

A turnout switch for the superconductively levitated transport system SupraTrans

Christoph Beyer;

IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany, email: c.beyer@ifw-dresden.de

Lars Kühn, Oliver de Haas and Ludwig Schultz;

IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany

ABSTRACT: The development and creation of a full working prototype of a superconductively levitated transport system was the aim of the SupraTrans project. The levitation and guidance system is based on flux pinning in melt-textured bulk $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) that stabilizes the vertical and lateral positions of the vehicle above the magnetic track. A maximum total load of nearly 800 kg and stiffnesses up to 800 N/mm at 77 K has been achieved. To establish a highly branched transportation network a fast working turnout switch is essential. An experimental set-up for an electromagnetic turnout switch has been created. The evaluation of the experiments shows a small retarding but appropriate levitation and guidance behavior and will be discussed in detail in the paper.

1 INTRODUCTION

Magnetic levitation on the basis of electrostatic or magnetostatic interactions between macroscopic bodies is impossible, according to the sobering conclusion to draw from Samuel Earnshaw's theorem published in 1842 (Earnshaw 1842). Most of today's solutions for magnetic levitation are, therefore, based on dynamically controlled electromagnets, facing all the problems of sophisticated control systems and considerable power consumption. The more seducing is it to find a system with the simplicity of a fixed arrangement of magnets and iron yokes, which does not violate Earnshaw's theorem. The system, which fulfills all these requirements, consists of superconducting materials levitating in the static magnetic field of permanent magnets. Several groups are working on projects to use this simple technique to design new machines with frictionless rotating bearings (Weinberger et al. 1990, Stoye et al. 1995, Hull 2000, Kameno et al. 1999). Linear bearings can also be made by superconducting levitation (Schultz et al. 2002). The idea to set up a superconductive maglev transporting system is then just a small step away. The first man loading maglev system of this kind was presented in Chengdu, China in 2002 (Wang et al. 2002) and Stephan et al. (2004) are running a speed test facility.

The SupraTrans project was started to develop a demonstrator containing all components needed for a transporting system and also taking into account

the requirements of a future operator. Therefore SupraTrans is a joint venture of research institutes (IFW Dresden), universities (Dresden University of Technology, Dresden University of Applied Sciences), industrial companies (ELBAS GmbH–



Figure 1: The SupraTrans train at its first presentation at the IFW Dresden in September 2004.

railway consulting and engineering, Baumüller Kamenz–linear drives, CIDEON engineering Bautzen–railway conveyer design) and the Dresden Transportation Company (DVB AG) as a potential user. All together, has designed a fully working demonstrator and a test line, which allow to study all the mentioned issues (Haas et al. 2004).

2 THE SUPRATRANS SYSTEM

2.1 Levitation and guidance system

The magnetic guideway is characterized by a magnetic field exhibiting a strong field gradient perpendicular to and a homogeneous characteristic along the moving direction. Forces between the superconductor and the guideway are proportional to both, the maximum field and the field gradient. The field has to penetrate the space above the guideway to enable a considerable levitation gap, but should not affect potential passengers or environment in its close neighborhood. The arrangement of Nd-Fe-B permanent magnets and iron yokes working as flux collectors, has to be optimized to fulfill all these requirements.

Due to the size of the melt-textured triple-seeded YBCO bulk superconductors of $90 \times 35 \times 15 \text{ mm}^3$ (Schätzle et al. 1999), the width of a single track is set to 90 mm. The design of the track has been optimized using two-dimensional finite element methods (QUICKFIELD-software) and three-dimensional finite boundary element simulation (AMPERES-software). The resulting optimized geometry for a single track is shown in figure 2.

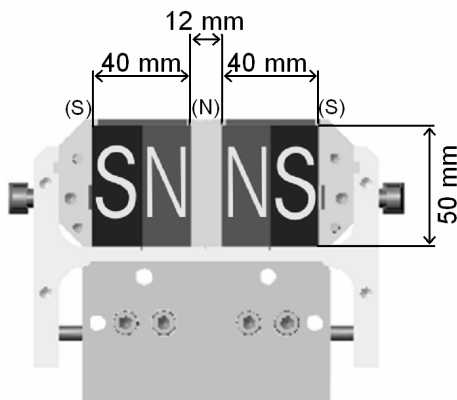


Figure 2: Cross section of a single magnetic track. Nd-Fe-B magnets with opposite magnetization (head-on) are mounted in the soft magnetic steel yoke.

Two rows of Nd-Fe-B permanent magnets with a size of $50 \times 50 \times 40 \text{ mm}^3$ are mounted in a soft magnetic steel yoke with head-on magnetization. In this arrangement, the soft magnetic steel in between and beside the permanent magnets acts as a flux concentrator. By this, a magnetic field of more than 1 Tesla at a distance of 0.5 mm above the track has been

achieved. At the working distance of 10 mm above the track, the magnetic field is about 0.5 Tesla, which is a good basis for an appropriate levitation force and sufficient stiffness.

Levitation and guidance forces were measured using a three-dimensional force measurement device. Fig. 3a shows the levitation force as a function of the distance between track and superconductor surface in the case of zero-field-cooling for a $90 \times 35 \times 15 \text{ mm}^3$ YBCO bulk sample at 77 K. With decreasing distance the force increases and reaches a value of 190 N at 8 mm distance by a vertical stiffness of 10 N/mm. Using 40 YBCO bulks of the same kind, as is done in the SupraTrans vehicle, a total weight of up to 800 kg can be carried. The stiffness in vertical direction is depending on the cooling position between 560 and 1000 N/mm and in lateral direction between 400 and 600 N/mm. (Beyer et al. 2004) Concerning this the vehicle could run with a speed of 60 km/h through a 10 m radius curve, hypothetical.

2.2 Propulsion and Positioning system

A linear motor will drive the demonstrator with a maximum acceleration of 0.5 m/s^2 . The linear drive works in an asynchronous mode, so that both, the stator and the rotor are supplied with a three-phase current. For the stator, the European standard three-phase current of 50 Hz, 380 V is applied, leading to a traveling field of constant amplitude and wave velocity. The wave velocity is given by:

$$v = 2 \tau_p \cdot f_N = 3.6 \text{ m/s} = 12.96 \text{ km/h} \quad (1)$$

where τ_p , the distance between the magnet poles in the stator, equals 36 mm. The speed of the vehicle is determined by the difference of the wave velocities of the stator and the rotor. It can be adjusted by the speed control on the vehicle, which sets the frequency of the three phase current in the rotor coils. Depending on phase direction and frequency, the vehicle can stop, break or accelerate to a velocity even higher than the fixed wave velocity of the stator field. The information about the phase shift of the traveling field, which is necessary for generating the corresponding rotor current is obtained by Hall sensors mounted on the vehicle and placed in the air gap of the stator

2.3 Operational concept

Following the aim of the SupraTrans project, to prove the concept of a superconducting magnetic levitation train, the operational concept supports demonstration and testing of the interplay of all technical components. Thereby, the vehicle motion

is controlled by the vehicle itself or by an operator sitting on the vehicle. This is in contrast to operational concepts of other modern transport systems (i.e., the Transrapid System) but exhibits the advantage of individually driven cars, which interact by the formation of a network of intelligent autonomous members

Table 1: Technical data of SupraTrans

guideway	
distance between magnetic rail mid points	575 mm
length of guideway	7 m
flux density at superconductor level	0.6 T
power consumption of drive	3.5 kVA
vehicle	
length	1322 mm
width	800 mm
mass when empty	170 kg
maximum payload	350 kg
energy storage	
voltage	42 V
capacity	67 F
energy content	59 kWs
maximum power consumption	700 W
distance between superconductor and magnetic rail	13...18 mm
constructive air gap between cryostats and magnetic rail	10...15 mm

3 THE TURNOUT SWITCH

3.1 Principle of the turnout switch

In order to draw maximum advantages from a non-contact transport system, a non-mechanical turnout switch for fast vehicle distribution would be favourable. Such a turnout switch has been constructed using electromagnets for the switching parts. The working principle is schematically shown in figure 3.

In this working principle, the rail is simplified by three magnetic poles. The switchable part consists of four magnetic poles generated by electromagnets. It is followed by five permanent magnetic poles, which in principle represent two rails, while the innermost magnetic pole is shared by both rails. One further extension to six poles completes the turnout switch (not shown in figure 3) by splitting off the inner part to two individual magnetic poles for each rail. As the part with four poles can be switched the turnout switch directs to either one or the other direction. Using this arrangement of permanent magnets and electromagnets it is possible to construct fast turnouts and intersections.

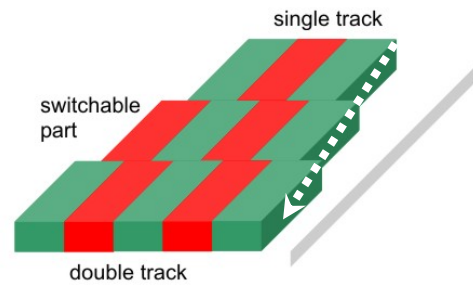


Figure 3: scheme of a fast electromagnetic turnout switch with an idealized way across the switch (dotted white arrow).

3.2 Experimental setup

The first experimental setup of such a turnout switch has been constructed for the toy-sized model train of IFW Dresden (Schultz et al. 2002) as shown in figure 4. For the electromagnetic switchable part, 3 coils are embedded in an iron yoke to form the magnetic field above the coils similar to the permanent magnetic track.

The coils are connected to an electric shunt which is supplied by three power supplies with a maximum power of 300 Watts. The shunt switches the connection of each coil to the relevant power supply. With this the distribution of the magnetic field above the iron yoke can be optimized by adjusting the current in each coil separately.

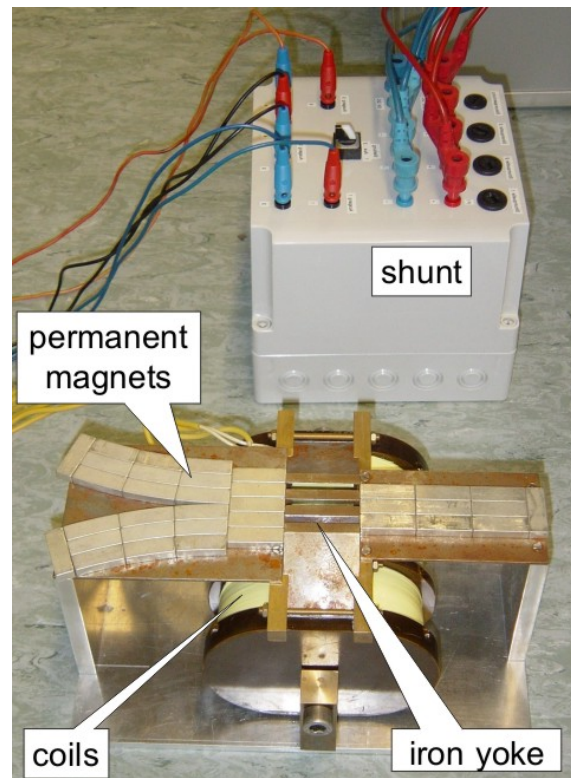


Figure 4: Experimental setup for experiments crossing an electromagnetic turnout switch.

3.3 Performance check of the turnout switch

A first qualitatively evaluation of the function of the electromagnetic turnout switch showed a proper working capability. For a detailed investigation of

the turnout switch measurements of the distribution of the magnetic field and the vertical and lateral forces have been performed.

The distribution of the magnetic field at the intersection from the permanent magnetic track to the electromagnetic part (figure 5) show a quite inhomogeneous behavior, which corresponds to the observed inhibitory effect of the turnout switch in moving direction.

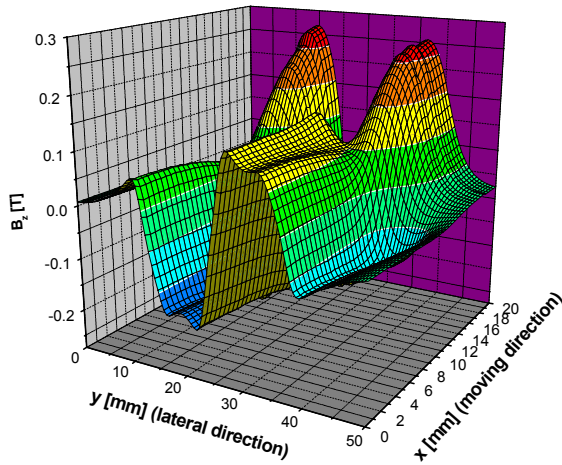


Figure 5: Distribution of the magnetic field above the magnetic track at the intersection between the permanent magnetic part and the electromagnets

To evaluate this inhibitory effect measurements of levitation forces and retarding forces in the moving direction have been performed whereas the movement of the superconductor corresponded to an idealized line to cross the turnout switch (dotted white arrow in figure 3). The levitation force (see figure 6) changes due to the inhomogeneity of the magnetic field along this line. In the diagram the distance s is corresponding to the position on the idealized line across the turnout switch, but not to the real way. The arrows are indicating the direction (forward and backward) across the switch.

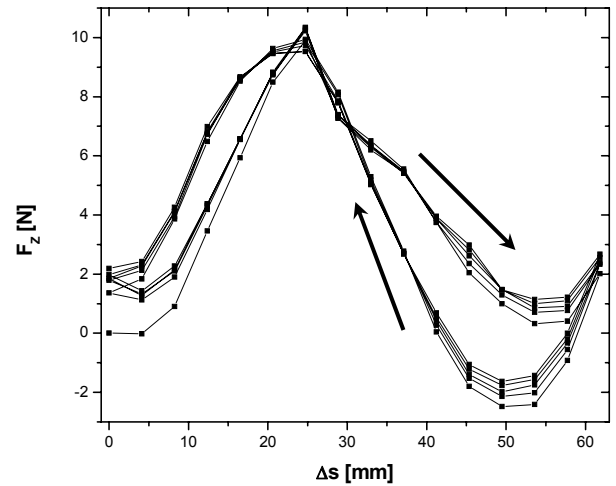


Figure 6: Levitation force depending on the position above the turnout switch following an idealized line; measured with a $35 \times 30 \times 15 \text{ mm}^3$ YBCO-Block cooled at 3.5 mm above the surface.

The slope of the graph is indicating a hysteretic behavior which is caused by moving flux lines due to the inhomogeneous magnetic field. Song et al. 2005 show, that these movement of magnetic flux lines can occur in a reversible mode (return after relaxation; no influence to levitation and guidance forces) or in an irreversible mode (no return; decrease in levitation force). The main object of further investigation will be to find out, if there is real decrease in the total levitation force after several crossings over the turnout switch.

Of much more interest than the levitation behavior is the retarding force in moving direction. It has been measured in the same way like the levitation force and is shown in figure 7, which displays the retarding force depending on the position above the turnout switch.

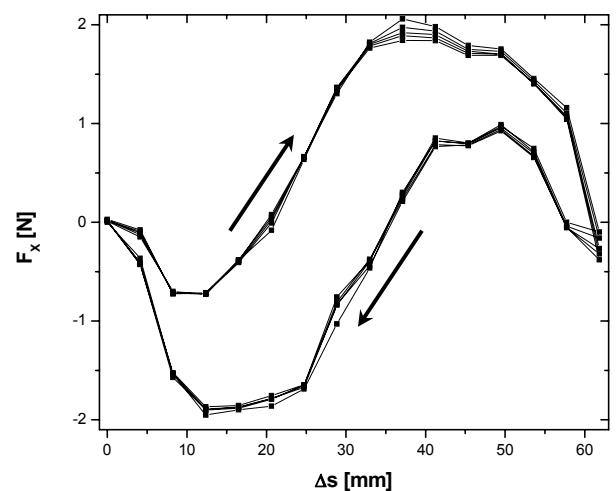


Figure 7: Retarding force depending on the position above the turnout switch following an idealized line; measured with a $35 \times 30 \times 15 \text{ mm}^3$ YBCO-Block cooled at 3.5 mm above the surface

It is obvious that there is again a hysteretic behavior indicating moving flux lines during the crossing over the switch. Compared to the slope of the graph of the levitation force in figure 5 it is a reversible process, because after several crossings the graph is almost overlaying itself and the points of reversal are similar. Also the slope shows a symmetry, that we conclude, it has no influence to a decrease in levitation and guidance force.

To assess the variation in levitation force and the retarding force a measurement of the levitation force has been performed to compare the crossing results with the stiffnesses of the entire system (figure 8). The stiffness above the permanent magnet is around 10 N/mm and above the electromagnets around 9 N/mm. Therefore a vehicle crossing the turnout switch will not get a perceptible displacement due to the inhomogeneous magnetic field in collaboration with an appropriate propulsion system like a linear motor.

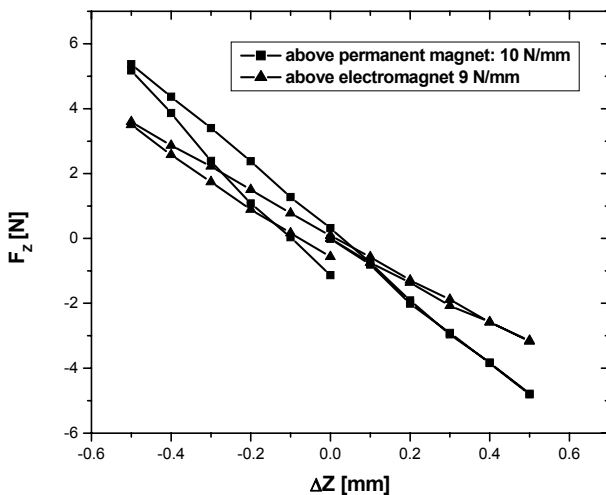


Figure 8: Levitation force depending on a vertical displacement of a $35 \times 30 \times 15 \text{ mm}^3$ YBCO-Block cooled at 3.5 mm above the surface; Stiffness [N/mm] calculated from the slope of the curve

4 SUMMARY

A new full working prototype for a magnetic levitated transport system based on the self stabilizing of a bulk superconductor has been developed and put into operation. It is a test facility to investigate the interplay between the levitation and guidance system and the propulsion and positioning system, and to optimize these components. On the other hand it is a sensational facility to demonstrate the appropriate capability of such a superconducting levitated transport system. To establish a highly branched transportation network a fast and complete non-mechanic turnout switch has been created and its capability has been tested. Due to the inhomogeneous magnetic field at the intersection between permanent magnets

and the electromagnet, the turnout switch shows a retarding behavior but no critical limits for levitation or guidance force.

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