Design of the Guideway 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 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.

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 [6-8].

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 Bautzen–technical engineering, and the Dresden Transportation Company, DVB.

Flux pinning in melt textured bulk 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.

In a first step, permanent magnets will be used for the prototype rail with a length of 7 m. The rail is built up from two single magnetic guide tracks. According to first experiments a total load of almost 800 kg will be possible.

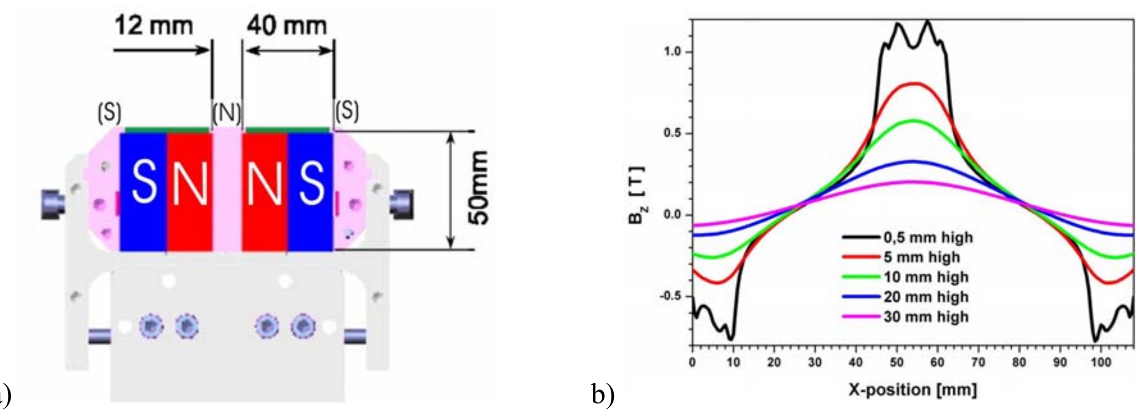
A contact-free transport system has several advantages. For example no abrasion due to mechanical contacts will take place, which is advantageous for transport systems in clean rooms. In consequence all components especially the turnout switch have to be contact-free. Therefore electromagnetic components 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 YBaCuO 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].

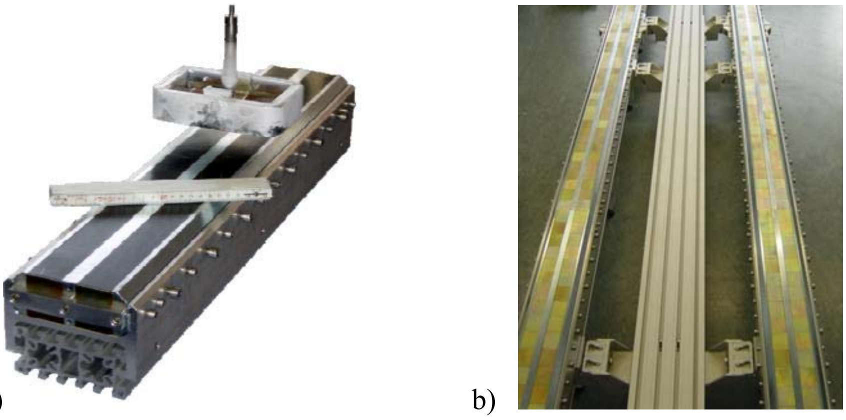
2.1 Design of the track

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. Figure 1a shows the cross section of a single track. Two Nd-Fe-B permanent magnets with a size of 40×50×50 mm^3 are mounted in a soft magnetic steel yoke with the magnetic north poles facing each other (see figure 1a). 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 1b). 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 stiffness. Figure 2 shows a single track of a length of 70 cm as well as the rail made from two single tracks.



a) b)

Figure 1 Cross section of a single track
(a) head on magnetized permanent magnets (red-blue) in a soft magnetic steel yoke working as flux concentrator (pink)
(b) horizontal distribution of the vertical component of the magnetic field in different distances above the permanent magnet track



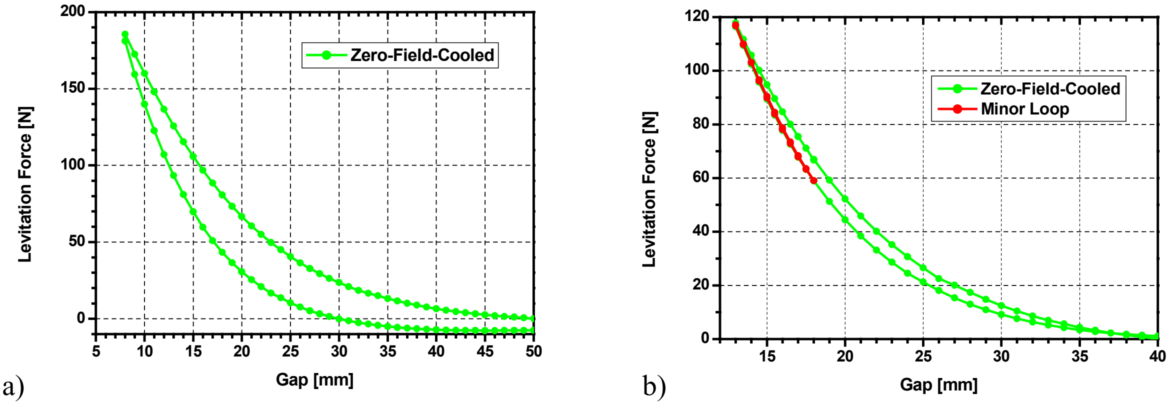
a) b)

Figure 2 (a) 70 cm long single track segment with a levitating bulk YBCO in LN_2 – bath
(b) rail made from two single tracks for the SupraTrans demonstrator

2.2 Levitation force and stiffness

With a three dimensional force measurement device, the vertical levitation force and the lateral guidance force were measured.

Figure 3a shows the levitation force depending on the distance between the track and the superconductor surface in zero-field-cooled mode for a single 90×35×15 mm bulk YBCO sample at 77 K. In this case, the superconductor is cooled below its critical temperature at a high distance above the track in a zero-field position and then moved into the magnetic field above the track. At a distance of 8 mm a levitation force of nearly 200 N and a vertical stiffness of 10 N/mm has been measured. Using 40 of these bulk YBCO samples for the vehicle, a total possible weight of up to 800 kg can be carried. The curve shows a hysteretic behaviour of the levitation force due to the shift of the magnetic field within the superconductor. This results in a lower levitation force caused by energy dissipation.



a) b)

Figure 3 Levitation force
(a) measured in zero-field-cooled mode for a single 90x35x15 mm^3 bulk YBCO superconductor. The measurement starts at a height of 50 mm above the track, then the distance is reduced to 8 mm and later on increased again to the initial position.
(b) measured in zero-field-cooled mode for a single 90x35x15 mm^3 bulk YBCO superconductor. In this case the initial position of 40 mm is reduced to 13 mm. Before increasing the distance a minor loop to 18 mm and back to 13 mm was made.

The situation during a load change is shown in figure 3b. In the according experiment the superconductor has been moved from the cooling position to a working position. From that position the distance is lowered to 13 mm. A minor loop was performed, where the distance is increased to 18 mm and lowered to 13 mm again. Within that loop of 5 mm a change in the levitation force of 60 N is observed for a single bulk YBCO sample. When scaling up this force for a vehicle built from 40 YBCO samples a change of the load of about 200 kg can be expected. Within the minor loop no hysteretic behaviour of the levitation force can be detected. Thus, no flux creep within the superconductor occurs, the system is in an elastic state and the cycles of loading and unloading are reversible.

Beside the levitation force, the stiffness in any position is of high interest. For a technical application the superconductor will be cooled below the critical temperature in 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. In figure 4, a collection of levitation force curves in different positions above the track, is shown. The cooling position is denoted by CH and the working position by WH. The stiffnesses are obtained from the slope of the levitation 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. Furthermore, the 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 figure 5). 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 has to be found.

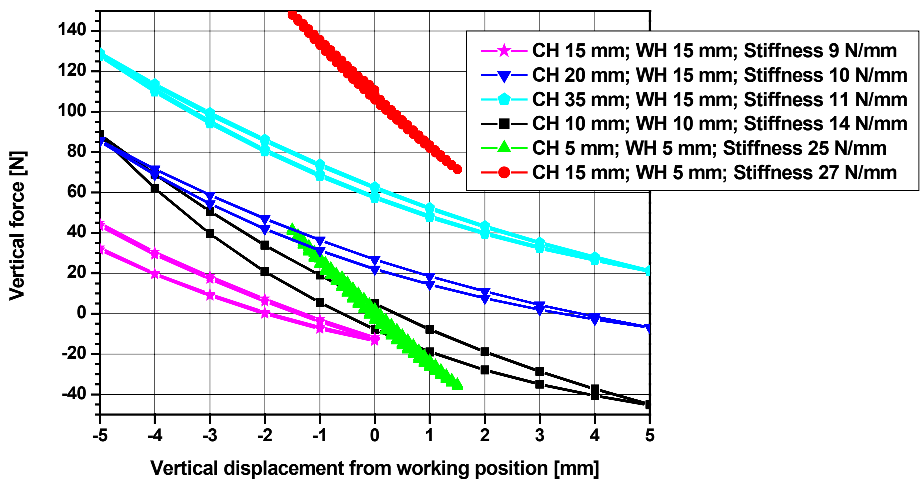


Figure 4 Vertical forces caused by a displacement around the working position; stiffnesses calculated from the slope of the force curve (CH = cooling position; WH = working position)

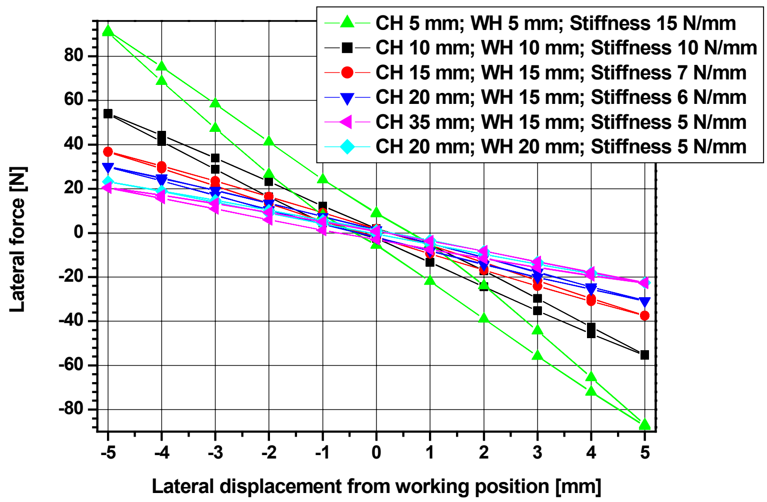


Figure 5 Lateral forces caused by a lateral displacement around the working position; stiffnesses calculated from the slope of the force curve (CH = cooling position; WH = working position)

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 6. The rail is simplified by three magnetic poles. The switch 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 6). 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.

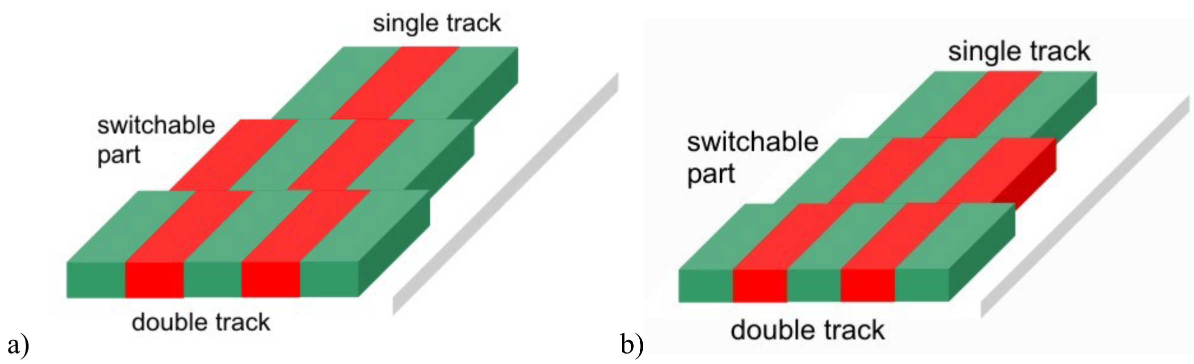


Figure 6 The scheme of a fast turnout switch.
Depending on the magnetization of the electromagnet the direction of the rail can be controlled:
(a) moving direction to the right
(b) moving direction to the left

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 up to 800 kg can levitated 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.

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