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A superconducting levitation transport model system for dynamical and didactical studies

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Abstract

Superconducting levitation transport systems might become very attractive in the near future due to various reasons. The realisation of contactless systems allows e.g. extended maintenance-free operation with high efficiency since such a system only needs energy for cooling and propulsion.
We established a small superconducting levitation transport model system called "*SupraTrans Mini*" consisting of permanent magnetic rails and a levitated vehicle including four YBCO-bulk samples in a cryostat. The rail system consists of an oval shaped loop (2.90 m x 1.44 m), which was build up from individual linear and curved track modules. Inside the vehicle position variations of the superconductors are possible. By means of velocity, acceleration and temperature measurements different dynamical aspects of our complex levitation system can be investigated. We also show the broad applicability of the experimental setup for didactical studies in physics.

Keywords: levitation; high temperature superconductor; permanent magnetic rail; bearing conditions; YBCO bulks; large scale application

1. Introduction

New solutions for transport systems are essential for modern societies. A magnetic levitation system which only has to overcome air friction could demonstrate a way to use propulsion energy more

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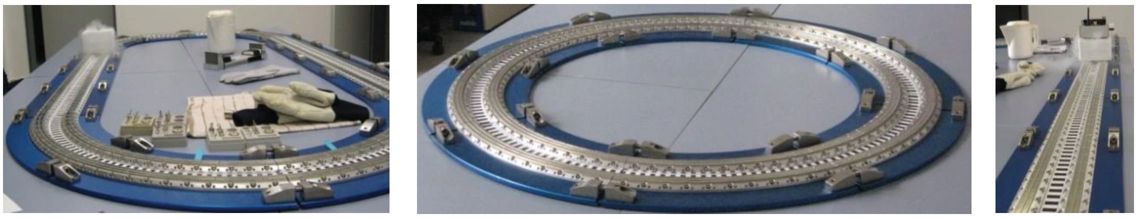
efficiently. Additionally the widely maintenance-free operation of this contactless system could minimize the maintenance costs. In contrast to the Maglev systems in Shanghai/China [1] and Japan [2] we investigate a levitation transport system based on High Temperature Superconductors (HTS) as bearing elements. The HTS bearings allow the operation with liquid nitrogen (LN_2). In addition this system can work at very low as well as high velocities due to its excellent passive physical levitation properties [3-5]. For the function of this system no additional levitation energy is necessary in contrast to the actively levitated commercial Maglev systems in China and Japan.

The principal function of a levitation transport systems based on HTS bearings was shown with the *SupraTrans Demonstrator* [6]. In this work we present a superconducting levitation model called *SupraTrans Mini* for dynamical and didactical studies.

The didactical dimension of our experimental setup is driven by the search for new teaching solutions to overcome the demotivation problems of pupils for physics. Nowadays the commitment of students for physics is unacceptably low, e.g. 45 % of grammar school pupils name physics as their most unpopular subject [7]. For this reason we developed a new teaching concept including the participation of pupils in research on HTS using the *SupraTrans Mini*.

2. Main aspects of the experimental setup

The magnetic levitation system is based on a modular oval round course with a length of 290 cm and a width of 144 cm (Fig. 1). The system includes 8 linear track modules with a length of 36 cm and 8 curve tracks, which can be mounted in different configurations (Fig. 1). The modules consist of aluminium plates (blue panels in Fig. 1) with two permanent magnetic rails mounted on top, whose geometries are shown in Fig. 2. The latter consist of stainless steel as the base for two rows of Nd-Fe-B permanent magnets magnetized horizontally in opposing direction. Fe sheets are mounted along the sides of the permanent magnets as magnetic flux line collector.



(a) (b) (c)

Fig. 1. Rail system of *SupraTrans Mini*: (a) complete oval course consisting of 16 modules; (b) round course only with the 8 curve tracks; (c) variant with the 8 linear tracks

The magnets used for the linear track have a size of (36 x 10 x 8) mm^3. The curve magnets are equal in width and height but four different radii from 470.8 mm to 569.2 mm are available. This geometry corresponds to the test drive facility *SupraTrans II* [8] in the scale of 1 : 12.5. Both concepts are based on the *SupraTrans I Demonstrator* [6].

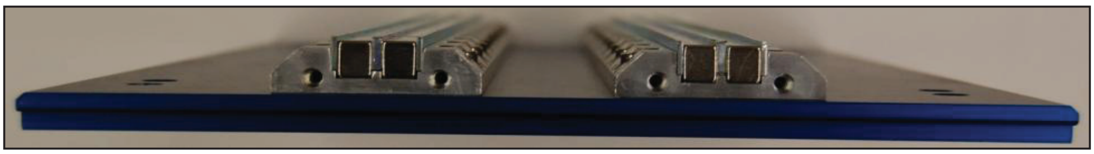
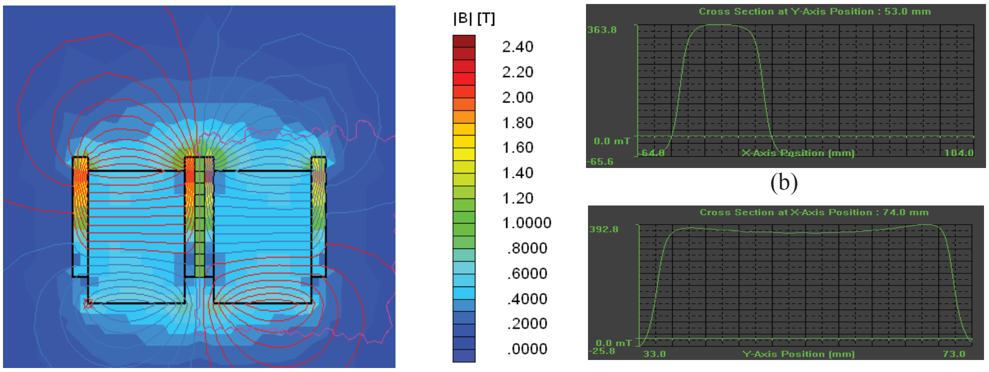


Fig. 2. Geometry of a complete linear track of the rail system of *SupraTrans Mini* in cross section view

The importance of the flux line collectors is visible from flux calculations performed with the magneto static solver FEMAG by Integrated Engineering Software (Fig. 3). The flux inside the magnets is homogenously distributed with a magnetic flux density around 0.4 T. Near the Fe sheets the calculated flux increases to approximately 2.0 T. This geometry allows the realization of very stable magnetic bearings for the HTS close to the permanent magnet system.



(a) (b) (c)

Fig. 3. (a) Calculated flux density in cross-section of the permanent magnetic rail system consisting of two rows of Nd-Fe-B magnet with horizontal and opposite magnetisation direction embedded in between three Fe sheets as flux lines collectors; (b) magnetic flux density measurement of one linear magnet across its width; (c) same measurement as in (b) across the length of the magnet.

Magnetic flux measurements at the surface of an individual magnet were performed with a Hall sensor mounted on a 300 mm x 300 mm areal scanner (MagScan by Redcliffe Magtronics Limited). The peak value of 0.39 T (Fig. 3b, c) is in good agreement with the theoretical values in Fig. 3a.

The main parts of the levitation vehicle are four $YBa_2Cu_3O_{7-\delta}$ (YBCO) bulk HTS mounted in a vessel filled with liquid nitrogen (LN_2). These (36 x 36 x 14) mm^3 sized YBCO bulks can be positioned in different configurations.

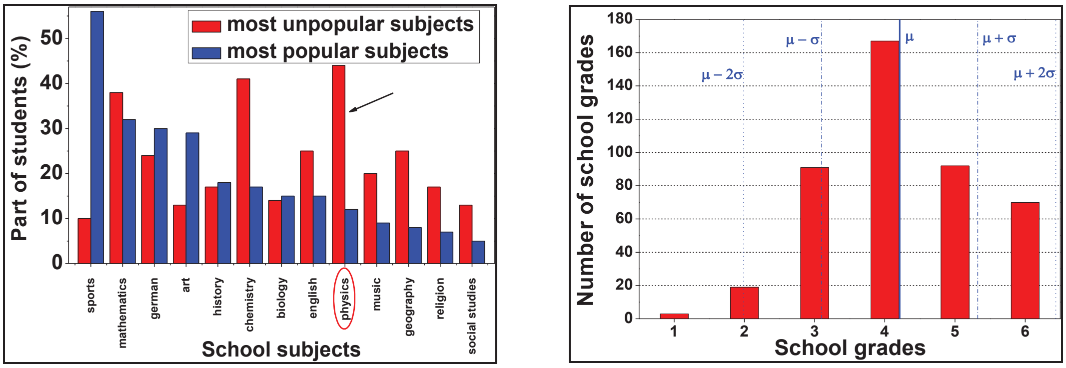
The measurement equipment is mounted inside the vehicle. This includes the electronic part with different sensors, a fit-PC2-C1600-W Embedded Server and an energy storage system. The electric power supply is realized by commercial lithium ion accumulators. The PC serves as a data collector and data processor. This Mini PC interacts with a normal notebook, connected to the vehicles PC via WLAN and virtual network computing software. Two data acquisition units (DAQ USB-6008 by National Instruments) provide 16 measurement channels to acquire all process data.

Sensors are installed for measuring vehicle velocity, HTS positions, acceleration, temperature and accumulator status. All sensor signals are converted into voltages for further processing by the USB-6008 modules.

3. Short overview of the didactical dimension of *SupraTrans Mini*

The motivation of pupils for physics in comparison with other topics was studied by Greck [9] and is presented in Fig. 4. The author asked 751 pupils at the age of 14 - 16 years about their favourite subjects. The result clearly demonstrates that physics is the most unpopular topic in school (Fig. 4a). This is also confirmed by an evaluation performed in an 11^{th} class of a grammar school (Fig. 4b). The pupils assigned school grades from 1 (very good topic) to 6 (dissatisfactory) to the subject physics. Since the mean value is 4.21, the motivation for physics is apparently very low.

For this reason we developed a new teaching concept including experiments of the pupils on the *SupraTrans Mini* as main part of the concept. Furthermore this three-modular teaching model is based on lectures of basic school physics and seminars with presentations and exercises.



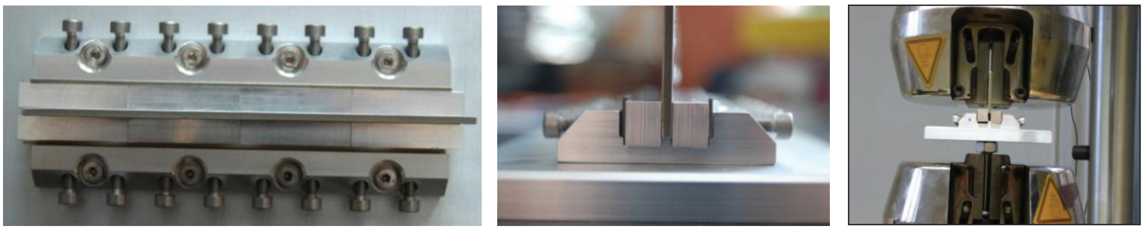
(a) (b)

Fig. 4. The role of school physics: (a) compared with other topics physics is the most unpopular subject [9]; (b) the mean value of 4.21 (presented at school grades) in an 11^{th} grammar school course shows the bad motivation situation for physics

This new concept was developed for a full school year and is based on fundamental principles of university teaching methods. It was tested with pupils of an 11^{th} course in a grammar school. More details of this teaching concept will be published elsewhere.

4. Measurements of the experimental setup

The properties of the permanent Nd-Fe-B magnets were presented in II. The opposing magnetization direction within the magnetic rows in each magnetic rail needs special holders with strong clamping capabilities. This capability was tested mechanically in a 14 cm long rail model of the *SupraTrans Mini* with eight magnet dummies and an extended Fe sheet clamped in between (Fig. 5a, b). The rail and the Fe sheet were mounted in a mechanical testing device (Fig. 5c) and a drawing experiment was conducted. A force of 5.20 kN was necessary to displace the Fe sheet from its clamped position (Fig. 6). This value guarantees the stability of the holder system.



(a) (b) (c)

Fig. 5. Mechanical check of the holder forces of a *SupraTrans Mini* rail model: (a) overview of the model; (b) cross section view of the model with the higher Fe sheet in the centre position; (c) the rail model in the check position: the Fe sheet in the middle were extracted

Also the bearing force by zero-field cooling in z-axis direction was measured for each superconductor in a force sensor device. The levitation force as a function of the gap size (distance *s* between rail and the HTS) is shown in Fig. 7. Considering the air gap between LN_2 vessel and YBCO bulk and the vascular wall thickness of the vessel of 1 mm each, a desired air gap between the rail system and the vehicle requires a minimum working height of 3 mm. This results in maximum bearing force of around 20 N for each HTS. In real operation the cooling process in the magnetic field of the rails takes place at a distance of minimum 4 mm for the whole vehicle with all components. Thus, the maximum bearing force amounts to approximately 60 N for all four YBCO superconductors of the vehicle. Compared with the whole mass of the vehicle of around three kilograms in the working modus the levitation status can be easily realised.

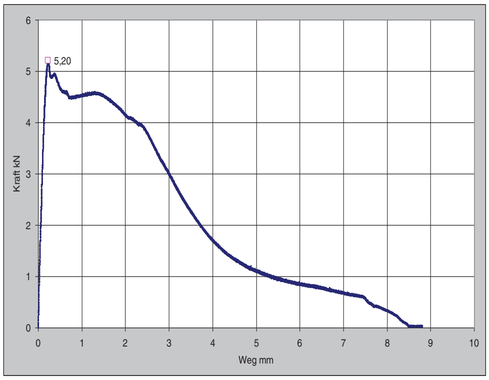


Fig. 6. Measurement of the mechanical stability of the holder system of a *SupraTrans Mini* rail model

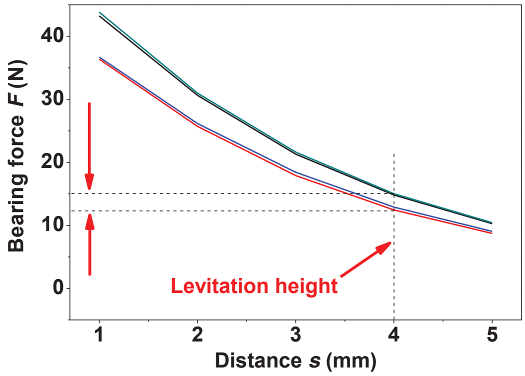
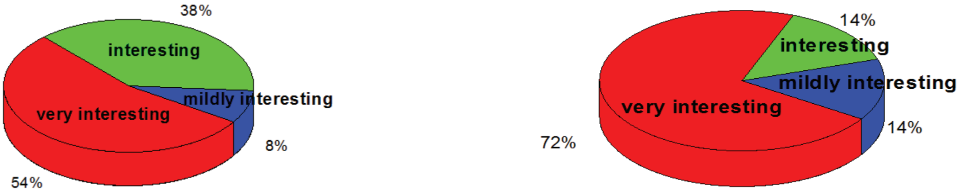


Fig. 7. Bearing force between magnetic rail and the four YBCO superconductors in dependence of the levitation distance

5. Some didactical results

The main part of didactical investigations was the development of pupil's motivation for physics. We focused on the pupil´s experiences on the superconducting levitation system. Each group had to work minimum three times in the whole school year on the experimental setup of *SupraTrans Mini*. After each experimental session they were asked by special questionnaires. The main result is the increase of motivation concerning the different experiments on *SupraTrans Mini* (Fig. 8).



(a) (b)

Fig. 8: Development of pupils physics interest due to the work on the levitation system (a) after the 1st experiment and (b) after the 3rd experiment

The interest for work with the levitation system increases from the 1st to the 3rd experiment during the school year. In particular, 54 % of pupils name the work on *SupraTrans Mini* very interesting after the 1st experiment, but this number increase of 72 % after the 3rd experiment. This result shows the important role of participation of pupils in modern research areas. More didactical results are published elsewhere.

Summary

We presented a 290 cm x 144 cm superconducting levitation transport device called *SupraTrans Mini* as a model of the test drive facility *SupraTrans II*. This system consists of 16 modules of permanent magnetic rails with more than 600 Nd-Fe-B – magnets and a vehicle including four YBCO bulks (36 x 36 x 14) mm^3 cooled with LN_2. Various electronic equipments allow measurements of the vehicle`s velocity, acceleration and temperature. Furthermore it is possible to measure the individual rotating positions of the HTS inside the vehicle. This experimental setup can be used for different dynamical and didactical investigations. Mechanical measurements showed the high stability of the magnetic rail holder system. Only a minimum drawing force of 5.2 kN displaced a Fe sheet from the rail system. Investigations of the bearing force of the YBCO bulks in dependence of the levitation distance showed the easily levitation behaviour of our system. In a working distance was measured an additional bearing force for all HTS of around 60 N. Dynamical and didactical studies with this experimental setup are possible.

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