Inductive Power Supply (IPS®) for the Transrapid

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ABSTRACT: At velocities below 100 km/h and during stops the Transrapid vehicle has to be supplied with energy by an external source for the on board power consumers like levitation magnets and climate control. A new contactless inductive power supply system, IPS®, was developed for the German Transrapid project in Munich on behalf of the BMVBS. With IPS® the power supply will work without mechanical contact to the guideway as a consequent performance enhancement for the Transrapid. Details of design, function and qualification of the IPS® system will be presented.

1 INTRODUCTION

1.1 Power requirement and supply of the Transrapid vehicle

A main design feature of the Transrapid is the long stator concept with the motor winding being part of the guide way equipment. Therefore, the vehicle does not need energy for the propulsion as conventional railway systems. The power requirement are reduced significantly as only the magnets for support and guidance, climate control and vehicle electronics have to be supplied. This energy is provided by linear generators (LIGs), coils integrated into the poles of the support magnets. They convert kinetic energy, which is supplied by the propulsion system, back into electrical energy for the on board systems. Due to the physical principle of the linear generators, the maximum energy, which can be supplied by LIGs, is proportional to the velocity of the vehicle. In the optimized setup used in the TR08 a 100% supply is achieved above 100 km/h.

At low velocities and standstill, e.g. in and near stations, the Transrapid needs additional energy supply. The TR08 uses a conventional system composed of current collectors and power rails attached to the guideway. This mechanical system is contrary to the basic concept of the Transrapid - contact free operation in the whole velocity range from standstill to 500 km/h – and has several disadvantages:

- regular maintenance of the current collectors due to frictional wear is necessary,
- sparkling is possible,
- position of power rails has to be ensured with low tolerance,
- unfavorable aerodynamic and aeroacoustic contour due to the current collectors at the vehicle,
- function is sensible to snow, ice, and dirt, and
- position of the current collectors (engaged or not engaged) is safety relevant.

Due to this disadvantages a new contactless system for the energy supply called **I**nductive **P**ower **S**upply or IPS®, was developed.

2 DESCRIPTION OF THE IPS® SYSTEM

2.1 Functional principle

The fundamental principle of the IPS® is the electromagnetic induction similar to a transformer. This is shown in Figure 1.

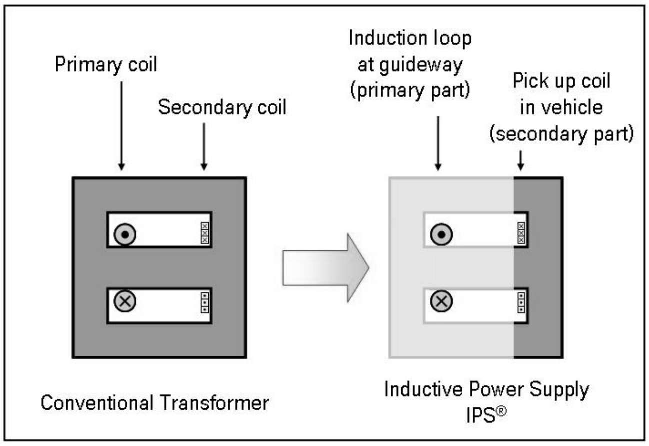

Figure 1: Physical principle of the IPS®-system.

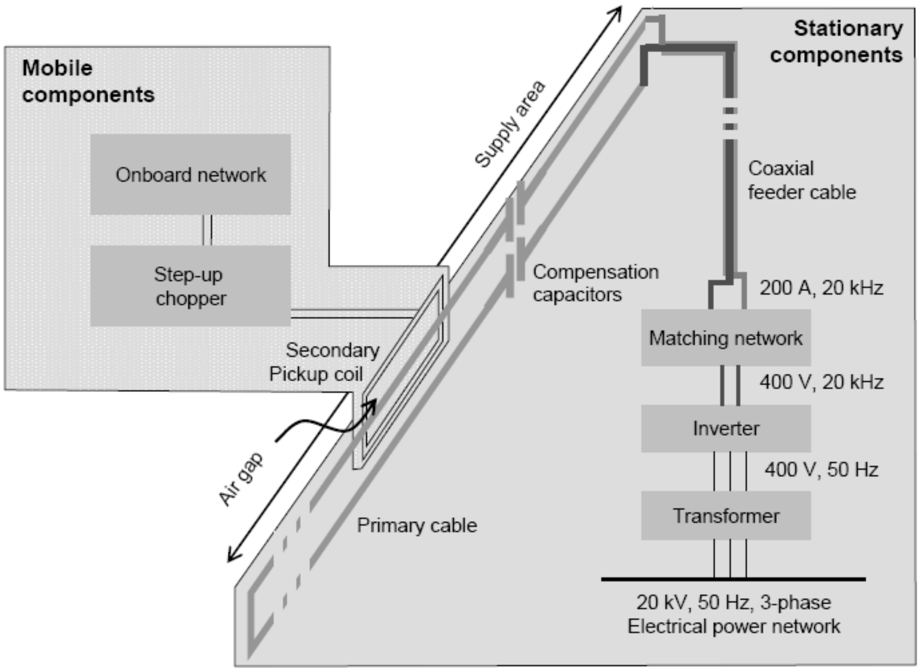

Figure 2: Schematic representation of the fixed and mobile IPS components.

The primary coil becomes the induction loop at the guideway and the secondary coil is converted to the pickup coil fixed to the vehicle.

The main difference to the transformer is that the magnetic field can not be closed via an iron core. To achieve an efficient energy transfer nonetheless, the frequency is increased from 50 Hz to 20 kHz. This makes it possible to realize a non-contact system with an air gap (further details in Meins et al. 2006).

The geometrical arrangement of the induction loop is such that the electromagnetic induction is mainly independent of any relative motion in the direction of travel. This means that also the power transfer is independent of speed.

The IPS® system consists of the following essential components shown in Figure 2:

stationary components at or near the guideway:

- power supply with transformer, inverter and matching network,
- coaxial feeder cable between power supply and induction loop as well as
- induction loop at the guideway with primary cable and compensation capacitors.

mobile components in the vehicle:

- pickup coil as part of the support magnet cladding (secondary component) and
- step-up chopper for rectifying and matching the voltage level to the on-board network.

2.2 Power Supply for the IPS® System

The IPS® power supply provides the primary components at the guideway with the 20 kHz current. It is typically connected to the 20 kV network to which also supplies energy for the propulsion system. A transformer provides the 400 V, 3-phase voltage for the inverter which generates a single-phase, square-wave AC voltage with a frequency of 20 kHz and a rated power of several hundred kW. The output quadripole converts this voltage source into a constant-current source with sinusiodial waveform and an effective current of 200 A.

Besides these main components, additional devices are part of the on-board-energy supply station: compensation capacitors to fine-tune the induction loop to 20 kHz, switches for the 50 Hz supply, switches to disconnect and ground the induction loop if needed, lightening protection, devices to control the IPS®-System, and so on.

A coaxial feeder cable is the electrical connection between the output quadripole in the on-board-energy supply station and the primary component at the guideway. It can be up to several 100 m long if needed. For example in tunnels it might be favorable to position the on-board-energy supply station not near the primary component to avoid large tunnel cross-sections for the power supply.

Figure 3: IPS primary cable.

Figure 4: Primary cable support made of GRP on the Transrapid Test Facility Emsland.

2.3 Guideway Components

At the guideway, the so called primary cable is attached along both sides of the guideway as an extended induction loop. As the system operates at 20 kHz, cables made of strands insulated with varnish are used, i.e. with several thousand individual thin wires that are electrically insulated from each other (Fig. 3). Using this kind of cable minimizes the skin effect and, therefore, the electrical power dissipation of the primary cable.

To compensate for the inductivity of the induction loop, capacitors are connected in series at regular intervals. The capacity is chosen so that the series resonant circuit, primary cable and compensation capacitors, is tuned to the system operating frequency of 20 kHz. Thus, it represents a pure ohmic load for the supply. Furthermore, the voltage level does not rise unnecessarily along the route.

The exact positioning of the primary cable on the guideway is accomplished using a support. The optimal design of this support depends on the type of guideway. For example, we developed a design for the concrete girder of the TVE which is shown in Figure 4. Its main components, brackets, support profile and cover, are made of GRP (Glass fiber Reinforced Plastic) to rule out eddy currents which are induced in any electrical conducting material near to the primary cable. This support was qualified for distances between the brackets of more than 2 m so that already existing anchors in the concrete girders could be used. It also provides good mechanical guard for the primary cable which is important in maintenance and vehicle integration areas.

2.4 Components in the Transrapid vehicle

In the vehicle secondary pick up coils are integrated into the support magnet cladding opposite to the induction loop at the guideway. This lightweight construction reduces both the weight and the number of components. Additionally, this geometrical arrangement ensures a minimum possible air gap between the induction loop and the pick up coil without compromising the vehicle clearance profile. Due to the smooth surface of the support magnet cladding, the design also guarantees an optimum aeroacoustic surface. Details of the design features and qualification tests of the support magnet cladding with integrated pickup-unit are given in Diekmann et al. (2006).

Every pickup coil is connected to a step-up chopper which rectifies the 20 kHz current and matches the voltage level to that of the on-board network. As every section of the Transrapid has several (32 systems according to the 32 step-up choppers per section) pickup coils, it is a highly parallel system. This is advantageous in contrast to the conventional current collectors with just two parallel systems per vehicle section. Additionally, the IPS® step-up choppers are distributed homogeneously along the vehicle similar to the magnet control units. Therefore, the number and diameter of power cables, which transfer the energy to the electrical loads, is greatly reduced.

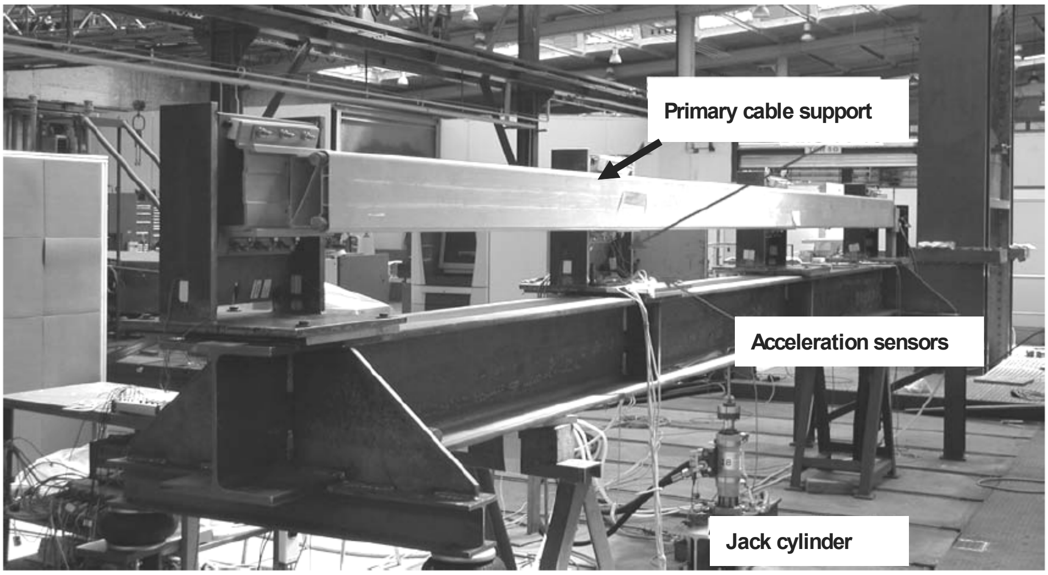

Figure 5: Laboratory test setup for the vibration test of the primary cable support.

3 QUALIFICATION

To qualify the IPS® system, we performed laboratory tests as well as system tests on the Transrapid Test Facility Emsland (TVE).

For example Figure 5 shows a laboratory test setup of the primary cable support to simulate the vibrations of the guideway girder when the vehicle passes. The GRP components were fixed to a 6 m long I-beam which is vibrated using jack cylinders. The amplitude and frequency of the vibration was chosen to be as high as the real load that was measured at the TVE. In similar way every relevant load was tested in order to qualify the support.

Another main step for qualification was the laboratory test of the inverter. It was tested with the maximum load corresponding to a Transrapid with 3 sections (75 m) in laboratory. Also different

operational situations like no load and reduced induction loop current were tested. It was proved that in non of these cases inverter parameter like the output current and maximum temperature of the switches are exceeded.

In order to test the whole system, a system test on the TVE was performed in Mai 2005. For this test a 300 m long induction loop (Fig. 6, left side) was fixed to the guideway. A more than 800 m long coaxial feeder cable connected the loop with the matching network of the power supply. All components of the power supply were installed in a container positioned near the maintenance hall of the TVE (Fig. 6, right side). The TR08 was equipped with four support magnet claddings with pickup coils and the corresponding step-up choppers.


Figure 6: Induction loop at the guideway (left) and container with power supply near the maintenance hall (right) for the IPS® system test on the TVE.

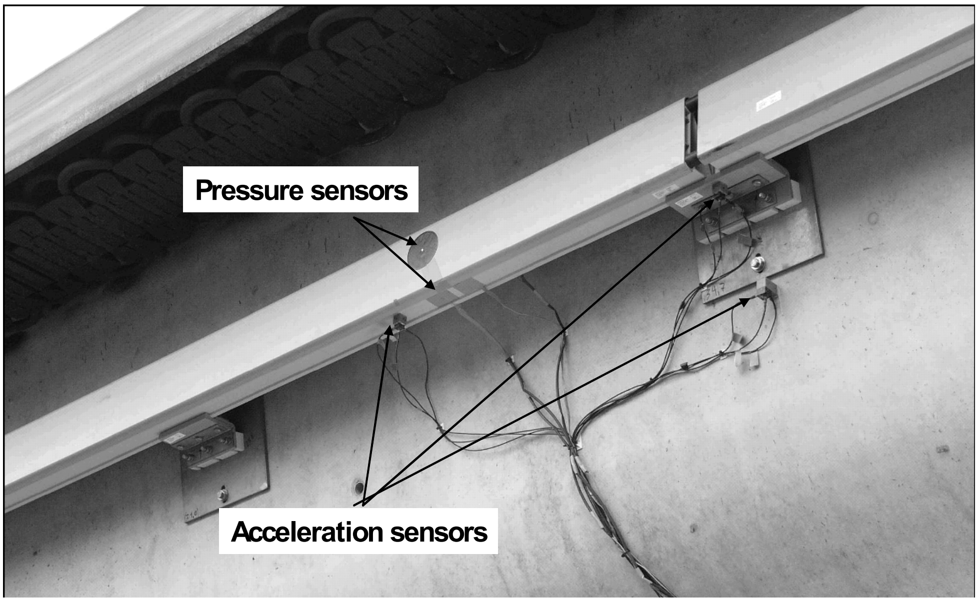

Figure 7: Pressure and acceleration sensors at the primary cable support and guideway.

During the tests the power transfer capability of the system was proofed by measuring the output current and voltage of the step-up choppers as well as the power supplied by the inverter. Additionally, other parameters were measured, which are relevant for the components in the vehicle:

- temperature of pickup-coils and its compensation capacitors,
- acceleration of the support magnet cladding as well as
- aerodynamic pressure at the support magnet cladding.

At the guideway
- the mechanical load of the primary cable support (Fig. 7),
- aerodynamic pressure at the support,
- the temperature of the primary cable and
- current and voltage at the compensation capacitors

were recorded and compared to the design parameters.

4 OUTLOOK

Due to the principle of contactless inductive energy transfer, the IPS® system has several advantages over the conventional power rail – current collector setup:

- lower noise at high velocity due to smoother surfaces,
- more robustness against environmental influences like snow, ice or dirt,
- no safety relevant control and functionality like the engagement of the current collectors necessary as well as
- higher redundancy due to 32 pick up coils per section.

The need for additional electronic components like the inverter and pickup-coils is easily compensated by changes in the vehicle and guideway system:

- less power cables in the vehicle,
- less stringent tolerances for the installation of the induction loop on the guideway,
- possibility of gaps in the induction loop (e.g. at guideway switches) and
- less maintenance (no mechanical wear).

The qualification of the IPS® system proved the functionality of this new power supply system and the correct mechanical and electrical design of the power supply as well as the components on the guideway and in the vehicle. It is now available for future applications of the Transrapid superspeed maglev system.

5 ACKNOWLEDGEMENT

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