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Bulk superconductors in mobile application

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Abstract

We investigate and review concepts of multi – seeded REBCO bulk superconductors in mobile application. ATZ's compact HTS bulk magnets can trap routinely 1 T@77 K. Except of magnetization, flux creep and hysteresis, industrial – like properties as compactness, power density, and robustness are of major device interest if mobility and light-weight construction is in focus. For mobile application in levitated trains or demonstrator magnets we examine the performance of on-board cryogenics either by LN_2 or cryo-cooler application. The mechanical, electric and thermodynamical requirements of compact vacuum cryostats for Maglev train operation were studied systematically. More than 30 units are manufactured and tested. The attractive load to weight ratio is more than 10 and favours group module device constructions up to 5 t load on permanent magnet (PM) track. A transportable and compact YBCO bulk magnet cooled with in-situ 4 Watt Stirling cryo-cooler for 50 – 80 K operation is investigated. Low cooling power and effective HTS cold mass drives the system construction to a minimum – thermal loss and light-weight design.

Keywords: Mobile application; trapped field; magnetic bearings; maglev train; levitation; cryogenics;

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1. Introduction

High-Tc superconductors can contribute to energy efficiency, primarily reducing the dissipation and losses in electric machines motors and generators, magnetic bearings and flywheels, in electric grids and transportation. Magnetic levitation with bulk superconductors has been widely tested and evaluated as rotational bearings for flywheel stabilization and linear transport systems. In most application the superconductor systems are used site – specific without any preparation and construction for mobility.

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The biggest worry for all superconducting mobile systems is the *refrigeration system*. In addition, a robust and safe construction is an ultimate requirement.

We have continued our design and construction progress of axial magnetic bearings for magnetic platform demonstration from 200 – 1000 N. In part of the smaller platforms the ability of cryogenics with a Stirling cooler is tested. This needs an extreme low thermal loss design of the cryostats. On the other hand, if LN_2 cooling is selected a good thermal insulation and a LN_2 storage capacity of a few liters allow to reduce the cryogenic service period to once per three days.

Fig. 1. Mobile HTS magnet platforms with LN_2 and Stirling cryo-cooler (right).

While in HTS platform demonstrators the system mobility is optional people and goods transportation systems on magnetic guideway require well designed and technically optimized vehicles of high mobility containing bulk superconductors. Most prominent are magnetic levitated (Maglev) trains which operate self-stabilized keeping the free-space distance to the guideway without any electronic control systems and following only the physics of superconductor – magnet interaction. After the first man-loading train vehicle [1, 2] about one decade before the inherent physical Maglev parameters like the optimal magnetic guideway [3, 4] or propulsion and vibration/ damping has been investigated and improved.

Maglev however is not confined to vehicle or train operation. Concepts for bulk levitation launch units have been proposed to reduce the launching cost for rockets to get in space. Simultaneously magnetic levitation can assist in electromagnetic rail gun systems.

The present study analyzes the characteristics of *mobile* superconducting levitated bearing and train. We evaluate the optimal magnetic excitations systems and describe the designed and constructed vacuum cryostats with well insulated bulk superconductors inside. We produced magnetic platforms with LN_2 and Stirling cooler cryogenics which can operate without service three days (LN_2) or continuously at temperatures between 40 and 50 K (Stirling). More than 30 Maglev vacuum cryostats we fabricated for assembling magnetic levitated vehicles of a magnetic train. The key parameters are good levitation to weight ratio of more than 10, a narrow magnetic gap of 2 mm and a low thermal loss behavior of 2.5 Watt under mobile conditions on a guideway.

2. Bulk material characterization

Superconducting materials for mobile devices are selected for large- area melt textured YBCO bulks. Multi-seeding growing technology has been favoured and performed. Because the superconducting and magnetic properties vary strongly with the position on a sample the performance of the total sample is important when applications are concerned. The seed crystals are placed on the top surface of the pressed YBCO samples followed by the heat treated melt processing route. With the top seeding technique high quality superconducting magnetic material in blocks of circular or rectangular geometries up to 100 mm can be fabricated. Therefore, the bulks must be machined, assembled, and glued into the desired shape.

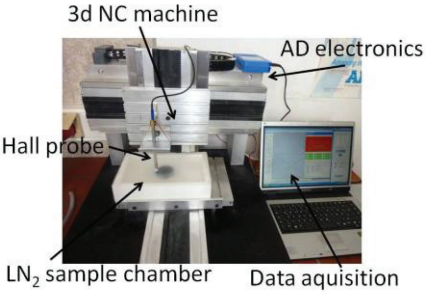

Fig. 2. Scanning Hall trapped field measurement equipment.

Sample characterization is performed using on-line scanning Hall measurements by a new high-precision measuring set-up shown in figure 1. The flat surface position of the sample is controlled during the measurement. Magnetic excitation is obtained by a Weiss magnet with maximum flux of 1.45 T. For larger Fe pole shoes (up to 100 mm) is excitation field is reduced. Between excitation and trapped field measurement we wait typically 30 minutes to achieve flux relaxation. Single grain samples are grown up to 56 mm diameter. Our 3-seed samples have a typical as –grown geometry of 67 mm x 34mm x 14 mm. For precise assembling in magnetic application cryostats the size is milled with numerical machines and diamond cutting tools to 64 x 32 x 13 mm³ with a precision of 0.1 mm. In contrast to single-grain cylindrical samples the exact lateral orientation of the SmBCO seeds is essential for the final superconducting properties of the GB's [5]. Largest multi-seeded YBCO samples consist of up to 8 grains with a total site of about 100 mm x 60 mm x 20 mm. Fig. 2 displays single, 3-seed and 8-seed trapped flux measurements. At 0.5 mm Hall probe distance maximum trapped field values of 1.2 T@77 K (1.45 T excitation) are obtained (Fig. 2). The trapped field measurement shows two interesting feature. The critical current density Jc which is related to slope gradient of the flux distribution is in the sample centre higher than at larger distances from the center. The precisely measured trapped flux distribution deviates from a symmetric cone shape to a fourfold edge-like peak geometry indicating a higher current density along the sample growth sectors. This result is consistent with recently investigated YBCO bulk samples.

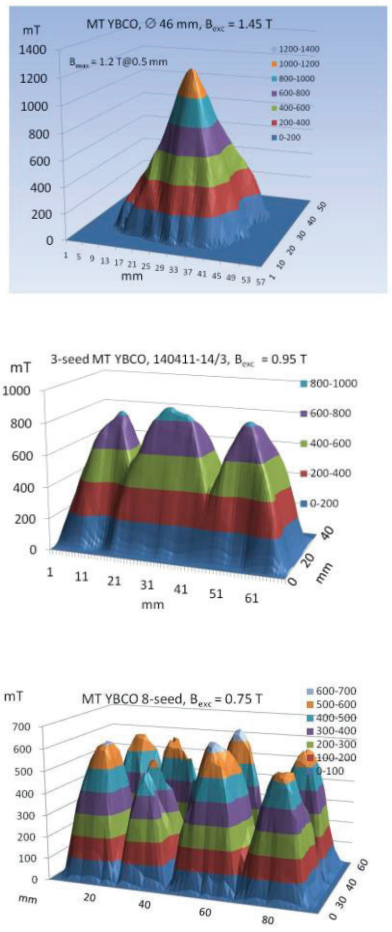

Fig. 3. Trapped field measurements of single, 3- seed, and 8- seed YBCO bulks.

3. YBCO platform design and construction

HTS bulk magnetic experiments are performed usually by cooling the bulks with LN_2 in open vessels or container thermally insulated by Styrofoam or comparable material. Because of the worse thermal long- time insulation the container are covered with frozen layers of moisture. The corresponding loss of liquid cryogenics enhances the necessary cooling effort, usually by refilling LN_2 into the HTS container periodically. Therefore, many industrial customers were concerned about cryogenics realization if HTS (or LTS) applications are considered and planned.

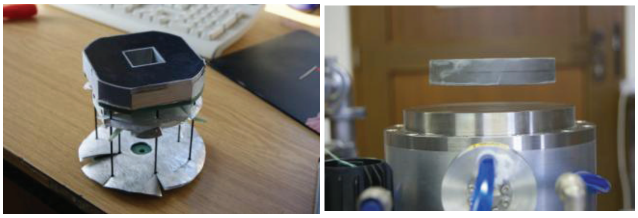

Fig. 4. YBCO part of the magnetic platform and PM levitation experiments.

An alternative solution for Maglev application is the using of *vacuum cryostats* shown in figure 1 reducing the cooling effort and increasing the overall efficiency. ATZ has developed several types of compact and mobile vacuum cryostats for magnetic levitation experiments. A long time we are searching and constructing technical improvements in refrigeration systems, which must combine extreme reliability with light weight for optimum performance. One striking feature in designing mobile cryostats is the reduced or completely omitted application of stainless steel because of weight.

Figure 4 displays the YBCO bulk assembly with part of the supporting G- 10 structure. The complete YBCO is mounted in the vacuum cryostat of figure 1 (bottom). The superconductor consists of four 3-seed melt textured bulk with a trapped field distribution displayed in figure 3. The residual thermal loss under cryo- cooler operation is less than 0.3 W@65 K. Because the platform use should be flexible in handling and mobile in transport a commercial Stirling cryo-cooler (AIM SL 400 B, AIM Corp. Heilbronn, Germany) was adapted to the YBCO desk by the cold head and provided the cryogenics of the platform. The Stirling- cooler was attached with an additional self – constructed water cooling system to reduce the temperatures on the compressor and on the warm side of the cold head. Due to this the performance of the Stirling machine could be further increased.

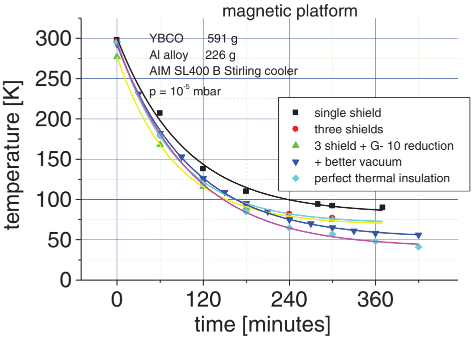

Fig. 5. Recorded cooling – down of the platform with Stirling AIM SL 400 cryo-cooler.

Even the nominal cooling power with 3.5 W@80 K of the Stirling cooler AIM SL 400 B was relatively low the recorded cooling - down curves of the platform in figure 5 indicate superconductivity after about four hours cooler operation.

4. Maglev cryostat

Bulk superconducting Maglev trains in demonstrator versions have been designed and fabricated in the last 10 years, mostly with short magnetic guideway (L < 10 m). The magnet design of the rail determines the levitation force. The vertical forces are generated by a field -cooled process at distances of 30 – 20 mm. Under load the gap is decreasing to about 10 mm above the PM guideway. Axial magnetic stabilization possesses generally low stiffness and hence low guidance forces perpendicular to the rail direction. Improvements are desired in three directions: (i) an efficient magnetic guideway design, (ii) high quality superconductor material, (iii) a perfect HTS cooling in a cryostat with low excitation distance and long-time operation.

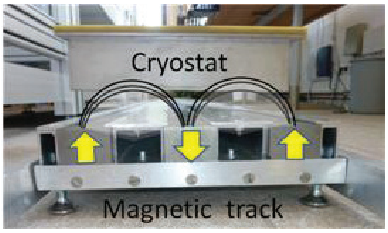

Fig. 6. Maglev cryostat in test on magnetic track

Finite element models (FEM) contribute to optimize magnetic guideways. Although the PM rail can be assembled with one or two rows of magnets with upward magnetization, better rail performance is obtained by collecting and biasing the magnetic flux using soft iron. Further on, improvements and advantages are obtained by the magnetic Halbach configuration. Here the Fe collectors are totally (full Halbach) or partial replaced by PM (partial or semi Halbach) with a magnetic polarization in the direction of the magnetic flux flow. This magnetic configuration generates a sinusoidal magnetic flux distribution over the rail cross section.

More than 30 superconductor cryostats are manufactured and tested. The attractive load to weight ratio is more than 10 and favors group module device constructions up to 5 t load on permanent magnet (PM) track. Inside of each cryostat 24 pieces of 3-seed YBCO bulks are glued and mechanical fastened in a copper holder. The total HTS area is about 490 cm² per cryostat. The superconductors are conduction cooled using LN_2 which is stored in chamber of the cryostat. The distance between the YBCO surface and the outer cryostat bottom is 2 mm only. This short magnetic distance allows large levitation forces respective a high load capacity. Each cryostat can provide magnetic levitation forces of 2.5-3 kN. The 2.5 liter LN_2 storage capacity ensured a one-day operation without refilling. Measurements give a thermal loss of less than 3 W per cryostat even under high mobility conditions.

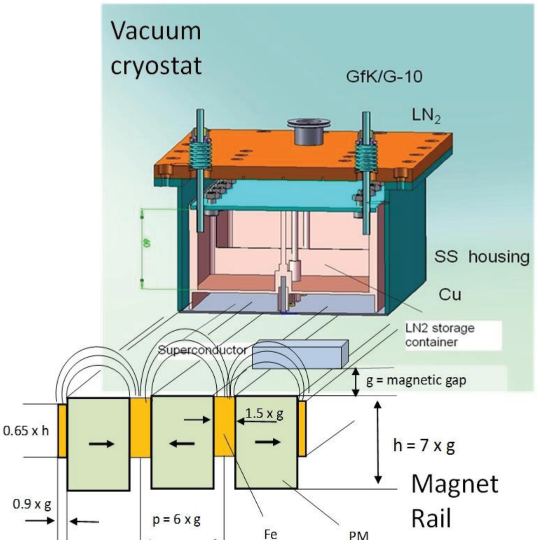

Fig. 7. Maglev cryostat and magnetic rail design.

5 . Conclusions

Bulk superconductors in mobile applications are investigated and technical solutions constructed. Substantial concerns about safe cryogenics, reliable construction and robustness of superconducting mobile devices could be debilitated by design and experiments. Vacuum cryostats are excellent housings for superconductors in magnetic application. LN_2 and Stirling cooler cryogenics in magnetic platforms has been demonstrated for reliable cooling during days or continuously. With a perfect thermal insulation a 4 Watt Stirling cryo-cooler achieved temperatures of 0.8 kg cold mass in the 40 K level after 5-6 hours. Superconducting magnetic train levitation could be updated with light-weighted YBCO containing cryostats. Both the force to weight ratio of more than 10 as well the 2mm magnetic distance between the cold YBCO surface and the outer stainless steel are technical highlights. The Maglev cryostats have a one- day operational time window with the on-board stored 2.5 l LN_2.

Acknowledgments

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