A MODEL VEHICLE WITH MAGNETIC FLUX PINNING EFFECTS OF HIGH-T_C OXIDE SUPERCONDUCTORS

Haruhiko Suzuki, Kozo Yogiashi, Takayuki Anzai, Koichi Kusano, Sei-Ichi Tanuma and Masaaki Takashige
College of Science and Engineering, Iwaki Meisei University
Iwaki-shi, Fukushima, Japan

ABSTRACT
This paper describes a non-contact running system utilizing oxide superconductors and permanent magnets. The vehicle containing superconductors can travel on the rail with homogeneous magnetic flux density along the moving direction, using acceleration of electromagnetic induction. Three kinds of permanent magnets, Sm-Co, Nd-Fe-B and ferrite magnets, were attempted. Such a traveling is possible by being hang under the rail of Sm-Co and Nd-Fe-B magnets, due to strong pinning effect of the superconductor. The division point for the direction of motion was also constructed on the rail of ferrite magnets by partially using electromagnets.

INTRODUCTION

Recent development of the fabrication technique for the oxide superconductors with the critical temperature T_c above the boiling point of liquid nitrogen enabled us to perform experiments of superconductors using liquid nitrogen very easily in any laboratory. While the most attractive nature of superconductors is resistanceless current, the magnetic properties are also interesting. In particular, the magnetic levitation phenomena of the superconductors originated from the flux pinning effect, which is a distinguished property of type II superconductors, yield high potentiality in practical applications such as noncontacting rotation devices, transportation systems[1].

In this paper, we would like to introduce models of running systems utilizing oxide superconductors and permanent magnets, which we have been concerned for past several years[2-4]. The vehicle consisting of styrol casing and the so-called Yttrium-Barium-Copper oxide with an appropriate handling can run smoothly by being floated or hang along the magnetic rail. Here we shall present the photos of rail loops, running scene, and information such as forces between the vehicle and rail, division point of the rail.

RAIL LOOP

First, we show the photos of the whole construction of three kinds of rail loops. Figure 1 show the Sm-Co loop, which consists of 500 pieces of 10x10x20mm magnets with the flux density of ~0.3T near the surface. The total length of the loop is 3.2m with curvature of 0.4m in radius. It was designed to turn the whole apparatus upside down for the hanging travel as shown the figure(later, see also Fig.12).

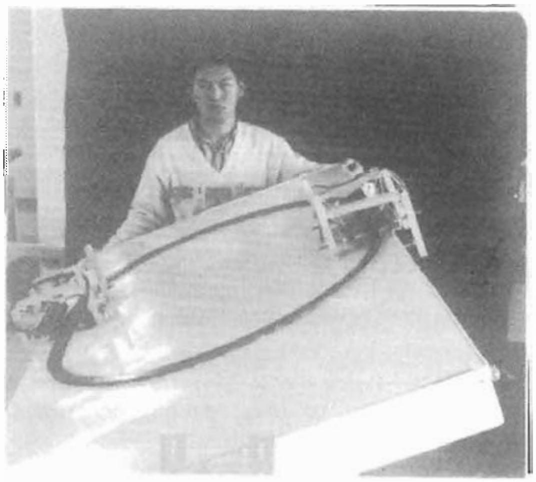

FIGURE 1: The Sm-Co loop. The whole apparatus is designed to be turned upside down for the hanging travel(see also Fig.12).

Figure 2 is the vertical loop, consisting 360 pieces of 5x10x15~30mm Nd-Fe-B magnets with the surface density of ~0.5T. The total length is 2.6m with curvature of 0.16m. In this case, we can see both hanging and floating runs on one cycle.
Figure 3 is the 8-style rail loop of ferrite magnets with the division points. As described later, the vehicle can change its direction of motion by switching the polarity of two electromagnets at the center of the division point.

FIGURE 2: The vertical loop of Nd-Fe-B magnets. The magnetic rotor(see also Fig.7) for the acceleration is attached.

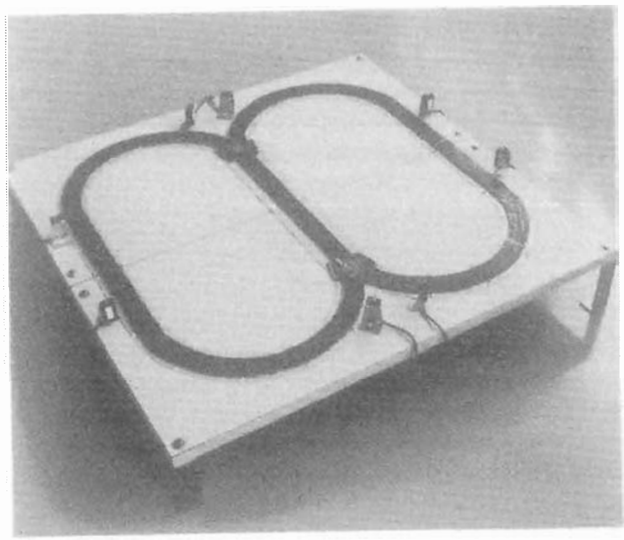

FIGURE 3: "8-style" track of ferrite magnets with the division points. The rods standing near the track are optical sensors.

Next, as shown in Fig. 4, the rail used in the above loops is an array of permanent magnets consisting three bands across its width. In the central band, the North-pole is facing up, while in side bands the South-pole is facing up. The flux density is shown in Fig.5, as a function of the height from the rail surface.

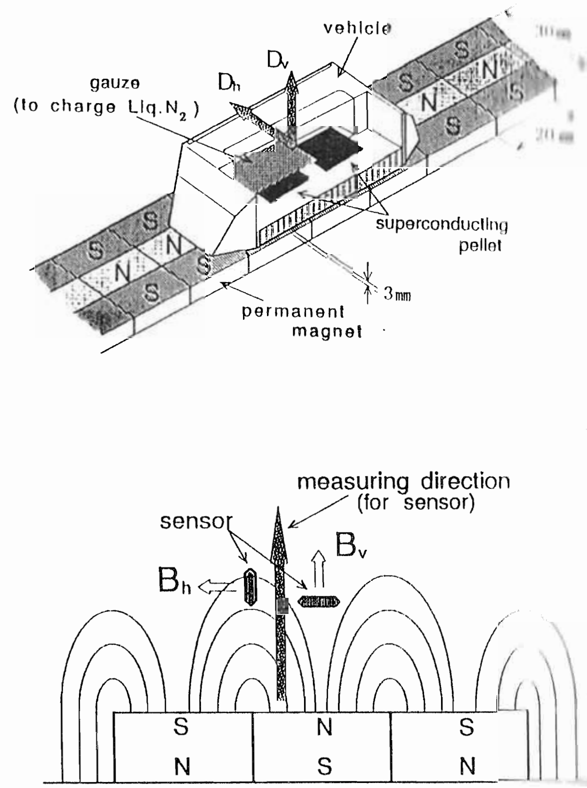

FIGURE 4: The construction of the vehicle and the magnetic rail.

VEHICLE

The vehicle consists of styrol casing for thermal insulation with two pieces of superconducting plates placed in the bottom also shown in Fig.4. The total weight is 20g and about 5g liquid nitrogen can be charged. Once the liquid nitrogen is charged, the vehicle can levitate for several minutes at resting state.
The superconductive material used here is the Yttrium-Barium-Copper oxide($YBa_2Cu_3O_x$) with T_c of the 90K range, prepared by the so-called MPMG(Melt-Powder-Melt-Growth)[1] method which contains fine dispersed insulating phase(Y_2BaCuO_x) as a pinning center(offered from Dr.Murakami, ISTEC). The materials with higher T_C's such as Bi- and Hg-based material were also attempted, however, at the present stage, it seems that the force induced in the magnetic field is not large enough for these kinds of experiments.

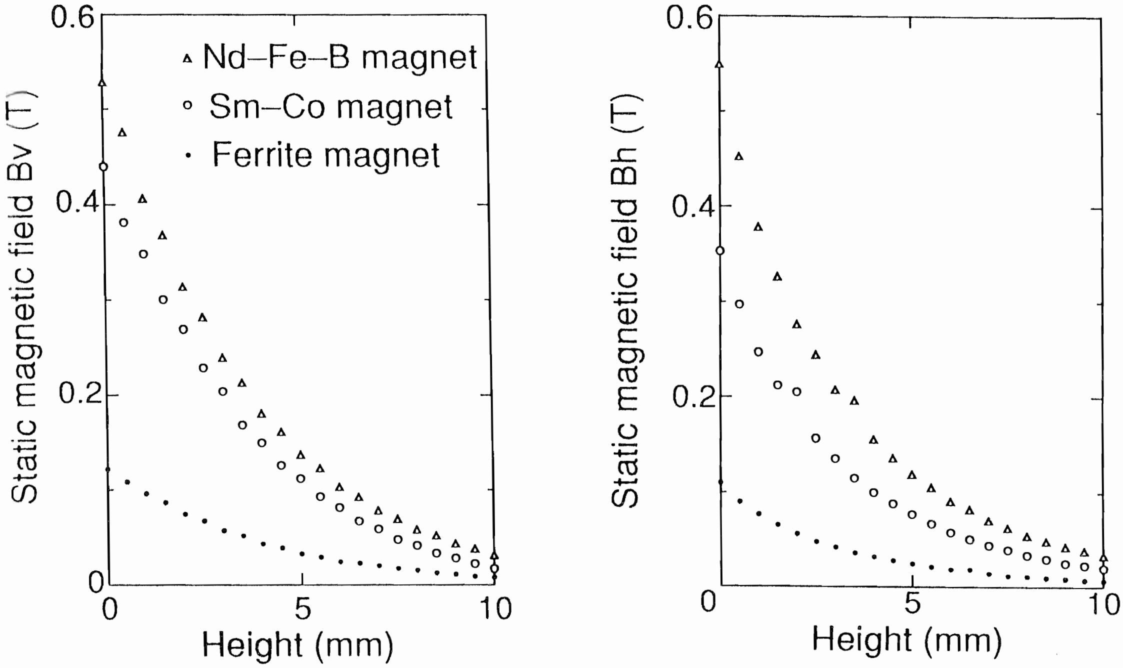

FIGURE 5: The magnetic flux density on the rail. The left figure indicates the vertical component at the center of the magnet and the right indicates the horizontal component at the joint of magnets(see also Fig.4).

ACCELERATION

How is the vehicle be powered without contact? We attempted two kinds of acceleration mechanisms. For the loop of Fig.1, the linear motor is placed on both sides of the rail shown in Fig.6, whereas it is placed under the rail of Fig.3. For the vertical loop of Fig.2, we need more powerful acceleration and hence the magnetic rotor containing 4 pieces of Sm-Co magnets is adopted(see Fig.7). To promote the acceleration power, an aluminum plate to induce eddy current is often glued on the surface of vehicle.

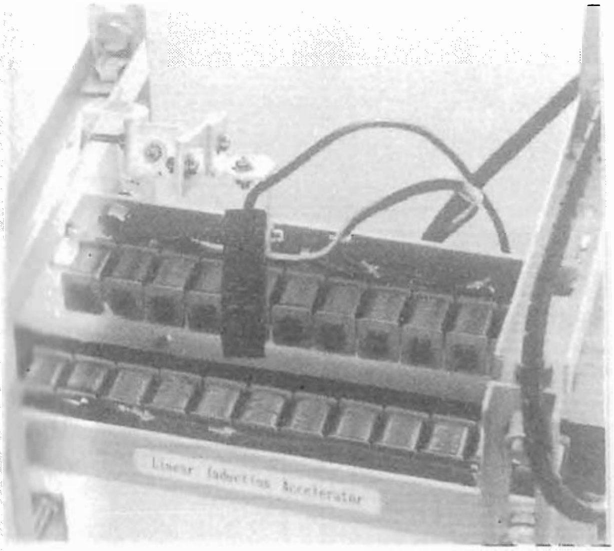

FIGURE 6: The linear induction motor. An optical sensor is set at the end of central rod.

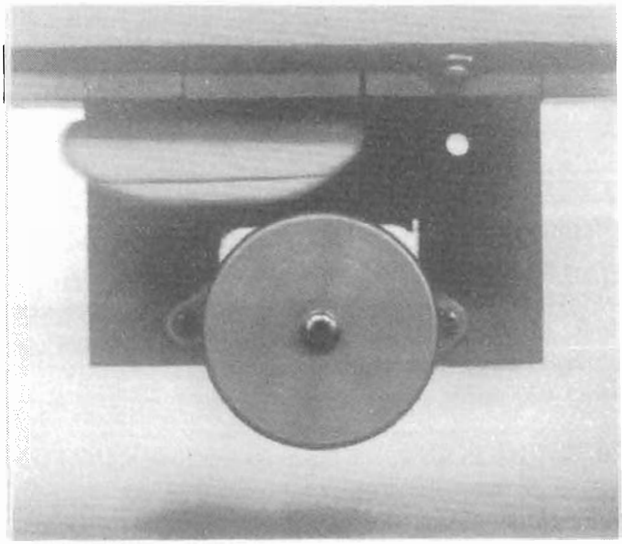

FIGURE 7: The magnetic rotor with four pieces of Sm-Co magnets.

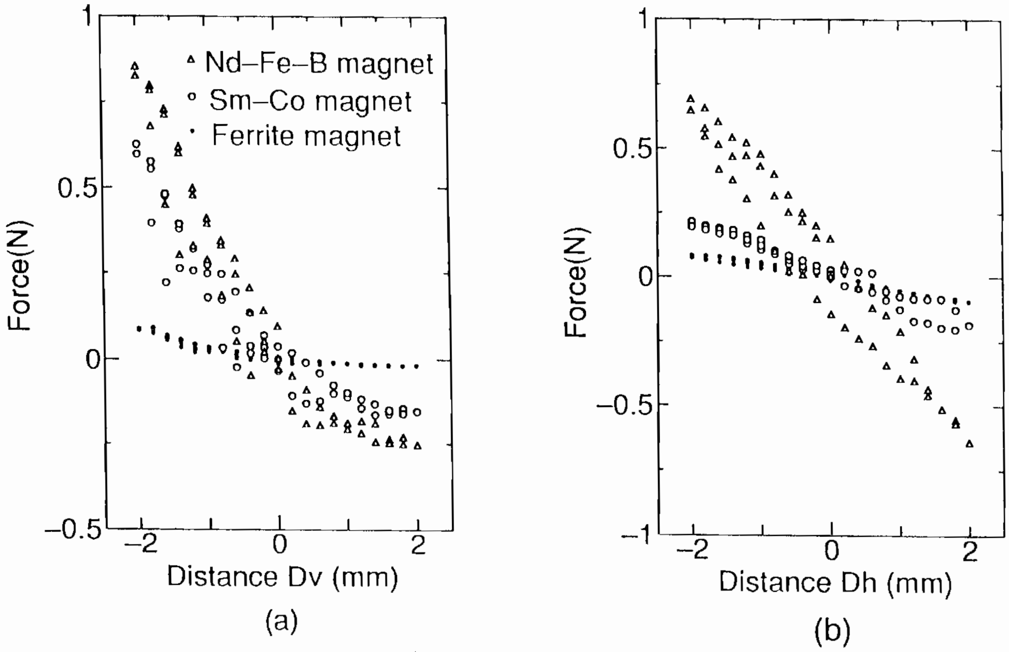

FIGURE 8: The force between vehicle and rail. The distance means the deviation from the center point 3mm above the rail surface(Dv and Dh are shown in Fig.4). The curves were obtained by varying ±2mm. (a)vertical force, (b)horizontal force.

FORCE MEASUREMENT

Forces acting vehicle on the rail were measured. Noted that the measurements were made on "track cooling"(field cooling), namely, the vehicle is placed 3mm above the rail and then cooled down below T_C there. By this setting more magnetic flux will be trapped than it would be brought from outside(zero filed cooling). The curves in Fig.8(a) indicates the results when the vehicle goes up and down after the track cooling and those of Fig.8(b) are horizontal forces measured by shifting the vehicle across the rail width.

As compared with the vehicle weight, observed forces are strong enough to support the vehicle on the rail in cases of Sm-Co and Nd-Fe-B, whereas it is not possible to hang the vehicle under the ferrite rail due to disappearance of attractive force in Fig.8(a). Curves shows slight hysteresis against the position shift of the vehicle, indicating slight amount of pinned flux is changed.

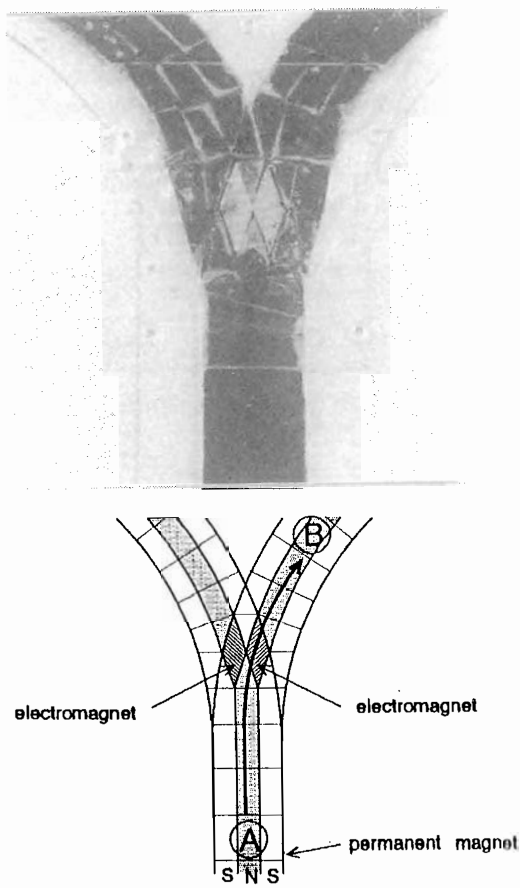

FIGURE 9: The division point.

DIVISION POINT

Figure 9 shows the enlarged photo of the division point from the 8-style loop of Fig.3, where twin rhombic electromagnets are seen. As easily understood in the figure, switching the polarity of the twin electromagnets, we can choose the moving direction. In Fig.10, this magnetic switch is visualized by

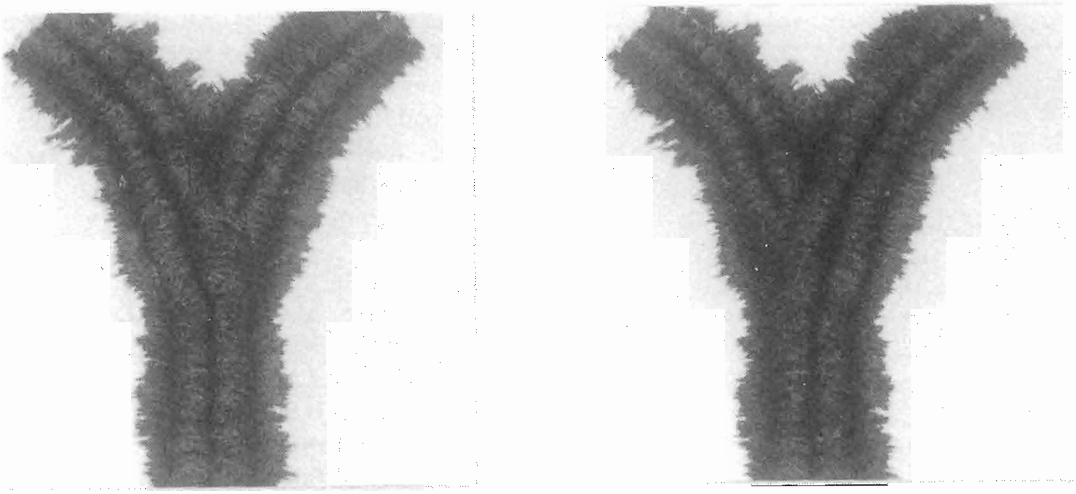

FIGURE 10: The switching visualized by iron powder.

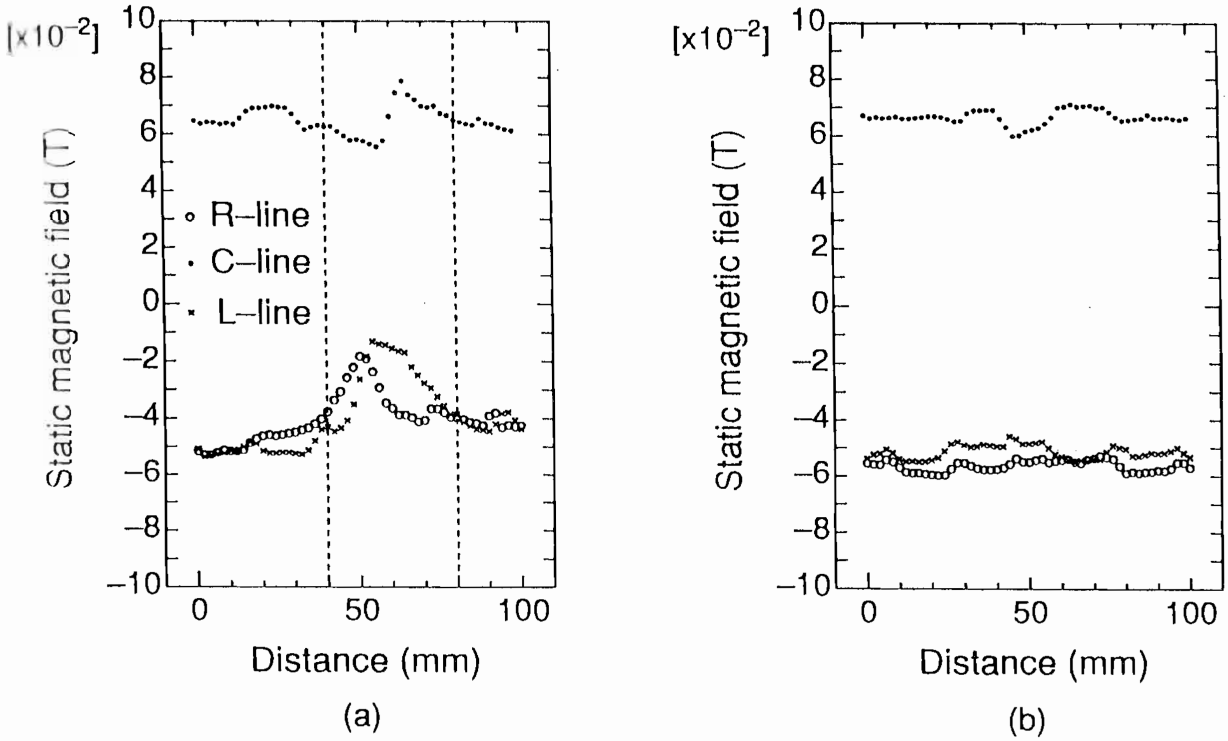

FIGURE 11: The vertical component of the field. (a)near the division point(measured along A to B in Fig.9 switching on this direction). (b)at the straight rail.

spraying iron powder. Furthermore, Fig.11(a) show the flux density measured along the rail on the division point.

Although the homogeneity of the flux distribution around the division point is not good enough as compared with that of the straight part also shown in Fig.11(b), it can be switched without derailment or very large shaking.

SUMMARY

It is difficult to describe the running scene and hence we show two photos of running.[1] Figure 12 demonstrates the hanging travel in the Sm-Co loop of Fig.1. The vehicle can travel more than 50 cycles without contact to the rail. By reversing the polarity

[1] The running scene was edited by VHS video(English). Please contact the present authors if you hope to get it.

FIGURE 12: The upside down running in the Sm-Co loop.

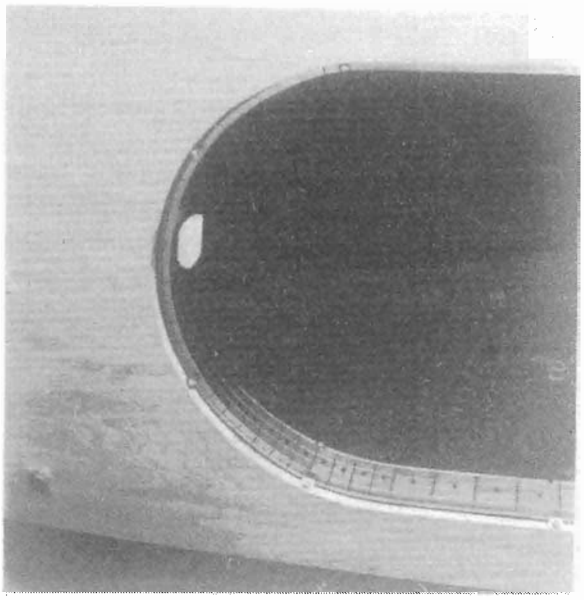

FIGURE 13: The running in the vertical Nd-Fe-B loop.

of the linear motor, it is possible to turn the direction of motion. The action of linear motor is triggered by an optical sensor which will notice the coming of vehicle and running patterns can be programmable by a personal computer.

Figure 13 demonstrates more dynamic running in the vertical loop of Nd-Fe-B magnets. In this case the vehicle velocity is about 2.0m/sec and 20 cycles continuous running is possible.

Our models show that, using a superconductor, we can construct a vehicle, that runs without contact to its rail as well as to the acceleration mechanism. At the present stage, our model is small but using larger superconductors, the vehicle will be able to carry heavier load. We are trying to explore such possibilities further.

REFERENCES

1. For instance, M.Murakami, T.Oyama, H.Fujimoto, T.Taguchi,S.Gotoh, Y.Shiohara, N.Koshizuka and S.Tanaka:Jpn.J.Appl.Phys. **29** (1990) L1991.
2. M.Takashige, H.Suzuki and S.Tanuma:Kotai butsuri **26** (1991) 461[in Japanese].
3. H.Suzuki, M.Takashige and S.Tanuma:GAKUTO International Series, Mathematical Science and Applications, **1** (1993) Nonlinear Mathematical Problems in Industry, pp.321.
4. H.Suzuki, M.Takashige and S.Tanuma:Kotai butsuri **28** (1993) 618[in Japanese].