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A small Maglev car model using YBCO bulk superconductors

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Abstract
Models of two small Maglev cars have been made. The track was paved with NdFeB magnets. The arrangement of the magnets made it easy to get a uniform magnetic field distribution along the length of the track and a magnetic field gradient in the lateral direction. When the car with YBCO bulk superconductors was field cooled to LN_2 temperature at a certain distance above the track, the car could be automatically levitated over the track and moved along the track without any obvious friction. The model can be used to demonstrate the Meissner effect and a fast transportation system to students and adults.

1. Introduction

Melt texturing growth (MTG) [1, 2] is one of the most important and effective ways to fabricate high quality YBCO bulk superconductors with a high levitation force at 77 K. The high levitation force makes possible various applications such as magnetic bearings [3, 4], flywheels [5, 6], levitated transportation systems [7–9] and motors or generators [10], but the application is mainly dependent on the quality of the YBCO bulk superconductors. The stable levitation system between YBCO bulk superconductors and permanent magnets shows a greater attraction than that of an unstable levitation system between a pair of permanent magnets.

The levitation force between a YBCO bulk superconductor and a permanent magnet at 77 K is enough for us to make various application models to study and demonstrate the advantages of superconducting materials and to find means for practical application. Two models of small superconducting magnetically levitated cars have been constructed, and have been used to demonstrate fast, frictionless and stable levitated transportation in this paper.

2. Experiments

The high T_c YBCO bulk superconductors used in this experiment were prepared by a modified MTG process [2]. The levitation force was about 10 N cm^{-2} (77 K). Figure 1 shows a side view of the car used in the models. As we can see, two or three YBCO bulk samples were uniformly arranged inside the car so that the car could be well levitated over the track. The car was made of aluminium metal or fibreglass with epoxy resin to avoid any magnetic interaction between the car and the magnetic track.

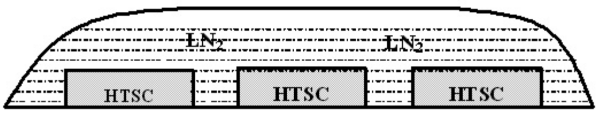

Figure 1. The side view of the superconducting car model (HTSC means YBCO bulk superconductors). The car is of length 12 cm and width 3–4 cm.

The track was paved with NdFeB permanent magnets. The size of the magnets is 10 × 10 × 10 mm^3, and the maximum magnetic field at the top surface is about 0.5 T. The track was designed to let the car move along the track smoothly. Three or four magnets were stuck together as S–N–S or S–N–S–N to form a composite magnet, and then the composite magnets were bound together to form a looped track with several turns and different heights. The track is about 4 cm in width and 10 m long, as shown in figure 2.

In addition, two linear motors were symmetrically set on both sides of the track, providing the driving force to propel the levitated car from the ground to the higher bridge over the

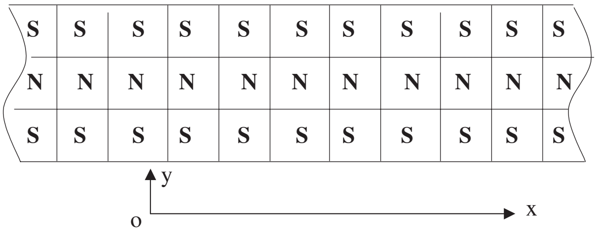

Figure 2. Schematic diagram of the track of the Maglev model using small magnets of size 10 × 10 × 10 cm^3. The magnetic field distribution is uniform along the *x* axis and with a larger field gradient in the *y* direction.

Figure 3. Photographs of small HTSC Maglev car models: (a) the track with three lines of magnets in configuration such as S–N–S; (b) the track with four lines of magnet in configuration such as S–N–S–N.

(This figure is in colour only in the electronic version)

lake as shown in figure 3. A highly sensitive photoelectric position-switch was installed near the linear motor, which was connected to the power supply and the linear motors. The switch ensures that the linear motors only work at those times when the car is travelling through them. There are at least two advantages in using this position sensor, one is to save energy and the other is to avoid any damage to the linear motors.

3. Results and discussion

The sides of the aluminium metal car or the aluminium metal glued onto the side surface of the fibreglass car acted as rotors for the linear motors. The car can be propelled in a designated direction by controlling the phases of the power supply to the motors, due to the interaction between the induced eddy current inside the aluminium of the car and the alternative magnetic field produced by the linear motors. Aluminium metal is a good heat conductor, but is not a good container for LN_2—the fibreglass car is much better from this point of view. To solve this problem for the aluminium metal car, epoxy resin was used to form a thin layer inside the car, and the YBCO bulk samples were also uniformly glued at the bottom inside the car.

The configuration of the magnets as shown in figure 2 offered a very good magnetic field distribution along the track, enabling the car to move smoothly and frictionlessly along the track, and without any deviation from the track. The arrangement of the magnets in the *x* direction is the nearly the same for a fixed *y* value, so that there is a uniformly distributed magnetic flux density and field distribution for a fixed *y* value along the length of the track. This indicates that there is no magnetic field dragging force acting on the car while it is moving along the track, resulting in frictionless transportation. The arrangement of the magnets in the *y* direction is as S–N–S or S–N–S–N, which results in a non-uniform magnetic field distribution, including the magnetic flux density and the magnetic polarity configuration. The large magnetic field gradient from the centre to both sides of the track provides a large dragging force (guidance force) on the model car, keeping the car stable and not allowing it to escape from the track. Therefore, without any active control the car can run along the track smoothly and not escape from the track.

Different cooling conditions will result in different moving scenarios for the superconducting Maglev car. There are two main kinds of cooling state. One is zero field cooling (ZFC). In this process, the YBCO samples inside the car are cooled to liquid nitrogen temperature far away from the magnetic track or other magnets. Then the car is put on the track. There will be a repulsive force against the car while it is moved towards to the track vertically: it is not stable in the lateral direction at the beginning, but will be more stable as the gap between the bottom of the car and the top surface of the track becomes smaller. The optimum gap allowing the car to be stably levitated over the track and run smoothly along it is around 3–5 mm. In the ZFC state, the car may run off the track on the turn if the car runs fast.

The other cooling method is the field cooled (FC) process. In this way, the YBCO samples inside the car are cooled to LN_2 temperature after the car is put on the track, but with a gap between the bottom of the car and the track. It is found that the stability of the car in the moving state becomes better as the gap becomes smaller, but it is not at its most stable for the smallest gap. It is also found that the car cooled in the FC state runs more stably along the track than the car cooled in the ZFC state with the same gap, which means that the guidance force of the car cooled in FC state is larger that that of the car cooled in the ZFC state.

The small Maglev car models are a good demonstration of the advantages of a superconducting Maglev train, but we have to optimize the levitation force and the guidance force for use in practical applications. First, the size and flux pinning force of the YBCO bulk superconductor must be improved to get a higher levitation force. Second, the track has to be well designed to improve the levitation force and the guidance force of the model, because these properties are very sensitive to the magnetic field distribution of the track [11]. Third the FC cooling gap has to be carefully investigated to get both a high levitation force and a guidance force.

4. Conclusion

Small high T_c superconducting Maglev car models have been constructed. It was found that there are many advantages to this kind of Maglev system, such as low energy consumption, safety, comfort, no environmental pollution and easily controlled, frictionless, high speed transportation. But there is still a long way to go, and there is still much work that needs to be done before there can be practical applications of HTSC Maglev trains in our lifetime.

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