The support magnet cladding with integrated IPS® pick-up coil of Transrapid vehicles

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ABSTRACT: For the high-speed maglev system Transrapid the Inductive Power Supply (IPS®) has been developed on behalf of the BMVBS to afford a non-contact power supply of the vehicles (Zheng et al. 2005). In particular, the IPS® system substitutes the conventional system using power rails and current collectors. The essential vehicle components are pick-up coils integrated in the inner claddings of the support magnets. The development of the support magnet cladding including the qualification tests is presented.

1 INTRODUCTION

1.1 Energy supply of Transrapid

The high-speed maglev system Transrapid is based on the principle of electromagnetism. It is equipped with a non-contact levitation and guidance function for the entire speed range, i.e. from zero to approximately 500 km/h.

The energy requirement of the Transrapid vehicle essentially follows from the power supply of the support and guidance magnets as well as communication facilities, air conditioning and lightning. Particularly, due to the chosen long stator linear motor implemented in the guideway, the vehicle itself does not require on-board power for propulsion.

The energy supply is realized by contactless operating linear generators embedded in the poles of the support magnets. However, due to the physical principle of the linear generators converting kinetic into electrical energy, the power is proportional to the vehicle velocity. With the optimized design of the Transrapid vehicle the energy required is completely covered at a speed of approximately 100 km/h.

In reverse, at speeds below 100 km/h – e.g. when close to stations – the Transrapid needs an additional on-board energy supply.

1.2 The IPS® system

This additional energy supply can be provided by on-board network batteries in the vehicle. In order to minimize charging cycles and so to reduce maintenance requirement and costs of the batteries, a conventional system using power rails and current collectors has been used until now. But since this system does not operate without mechanical contact, various disadvantages occur, e.g. no wear-less operation, additional sound emission, high requirements for the positioning of the power rails and for the control of the current collectors and finally a high sensitivity to environmental influences.

To avoid these disadvantages the contactless Inductive Power Supply (IPS®) has been developed. Essentially the IPS® system consists of the following components (see Figure 1):

- induction loop alongside the guideway powered with field current (primary component),
- pick-up coils alongside the Transrapid vehicle (secondary component).

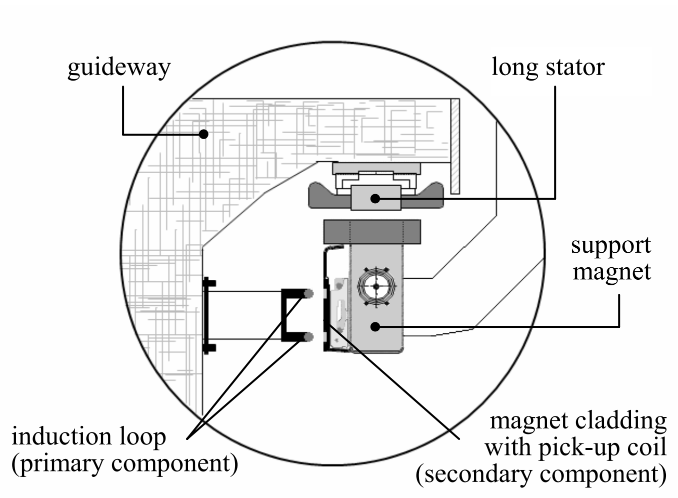

Figure 1: Components of the IPS® system.

The functional principle is based on electromagnetic interaction between the primary component fixed at the guideway and the secondary component installed in the vehicle. In principle, the system operates like a standard transformer, but for the IPS® system the magnetic circuit is not closed via an iron core in order to provide a contactless operation. In particular, the nominal air gap between primary and secondary component is 40 mm.

The pick-up coils of the Transrapid vehicle are integrated in the inner cladding of the support magnets. Ferrite elements are arranged behind the coils to concentrate the magnetic flux. They also serve to simultaneously shield the IPS® system from other electrical components of the vehicle and from metallic elements such as the fastenings of the inner cladding on the support magnets, which could otherwise be subject to heating due to eddy currents. Along with capacitors, also mounted at the magnet cladding, the pick-up coils form a resonant tuned circuit each with the IPS® operating frequency of 20 kHz.

For further details on the design and functionality of the IPS® system we refer to Zheng et al. 2005, Bauer et al. 2006 and Meins et al. 2006.

2 DEVELOPMENT OF THE SUPPORT MAGNET CLADDING

2.1 Operating requirements

Until now the inner cladding of the support magnet as shown in Figure 2 has been exclusively used to provide a smooth surface at the inner side of the support magnet in order to achieve optimal acoustical and aerodynamical properties of the Transrapid vehicles.

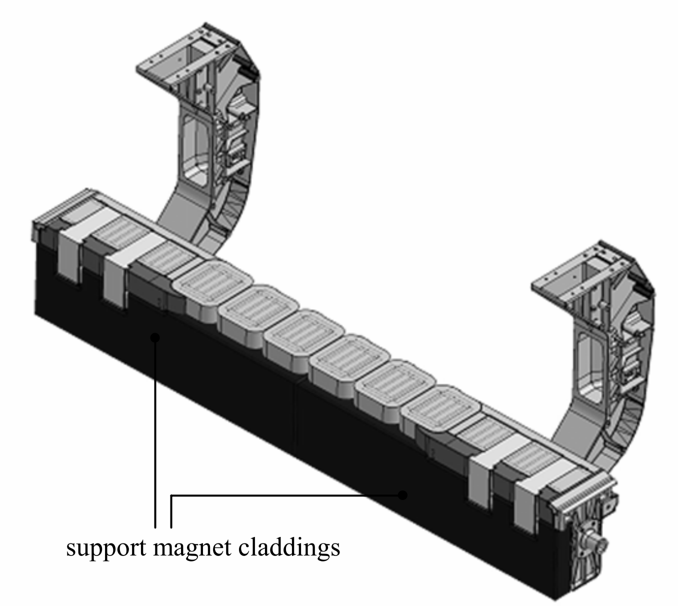

Figure 2: Support magnet of Transrapid vehicle with symmetrical left and right inner cladding.

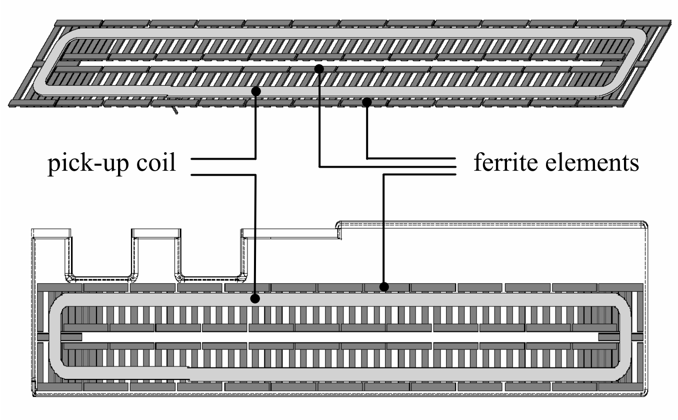

Figure 3: Arrangement of the pick-up coil and ferrite elements and schematic structure of the support magnet cladding.

With respect to the supplementary functionality of the support magnet cladding being now the carrier element of the secondary IPS® component, the cladding had to be redesigned in order to integrate the electrical components, i.e. pick-up coil and ferrite elements, as schematically shown in Figure 3. Since the support magnet cladding is mounted before the primary level of the vehicle suspension and therefore has to withstand heavy mechanical loads the appropriate embedding of the integrated electrical IPS® components is of particular importance.

In detail, the further development has been carried out with regard to the following items:

- mechanical strength,
- protection against mechanical stresses for the integrated IPS® components,
- temperature resistance and aging stability,
- fixation of the fastenings of the cladding, and
- fire protection requirements.

Moreover, although now the electrical components are integrated in the cladding, the weight of the further developed subassembly must not increase. That is, the additional weight of the electrical components has to be compensated by a lighter construction design of the cladding and the fastenings. The target value of the subassembly weight including the electrical components and fastenings has been given by approximately 20 kg.

2.2 Preliminary investigations and tests

The design of the support magnet cladding is realized in sandwich skin construction by means of glass reinforced plastic (GRP). That is, two thinner GRP laminates are separated by a lightweight core in order to increase the rigidity of the subassembly by increasing the effective thickness.

For this sandwich construction the pick-up coil and the ferrite elements are embedded in the sand-

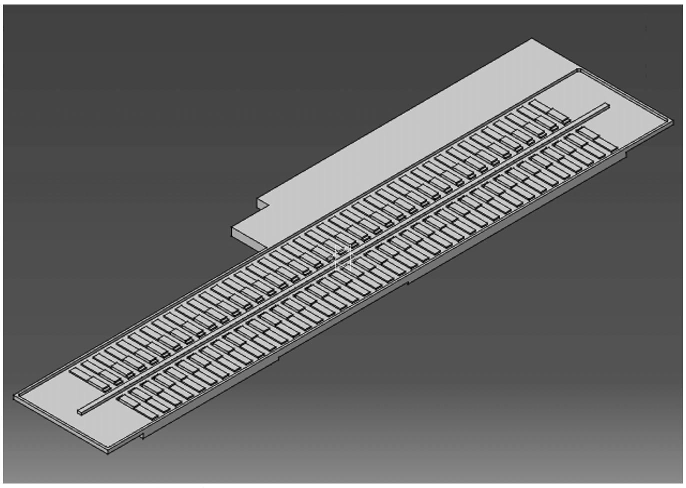

Figure 4: Sandwich core.

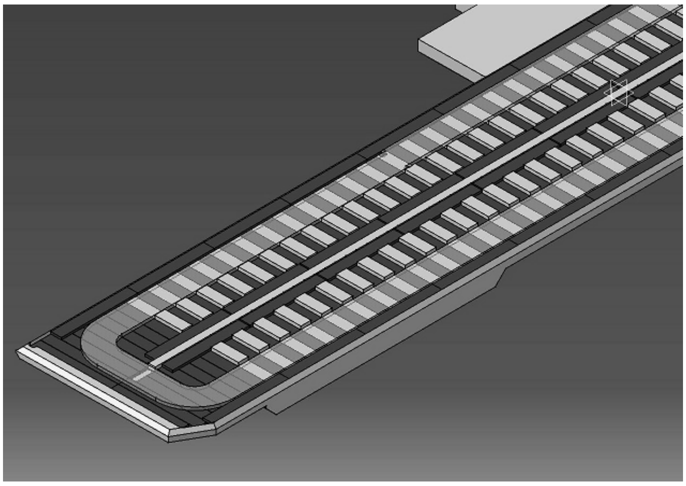

Figure 5: Inlayed pick-up coil and ferrite elements.

wich core. This design provides optimal protection against mechanical stresses even for the brittle ferrite elements. As the core material a closed-cell, thermoplastic structural foam has been chosen due to the mechanical properties in combination with a high degree of fire resistance and excellent long term thermal stability. In Figure 4 the sandwich core for the left version of the support magnet cladding is shown. The slots integrated into the core can be seen in order to position the ferrite elements and the pick-up coil. Finally, in Figure 5 these components inlayed into the sandwich core are shown.

As described above, the skin of the sandwich construction provides the necessary rigidity and – for the outer skin of the cladding – also the required impact resistance. In order to obtain a suitable selection of GRP laminates, first bending and tensile tests have been carried out on various samples to get first results of the modulus of elasticity, the mechanical stability and the tensile strength, Moreover, the impact performance has been verified at an impact and crash test bench with a velocity up to 120 m/s.

After determining the material and laminate configuration of the sandwich construction further mechanical tests have been conducted with initial sam-

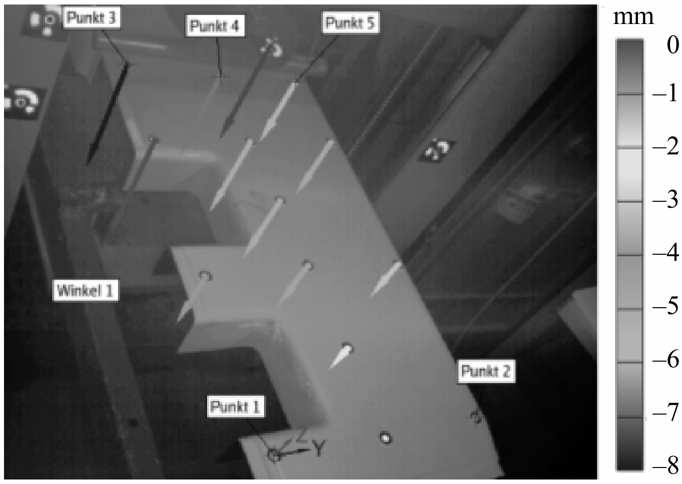

Figure 6: Displacement measurements with the optical measurement system PONTOS.

ples of the support magnet cladding. Measurements with the measuring system PONTOS gave detailed information about the flexural stiffness of the subassembly. PONTOS is a system for optical, dynamic 3D analysis. It enables the precise position, motion and deformation calculation of structures and components. In Figure 6 the results of a displacement measurement from a 3-point bending test in transverse direction (in relation to the mounting position on the vehicle) are shown.

2.3 *Prototypes*

For the qualification process prototypes have been manufactured in accordance with the results of the preliminary investigations and tests as described above. The processing method for these prototypes has been chosen following the vacuum bag molding in order to achieve a good ratio of fiberglass and laminating resin with regard to the component weight.

Before starting the manufacturing process of the prototypes themselves, each sandwich core has been assembled first separately. That is, the pick-up coil

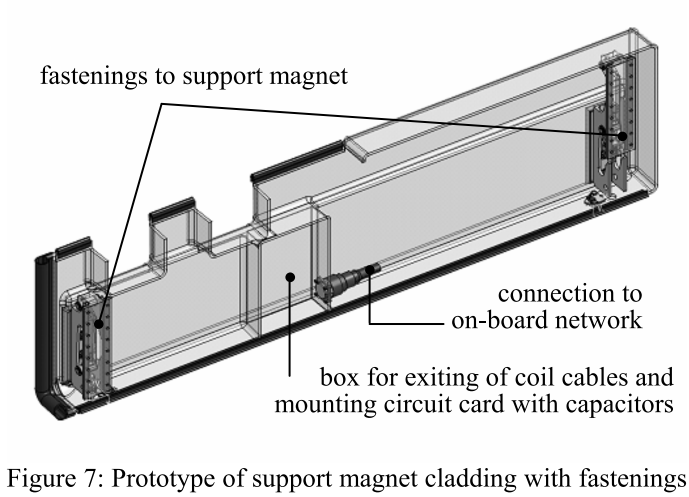

Figure 7: Prototype of support magnet cladding with fastenings and connection components to the on-board network.

Figure 8: Capacitor card casted with silicon rubber.

and the ferrite elements have been inlayed and fixed in the sandwich core by means of filling with the laminating resin. Hence, the handling for the manufacturing is much improved with regard to process stability and quality assurance.

In Figure 7 the prototype of the support magnet cladding is shown. Among the fastenings to the support magnet the components for the connection to the on-board network can be seen on the back side of the cladding. The fastenings are attached at the cladding by means of four stud bolts each integrated in the inner GRP laminate. It is of particular importance for a tensionless assembling on the support magnet to keep the specified narrow tolerances for the positioning of the stud bolts. This has been realized with a special positioning device used during the manufacturing process of the prototypes.

Figure shows the circuit card with capacitors for the resonant tuned circuit being casted in the designated box at the inner side of the cladding by means of silicon rubber. Furthermore the cable connector for the connection to the on-board network can be seen.

3 QUALIFICATION TESTS

3.1 Flammability test

As described in section 2.2 all materials have been chosen according to the fire protection requirements.

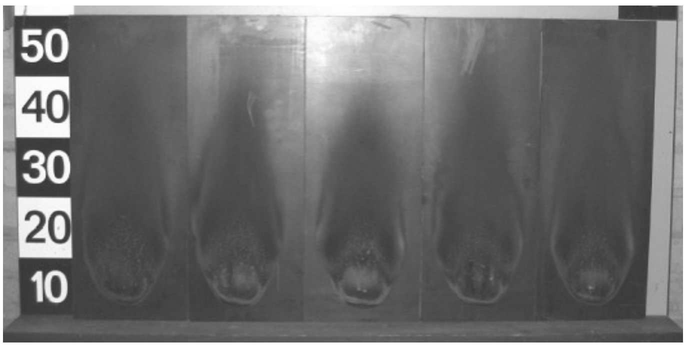

Figure 9: Test results flammability tests.

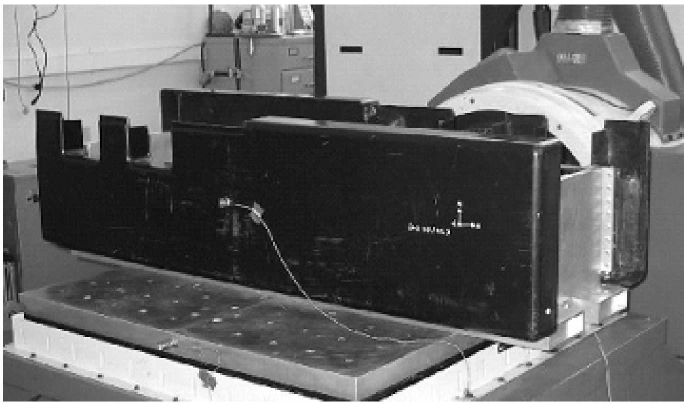

Figure 10: Test configuration vibration tests.

But nevertheless, for the complete assembly flammability tests according to DIN standard 54837 have to be performed in order to verify the required properties.

These tests have been conducted with five test samples manufactured analog to the prototype cladding. In particular, with the standardized flame impingement the following relevant properties have been determined:

- destroyed length ≤ 16 cm,
- duration of burning ≤ 38 s,
- integral of smoke density ≤ 10 %*min.

According to the specification given in DIN standard 5510, the required classifications S3 for flammability and SR2 for smoke emission are satisfied. The five test samples used for the flammability tests are shown in Figure 9.

3.2 Environmental test

In order to prove the applicability of the support magnet cladding regarding numerous climatical and vibrational load configurations resulting from transport, assembling and operation, a number of environmental tests have been conducted. Besides checking the mechanical integrity after each subtest, an electrical function test has been accomplished for each prototype proving possible deviation of the resonant frequency and the quality factor of the resonant tuned circuit.

The environmental tests concerning climatical and temperature stress have been performed in accordance with DIN standard 60068-2. The following loads have been tested:

- cold storage,
- temperature cycling, and
- damp heat, cyclic.

The electrical function tests did not show any significant deviation of the electrical properties. Even the visual control of the prototypes did not yield any substantial findings.

Finally, after having finished the climatic tests, the aging stability has been investigated using the Differential Scanning Calorimetry (DSC). DSC is a thermoanalytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference are measured as a function of temperature. The basic principle underlying this technique is that, when the sample undergoes a physical transformation, more or less heat will need to flow to it than the reference to maintain both at the same temperature. Whether more or less heat must flow to the sample depends on whether the process is exothermic or endothermic. The result of the DSC applied on the prototypes of the cladding did not show any relevant differences between the samples and the references.

The shock and vibration tests have been conducted in accordance to DIN standard 61373. In particular, the life cycle test has been realized by means of the so-called amplification test method, i.e. the time basis is decreased whereas the test level is increased. In Figure 10 the test configuration for the vibration test in transverse direction is shown. The mechanical shaker with two prototypes mounted on the sliding surface table can be seen. Each test has been carried out according to the following steps:

1 resonance testing (sine sweep, 5 Hz to 1.6 kHz),
2 broad-band random vibration,
3 shock test,
4 resonance testing as in 1 in order to detect material damage.

The results of the resonance testing showed only a slight deviation of the resonance frequency after reaching the life cycle of the prototypes.

3.3 Strength tests

Among the theoretical strength test for the cladding structure and the fastenings, subsequent to the shaker tests described above the remaining strength of the fastening fixation at the support magnet cladding has been proven experimentally by a static test machine The prototypes has been fixed by an appropriate device and a stepwise increased static force has been applied on the stud bolts of the fastening until the GRP laminate break down. The results showed that even after the life cycle of the cladding the remaining strength is given with a safety factor greater than 5.

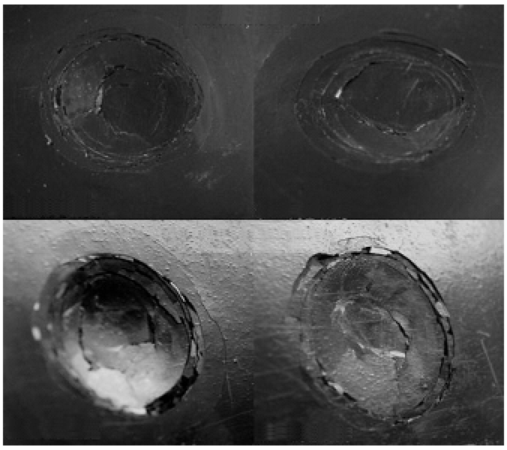

Figure 11: Tests results for impact behavior (velocity 100 m/s, weight 40 g).

Furthermore impact tests have been conducted at the prototypes. For the impact, a 40 g polyamide bullet has been used with an impact speed of 100 m/s and an impact angle of 90°. The results are shown in Figure 11. It can be seen that for no test the aramid layer has been cut. A break out of particles has not been determined.

4 CONCLUSION

Due to the contactless operation, the IPS® system for Transrapid vehicles has several advantages compared to the conventional power rail system, which can be summarized as follows:

- reduced noise emission,
- lower maintenance costs,
- simple operation, and finally
- environmental robustness.

With the development and qualification of the support magnet cladding with integrated IPS® pick-up coil, the IPS® system is now available for future application of the Transrapid system.

5 ACKNOWLEDGEMENT

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