Running Performance of a Pinning-Type Superconducting Magnetic Levitation Guide

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Abstract: A pinning-type superconducting magnetic levitation guide with bulk high-Tc superconductors was studied for use as a goods transportation system, an energy storage system, etc. A superconducting magnetic levitation running test apparatus with a circular track of ca. 38 m length, 12 m diameter, which comprises the magnetic rail constituted by Nd-B-Fe rare-earth permanent magnets and steel plates, was manufactured to examine loss and high-speed performance of the magnetic levitation guide. Running tests were conducted in air. These tests clarify that a vehicle supported by a superconducting magnetic levitation guide runs stably at speeds greater than 42 km/h above the circular track.

1. Introduction
Bulk high-Tc superconductors have developed remarkably with the advent of rare-earth superconductors. We have continued our study of a pinning-type superconducting magnetic levitation guide comprising bulk high-Tc superconductors and magnetic rail for use in a goods transportation system and other uses [1]. Magnetic rails of the superconducting magnetic levitation guide must generate high magnetic flux density at an upper position that is separate from the magnetic rail surface, thereby providing a large levitation force in a large gap. For low running loss, a homogeneous magnetic field distribution is necessary along the magnetic rail’s running direction. Former studies found a magnetic rail construction that provided a homogeneous magnetic field along the magnetic rail in the large gap [2–3].

For the present study, a superconducting magnetic levitation running test apparatus with a circular track of ca. 38 m length and 12 m diameter was manufactured for examining loss and high-speed performance of the magnetic levitation guide. Running tests were carried out in air. These tests clarify that the vehicle supported by the superconducting magnetic levitation guide runs stably above the circular track at speeds greater than 42 km/h. Furthermore, a three-dimensional numerical electromagnetic analysis program was developed. It uses the vehicle’s speed and mass as it runs above the 12 m diameter magnetic rail to calculate the limit speed at which the pinning force can support the resultant centrifugal force.
2. Construction of a superconducting magnetic levitation guide

2.1 Running test apparatus and superconducting magnetic levitation guide

Figure 1 shows a schematic diagram of a superconducting magnetic levitation running test apparatus along with a photograph of the magnetic levitation vehicle that runs, without contact, above the magnetic rail. The test apparatus is formed using 38 pieces of the partial 1-m long magnetic rail. Transparent acrylic ducts shown in the photograph are used as vacuum chambers for evacuating the running test passage, though it is not used in present experiments.

Figure 2 shows the cross-section construction of the manufactured superconducting magnetic levitation guide. This guide consists of the magnetic rail, which generates a magnetic field, and a non-contact running vehicle. The magnetic rail comprises Nd-B-Fe rare-earth permanent magnets and steel plates. They are arranged with each other in the direction of the magnetic pole. The temperature of the superconductors set in the vehicle is maintained at the liquid nitrogen temperature in the box where a vacuum thermal isolation was conducted. The superconductor is 65 mm wide, 53 mm long, and 10 mm thick; eight pieces of the superconductors are placed in two rows in the thermal isolation box of the vehicle. The total vehicle weight is 7.5 kg, including the liquid nitrogen, and a telemetry transmission system for measuring vibration and displacement of the running vehicle. The running direction of the vehicle is perpendicular to the plane of this paper. The vehicle is driven with a linear motor, but there is no control unit at present. Therefore, a pneumatic launching system was used as the way of propelling.

2.2 Measurement results of magnetic field distribution above the manufactured magnetic rail

Figures 3(a)–3(c) show a partial magnetic rail and magnetic field distribution at a distant space located over the magnetic rail surface. Figure 3(b) shows a magnetic field distribution at the 0.5 mm upper position away from the magnetic rail surface in the width direction. A high magnetic field of 1.1 T is...
Figure 3. Construction of a 1 m length magnetic rail and magnetic field distributions at upper spaces separated from the magnetic rail provided immediately above the center of one magnetic rail. Figure 3(c) shows the magnetic field distribution in the running direction at a 0.5 mm elevated position from the magnetic rail surface in the center of one side rail. A homogeneous magnetic field is created along with the running direction, except at both edges of the magnetic rail.

Figure 4. Magnetic field distribution above the magnetic rail in the circumferential direction, as measured using a telemetry system. The pulse magnetic digressions of several hundred Gauss occur in regular intervals over the whole magnetic rail because of the existence of gaps at junctions between the 1-m magnetic rails. Numerical analyses have demonstrated that the magnetic loss is not increased greatly by magnetic variation [2].

3. Running performance of superconducting magnetic levitation guide
3.1 Analytical prediction of possible supporting speeds
Figure 5 shows the analytical results on balancing positions and tilting angle of the vehicle which pinning force can support centrifugal force loading the running vehicle. Although the eccentricity

Figure 5. Balancing positions and tilting angle of vehicle which pinning force can support centrifugal force loading running vehicle
increases with vehicle speed, fluctuation is apparent neither with the gravity position nor the tilting angle to about 60 km/h. At speeds greater than 80 km/h, however, the magnetic force cannot support the centrifugal force because the center of gravity, position z, suddenly rises and the tilting angle increases. The vehicle supporting this magnetic guide runs stably to about 80 km/h above the magnetic rail.

3.2 Running test results

Figure 6 shows the horizontal vibration of the running vehicle, which is measured using a telemetry system with an acceleration sensor. The speed of the running vehicle is also shown in that figure. Large pulse acceleration changes at low speed are electrical noises that interfere with the electrical wave signal for transmission and reception. Displacement and horizontal vibration of around 2 G occur at about 33 km/h. At higher speeds, the vehicle vibration decreases even though the vehicle displacement increases in the width direction. The vehicle vibrates at a resonance frequency that depends on the guide stiffness with the vehicle mass; the resonance frequency in this guide is about 22 Hz. The 2 G acceleration is correspondent to the displacement of about 0.75 mm, if the resonance waveform is a sine wave. The vehicle cannot accomplish 80 km/h running speed obtained using the numerical analysis for the capacity shortage of supply air, but the vehicle runs very stably at speeds of more than 42 km/h (data not shown). Figure 7 shows the speed decrease and energy drop of the vehicle in a circumference in free runs versus mileage, and wind losses derived through calculations. The magnetic loss of the guide is extremely small because the energy loss matches wind loss.

4. Conclusion

A running test in air was carried out using the running test apparatus with a ca. 38 m long circular track with 12 m diameter. Thereby, we examined the loss and high-speed performance of the magnetic levitation guide. The vehicle can run very stably, though it cannot accomplish 80 km/h running speeds predicted using numerical analysis for the capacity shortage of supply air. In addition, the magnetic loss engendered by the nonhomogeneous magnetic field of the constructed magnetic rail seems to be very small.

These results clarify that the pinning-type superconducting magnetic levitation guide with bulk superconductors is useful as an excellent support system for transportation and other uses.

References

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