TVE operator and the industry. The EBA is the supervisory and licensing authority for revenue service Maglev applications in Germany. According to a law for test facilities (Versuchsanlagengesetz) the relevant authority for the TVE is the Technical Supervisory Body (Technische Aufsichtsbehörde TAB) for the state of Lower Saxony within the State Road Construction Office of Lower Saxony (Niedersächsische Landesamt für Straßenbau, NLStB).

TÜV experts have been involved in the aforementioned process, partly as experts of the federal state authority for the TVE, partly as experts recognized by EBA.

2 Short Description of the Vehicle (Design, Main Functions)

Each section consists of two main elements, a Maglev undercarriage and a carriage body. They are connected via the secondary suspension and x-linkages.



2.1 Carriage Body

To provide a light 24 m long tubular structure, a hybrid design was chosen. The bottom, side walls and roof consist of sandwich panels interconnected by means of aluminium hollow sections. The aluminium cover plates, thicknesses 0.8 and 1.0 mm are glued to the foam core with an epoxy resin (thickness 40 to 60 mm). The following hybrid connection type was selected for interconnection of the sandwich panels and hollow sections: blind riveted joints inside and two laser-welded seams outside.

The nose element was constructed from a one-piece element and a self-supporting sandwich structure. The structure consists of two glass-fibre-reinforced plastic cover laminates (5 mm outside and 3 mm inside shell) plus a foam core with a thickness of 35 mm. The inside of the cover shell is covered with a 2 mm adhesive rubber aramide layer to ensure sufficient resistance against bird collisions. A polyester resin was used to produce the laminates and connect them with the foam core. To ensure lightning protection, a fine copper net was laminated in just under the gel coat layer of the outer laminate. The 2^{nd} inside laminate (3 mm) was glued in on top of the rubber aramide layer. A 20 mm thick foam core was used for the three-part nose apron. The laminate thickness is 5 mm on the outside and 3 mm on the inside. TVE experience with bird collision damage made modifications necessary, which were then coordinated with the TÜV (hand laminate, aramide undercoat).

The nose element was produced using the vacuum injection method. The nose element was glued along the carriage body bottom and with the cylindrical parts of the carriage body cell to the doorposts and the roof seam. The nose aprons are glued at the nose bottom and nose bottom structure. The windshields were set in from the outside and also glued in.

The adhesive used was a single-component polyurethane glue that cures to form an elastomer in combination with booster paste. The effect of the booster paste is to bring about the curing (hardening) of the glue independent of humidity. The adhesive joints were sealed from the outside after application of lacquer. The seal contains UV-stabilizing components.

2.2 Maglev Undercarriage

The undercarriage consists of the sub-floor structure and four levitation chassis units, each of which supports the carriage body by means of four air springs.

The aluminium subfloor structure houses all the assembly groups of the Maglev under carriage systems (installation of the electrical, electronic and pneumatic equipment using slide-in units; cable channels for power and control cabling). It is mounted mainly on riveted standard aluminium alloy plates and profiles.

A chassis consists of four levitation frames, two on each side of the vehicle. Each frame is made up of two arms which wrap around the guideway. The frames are transversely connected complete aluminium alloy hollow profiles and longitudinally with so called x-linkages made from riveted aluminium alloy plates. The differ ent parts of the levitation frames are made of cast aluminium alloy. The parts are linked by high-strength prestressed bolts. The magnets are fixed to the frames along the entire length of the vehicle. So the vehicle load acts as a line load on the guideway. Support skids are also fixed on the frames which support the vehicle when it is at rest (16 skids/section).
In order to prevent dirt and snow from getting into the Maglev undercarriage, but also for aerodynamic purposes, cladding elements using aluminium-clad sandwich technology are provided both internally and externally with safe locking of the individual panels.

Due to weight limits, an aluminium alloy was the only alternative for the metal loadbearing structure of the Maglev carriage. To realize the rather filigree cross-sectional structure without welded seams, the following parts in particular were constructed using sand-cast aluminium alloys:

- levitation frame
- air spring beam
- balance beam
- Z-support

The structure of the levitation chassis cladding is essentially the same as the sandwich structure of the carriage body. The wall thicknesses of the interior and exterior aluminium cover plates are 0.5 mm / 0.7 mm. A foam core 20 mm thick is used as an intermediate layer glued in between the cover plates. Edge extrusions are glued into the upright edge areas of each cladding element. To improve accessibility for maintenance and inspection, the cladding elements are divided into upper and lower elements connected by a form-fitting hinge frame.

The nose chassis claddings were sandwich structures constructed using the hand laminating method, whereby additional metal elements are laminated in around the connection points. The sandwich core comprises a hard foam element worked in thicknesses of 10 to 40 mm depending on the dimensioning. Glass-fibre-reinforced plastic laminates made of vinyl ester resins with glass fibre reinforcements were used for the ceiling layers with a textile glass UD sublayer. To improve the impact resistance, aramide textile material was also laminated into the critical sections.

The bottom plate is located behind the nose floor and forms the transition element to the crash boxes in the middle structure of the first levitation chassis. It consists of a sandwich construction with a foam core 12 mm thick and carbon-fibre-reinforced laminates. The vacuum foil technique was used in its production.

3 Safety and quality assessment process

Development of the Transrapid system and operation of the TVE have been continuously monitored by TÜV Rheinland since the end of the 1970s. A basic feature of the process applied by TÜV is the four-eyes principle (one person prepares and another person checks the process). The safety assessment process applied by TÜV Rheinland is called PASC (Project Accompanying Safety Certification). This means that during the whole process of development the consideration of safety and quality aspects has been checked for compliance with the requirements and standards.

4 Safety evaluation and assessment for mechanical structural elements

Based on the functions of the vehicle (brakes, acceleration, running curves…), a hazard analysis is drawn up (EN 50126). Following systematic and complete identification of the relevant hazards, an FMEA was carried out on the basis of the construction blueprints for all primary structural elements in the force line and the TR 08 cladding elements. This failure mode effect analysis is part of the structural component engineering process and facilitates failure assessment. From the point of view of operational safety, protective measures or dimensioning changes can be derived from this analysis. Depending on whether the component or connection is determined to be fail-safe or non-fail-safe, a number of criteria apply to the FMEA of the TR 08.

- The following are of particular importance in case of failure tolerance:
  - Can the component or sub-parts be lost (violation to clearance envelope)?
  - Is there any cold or warm redundancy?
  - Are load shifts possible?
  - At what rate and in what way is the failure perpetuated (failure perpetuation rate)?
  - Is the part accessible and inspectable?
  - What are the planned inspection intervals?
- Additional points to be considered in case of a lack of failure tolerance:
  - What is the safety and availability relevance of the part?
  - Is the part and its attachment designed to be "safe." (durable or safe-life dimensioning)?
  - What QA measures have been planned for production and assembly?
  - What are the planned inspection and replacement intervals?

Accompanying the TÜV assessment, numeric structural strength analyses based on the FMEA, experimental tests of structural strength as well as verification of loads and stress during trial and demonstration operation are done.

Then the safety concept is presented:

- safety factors (loadbearing strength/ stress resistance)
- working service life
- inspection intervals

A number of materials and techniques for production and connection have been used in production of the TR08 for which an exhaustive assessment is currently not feasible on the basis of detailed specifications set out in the form of standards. The areas most affected are:

- Metallic materials: aluminium alloy cast
- Hybrid materials: composites (foam/ aluminium)
- Plastics: glass or carbon fibre reinforced polyester resin layers, with or without foam
- Assembling technologies: adhesive bonding, adhesive elastic thick-layer bonding, Automated laser welding, blind riveting, T-slot connection
- Hybrid structural connection: blind riveting/ laser welding

For this reason, safety assessment for these mechanical components was done as follows in cooperation with the Assessor within the framework of the approval process for the TR 08:

Based on the assumed loads set out in the system and reference documents, the stress factors applied to the structural components have been calculated using extensive FE computation models. For the carriage body, two complete FE models (end section with nose cell, sub-floor structure and middle section) have been done. For the Maglev chassis, there is a complete FE model of the nose levitation chassis including the "middle structure" (crash boxes). There are separate FE models for other parts, e.g. the nose chassis cladding and bottom plate.

For the most part, the stress factors were determined in these cases based on component trials, for which the test specifications and reports are on file. The theoretical assessment of loadbearing and fatigue strength are used to calculate the safety factor, the working service life and the inspection intervals. In addition, following the putting into operation of the TR 08 at the TVE, verification tests have been carried out to determine stress levels and loads. A small number of trials, for example experiments for tunnels and oncoming trains, require national tracks for realization.

To ensure that the production quality (stress resistance) in the specifications and calculations are met, experts on welding and plastics at TÜV have carried out monitoring and tests parallel to production.

4.1 Aluminium alloy cast

The fatigue strength characteristics of the material used for the cast sections of the levitation chassis were determined on the basis of reversed bending tests of flat samples by the manufacturer. A Woehler line for a probability of survival of 95% (working life line) was derived from the results. The permissible tension levels for fatigue strength assessment were determined including a safety factor of 1.3. In assessment of loadbearing capacity for special loads (e.g. mechanical loadbearing), the permissible stress level is calculated using a factor of 2.0 against ultimate stress or 1.5 against the yield point (0.2% ultimate strain) of the material.

To verify the stress and loadbearing strength, the manufacturer assessed the individual cast elements in trials designed to determine loads at failure.
To determine the interactions of the structural components, a manufacturer's test platform was used to test a levitation chassis unit with the modules levitation chassis, traverse module and Z-support for static and dynamic repetition testing. The objective of the static testing was to verify the FEM calculatory models, to determine the structural rigidities and to investigate the stress and shearing forces in their dependence on various external loads. To verify fatigue strength, dynamic repetition tests were carried out according to UIC 615. The loads used were taken from the regulatory load cases in the reference documentation and arranged in load cycles. The stress collective used was: 45%

straight with curved dip and round hilltop runs, 5% landing and 50% curve and switch runs. The stress cycle sum was $1.0 \cdot 10^7$.

4.2 Composites, general

Loadbearing and fatigue strength assessments were determined in terms of the stress factors from the structural analysis, whereby the gluing of the cover plates with the core was assumed to be perfect, since the peeling strength is much higher than the foam strength.
With regard to local failure, assessments for core shear buckling and local buckling of the cover plates were undertaken. Strain analysis techniques were used instead of fatigue strength assessment for the glass-fibre-reinforced plastic material with reference to ship construction dimensions.

4.3 Composites aluminium cover plates

To verify the resistances, the manufacturer carried out a number of tests and experiments:
- Sandwich sample bending tests (static and dynamic tests)
- Tensile strength test of sandwich samples (static tests)
- Impact testing of sandwich samples
- Hail exposure test followed by dynamic bending tests
- Fire test of core material (flame exposure test)
- Adhesive strength testing in peeling tests (aluminium plates/ foam)

Also material inspection involving parallel samples, carried out by TÜV InterTraffic:
- Bending tests of sandwich samples
- Peeling adhesive strength test according to DIN EN 4624

4.4 Composites with glass or carbon fibre-reinforced resin layers

To verify the stress resistance, the manufacturer performed the following tests:
- Penetration test (shooting test as per UIC 651
- Fire exposure test, sandwich material

Also material inspection involving parallel samples, carried out by TÜV InterTraffic:
- Mechanical and technological tests of cover laminates and sandwich samples (tensile strength, bending strength, hardness, etc.)

4.5 Adhesive elastic thick-layer bonding

In the structural analysis, the rigidity of the adhesive joints is modelled by spring elements (tension-compression spring, 2 shear springs).
To determine and verify resistance, the manufacturer carried out the following experiments and tests:
- Static and dynamic tests of the adhesive joint
- Test of adhesion in the form of the peeling test
- Determination of the fatigue strength of the adhesive composite

TÜV InterTraffic carried out supplementary material tests of the adhesive samples (adhesive sample)
- Adhesive strength
- Raw density
- Technological tests

as well as tests during the gluing procedure (final assembly):
- Production and laboratory testing of working samples.
- Temperature, humidity, pump pressure, mixing rations of components

4.6 Hybrid structural connection: blind riveting and laser welding

In the FE model used for structural analysis, the riveted joints and welded joints are shown as simplified bar elements. To determine stress resistance, the manufacturer performed verification tests, both static and dynamic:
- Riveted joints (tension-shearing tests of single-rivet splice joints)
- Laser-welded joints (component tests with original joints)

The general and special specifications for welding technique in manufacturing have been documented by the manufacturer. Selected welded joints were produced under production conditions in the presence of TÜV InterTraffic experts, then studied and tested in the TÜV Rheinland laboratory.
In accordance with the test specifications accepted by the expert, the manufacturer checked the laser-welded seams both in visual inspections and, in a random sample, by means of x-ray inspection, within the framework of production monitoring.

5 Results / perspectives

Assessments for type testing of the TR08 vehicle by TÜV InterTraffic are now concluded for the time being.

On April 12th, 2000, the EBA issued a decision called "assurance of type approval for the vehicle TR 08" containing several conditions. When the conditions are met, this assurance will be changed into official type approval.
On May 23rd, 2000, the federal state authority NLStB awarded a license for the testing and demonstration operation of the TR 08 at TVE.

TÜV experts are still at work within the framework of trial and demonstration operation. In addition to assessment of future trials, they are involved in verification of, in particular, parallel expert monitoring of continuous functional testing of the TR08 at TVE. This testing is also an integral part of the assessment of the mechanical components.