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Guideway and turnout switch for the SupraTrans project

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Abstract. This paper will deliver insight into technology and physics of the levitation system for the SupraTrans project, a prototype of a superconducting transportation system. The technology used herein bases on the flux pinning in melt-textured bulk $YBa_2Cu_3O_{7-X}$ (YBCO) that stabilizes the lateral and the vertical position of the vehicle above the magnetic track. A track made from permanent magnets and soft magnetic steel-yokes acting as flux collectors has been designed and its capability is presented. The concept also includes a fast electromagnetic turnout switch to establish a highly branched transportation network.

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1. Introduction

The stable levitation of bulk high temperature superconductors (HTS) in an inhomogeneous magnetic field has a high potential for the application in magnetic levitation systems, such as frictionless bearings [1, 2], flywheel energy storage systems [3] and linear transportation systems [4, 5]. As a consequence of the enormous efforts that have been made for the development of bulk HTS materials, the fabrication and processing of these materials is mastered. Thus, bulk HTS materials with a high critical current and a high trapped magnetic field are presently available [6, 7, 8].

The development and fabrication of a working prototype of a superconducting transport system is the aim of the SupraTrans project. It is a joint venture between a research institute, the IFW Dresden, universities, the Dresden University of Technology and the University of Applied Sciences Dresden, industrial companies, ELBAS GmbH-railway consulting and engineering, Baumüller Kamenz-linear drives and CIDEON engineering Bautzentechnical engineering, and the Dresden Transportation Company, DVB. Flux pinning in melt textured bulk $YBa_2Cu_3O_{7-X}$ (YBCO) is the basis of the levitation of the vehicle and is also responsible for the lateral and vertical stability of the vehicle above the magnetic track. This so called self-stabilization is the main advantage of superconducting levitation in comparison to conventional magnetic bearings, used, for instance, in the Transrapid-technology, which needs an electronic control system to keep a constant distance between the vehicle and the track. Permanent magnets have been used for the prototype rail with a length of 7 m. The rail consists of two single magnetic guide tracks. According to first experiments a total load of almost 800 kg will be possible to carry.

A contact-free transport system has several advantages. For example no abrasion due to mechanical contacts will take place, which is advantageous for transport systems in clean rooms. In consequence all components especially the turnout switch have to be contact-free and nonmechanical. Therefore electromagnetic components will be used instead of mechanically driven components. Furthermore, these turnout switches can be switched very fast, allowing a highly branched network, which is still easy to control.

2. The permanent magnetic track

The levitation forces generated in bulk YBCO superconductors by a constant magnetic field depend on the field strength and its gradient [9]. Based on investigations on a toy-sized model levitation train [4], a double track has been constructed. The track is made from Nd-Fe-B permanent magnets and soft magnetic steel-yokes, working as flux collector to enhance the magnetic field [10].

2.1. Design of the track

Due to the size of the melt-textured YBCO superconductors of 90 × 35 × 15 mm^3 [11], the width of a single track is set to 90 mm. The design of the track has been optimised using the QUICKFIELD™ software for a two dimensional finite element simulation and the AMPERES software for a three dimensional boundary element simulation. Two Nd-Fe-B permanent magnets having a size of 90 × 35 × 15 mm^3 are mounted in a soft magnetic steel yoke with the magnetic north poles facing each other. In this arrangement the soft magnetic steel in between and beside the permanent magnets acts as a flux concentrator and a magnetic field of more than 1 Tesla at a distance of 0.5 mm above the track has been achieved (see figure 1). At a working distance around 10 mm above the track the magnetic field is about 0.5 Tesla, ensure appropriate levitation force and stiffness.

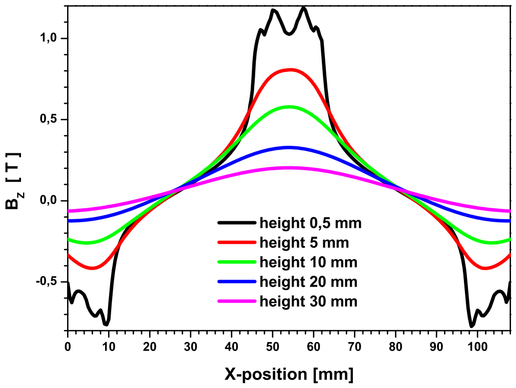

Figure 1. Horizontal distribution of the vertical component of the magnetic field in different distances above the permanent magnet track.

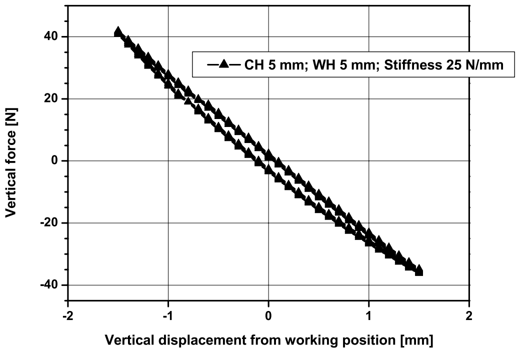

Figure 2. Vertical forces caused by a displacement around the working position; the stiffness is calculated from the slope of the force curve (CH = cooling position; WH = working position).

2.2. Levitation force and stiffness

With a three dimensional force measurement device, the vertical levitation force and the lateral guidance force were measured. For a single 90 × 35 × 15 mm^3 mm bulk YBCO sample at 77 K a levitation force of nearly 200 N at a distance of 8 mm and a vertical stiffness of 10 N/mm has been measured and was reported already [12]. Using 40 pieces of these bulk YBCO samples for the vehicle, a total weight up to 800 kg can be carried.

Beside the levitation force, the stability of any position is of high interest. For a technical application the superconductor will be cooled below the critical temperature at a certain position above the track and the magnetic field generated by the magnets in the track will be pinned within the superconductor. This "field-cooled mode" causes higher lateral and vertical stiffnesses than the zero-field-cooled mode. Figure 2 shows a levitation force curve based on a cooling height (CH) of 5 mm above the track at a working height (WH) of 5 mm above the track.

Table 1. Vertical and lateral stiffnesses for different combinations of WH and CH.

CH [mm]	WH [mm]	Vertical Stiffness [N/mm]	Lateral Stiffness [N/mm]
5	5	25	15
10	10	14	10
15	15	9	7
20	15	10	6
35	15	10	6

The stiffnesses are obtained from the slope of the force curves realizing displacements around the working position. The higher stiffness observed at a smaller distance above the track is caused by the higher field at the surface (see table 1). Furthermore, the vertical stiffness of the vehicle can be enhanced by moving the vehicle to a certain working position from a higher cooling position. A slightly different behaviour was observed from measurements of the guidance forces in lateral direction (see also table 1). High lateral forces occur at low cooling positions. However, moving to a certain working position from a higher cooling position lowers the guiding force. From these two results an optimum working position for appropriate levitation and guidance forces could be found.

3. Turnout switch

To create a new transport system, it is essential to develop facilities for vehicle distribution. To maintain the advantages of a non-contact system, a non-mechanical turnout switch based on electromagnets has been constructed. On this basis it is possible to construct a magnetic levitation system for a fast distribution system. This includes a very short switching time as there are no limits due to mechanical movements. The working principle is schematically shown in figure 3. The rail is simplified by three magnetic poles. The switch itself is built from four magnetic poles generated by electromagnets that can be switched. This switchable part is followed by five magnetic poles, which in principle represent two rails, as the innermost magnetic pole belongs to both rails. One further extension to six poles where the two innermost poles show the same polarity completes the turnout switch (not shown in figure 3). As the part with four poles can be switched the turnout switch directs to either one or the other direction. Utilizing this arrangement of permanent magnets and electromagnets it is possible to construct fast turnouts and intersections. Figure 4 shows the experimental set-up for a electromagnetic turnout switch.

4. Summary

A new track for a superconductively levitated transport system has been constructed and mounted. The track is made from head-on magnetized Nd-Fe-B permanent magnets mounted in a soft magnetic steel-yoke. A total load of to 800 kg can levitate in an appropriate distance above the track at proper vertical and lateral stiffnesses. An electromagnetic turnout switch has been constructed to realize a fast vehicle distribution without any mechanical movements.

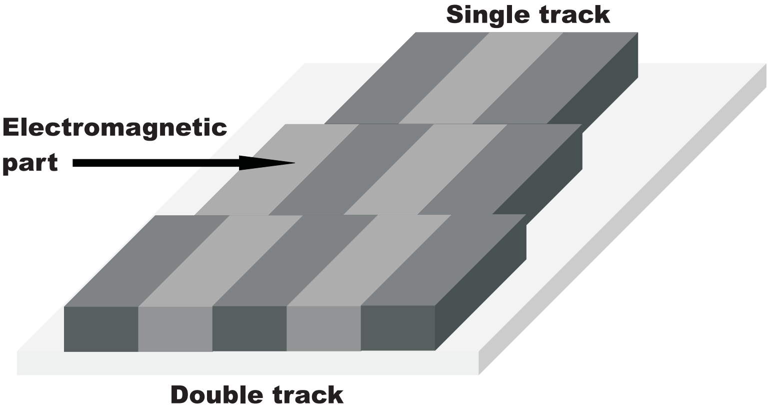

Figure 3. The scheme of a fast turnout switch. Depending on the magnetization of the electromagnet the direction of the rail can be controlled (moving direction to the right in the shown case).

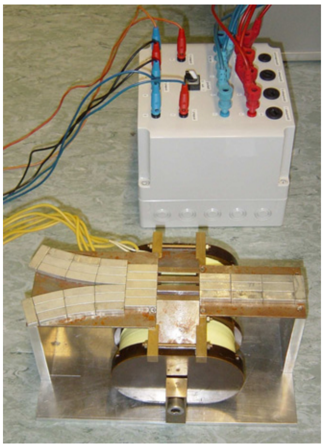

Figure 4. Toy sized model for a fast turnout switch driven by electromagnets connected to a changeover contactor.

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