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## A PERMANENT MAGNET REPULSIVE TYPE CONVEYOR HAVING VERTICAL AND HORIZONTAL CONTACTLESS ROLLERS

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### Abstract

A new passive magnetic repulsive type conveyor using repulsive forces of permanent magnets have been proposed as an application of a repulsive type magnetic bearing system in this paper. The conveyor is composed by putting several passive magnetic levitation units in order. The unit has the feature that a levitator shaft is supported by soft stiffness and rotates easily owing to noncontact in the radial direction. Two conveyance methods efficiently employing the above feature have been proposed and conveyance tests for each method were performed.

### 1. INTRODUCTION

A single axis controlled repulsive type magnetic bearing system using four cylindrical permanent magnets and one electromagnet have been fabricated and studied in our laboratory[1,2]. This system is well known as one of the simplest methods in magnetic levitation technique. In general, active/passive magnetic bearing system has neither a friction nor abrasion, and its lubrication is unnecessary. Moreover, the radial stiffness of the passive magnetic bearings using permanent magnets is small and constant as compared with that of the active magnetic bearings. For these reasons, naturally, the application scope was limited to the use to a small disturbance. Recently, a turbomolecular pump, a high-speed rotational type polygon scanner motor, and a micro-mass measurement device have been proposed as applications to the small-sized devices without a radial disturbance[3-5].

According to the Earnshaw's theorem, it is necessary to control at least one direction actively in order to achieve a stable noncontact levitation in three-dimensional magnetostatic field[6]. In other words, the theorem implies that a stable levitation only in a repulsive force of permanent magnets can be achieved by reducing the number of dimension spatially.

In this paper, the new conveyor system using many passive magnetic levitation units has been proposed. The unit consists of a roller (here it is called a levitator shaft),

two passive magnetic bearing sections, and so on. Fundamental characteristics of a fabricated passive magnetic levitation unit have been examined[7,8]. Two kinds of conveyor configurations based on the features of the unit have also been proposed. Since there is no lubrication problem for the proposed conveyor system like conventional repulsive type magnetic bearings, it will be especially useful in hygienic environment and clean-room condition.

### 2. BASIC CONFIGURATION AND CHARACTERISTICS OF A PASSIVE MAGNETIC LEVITATION UNIT

#### 2.1 Components

Configuration of a passive magnetic levitation unit is shown in Fig.1. This unit consists of a levitator shaft, four Nd-Fe-B cylindrical permanent magnets, and two positioning screws. Repulsive forces between rotor and stator permanent magnets magnetized in the same direction stabilize the levitator along the radial direction. The instability of the levitator shaft to the axial direction is cancelled by setting the positioning screw to a suitable position. The both ends of the shaft are machined in the shape of a hemisphere. Furthermore, in order to reduce a friction, polyimide film is put at the edge of the positioning screw. The total mass of the levitator is

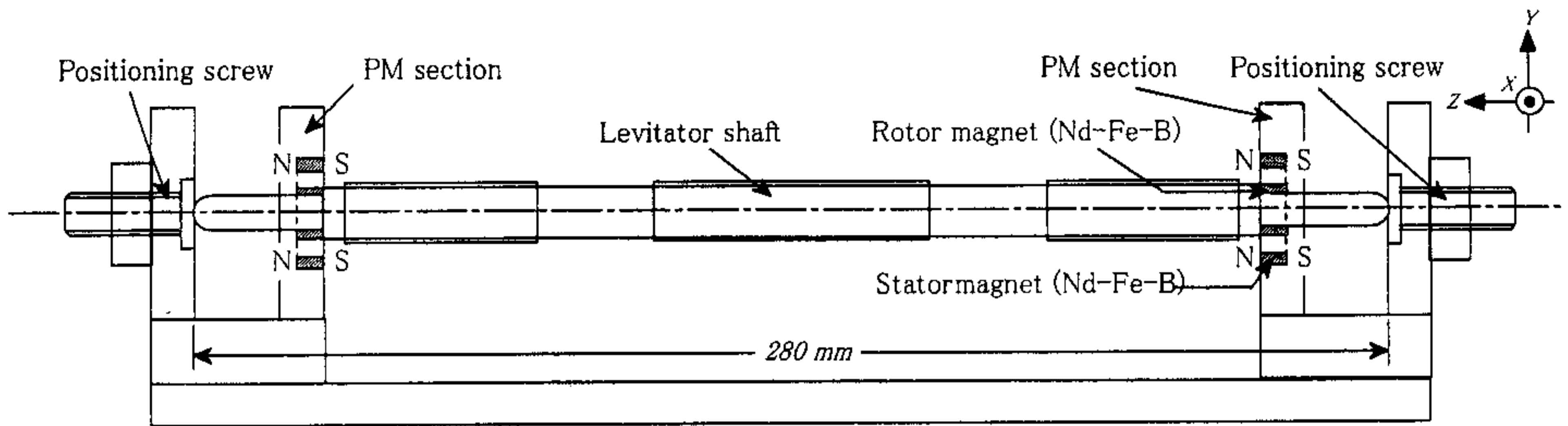


Fig. 1 Configuration of a passive magnetic levitation unit.

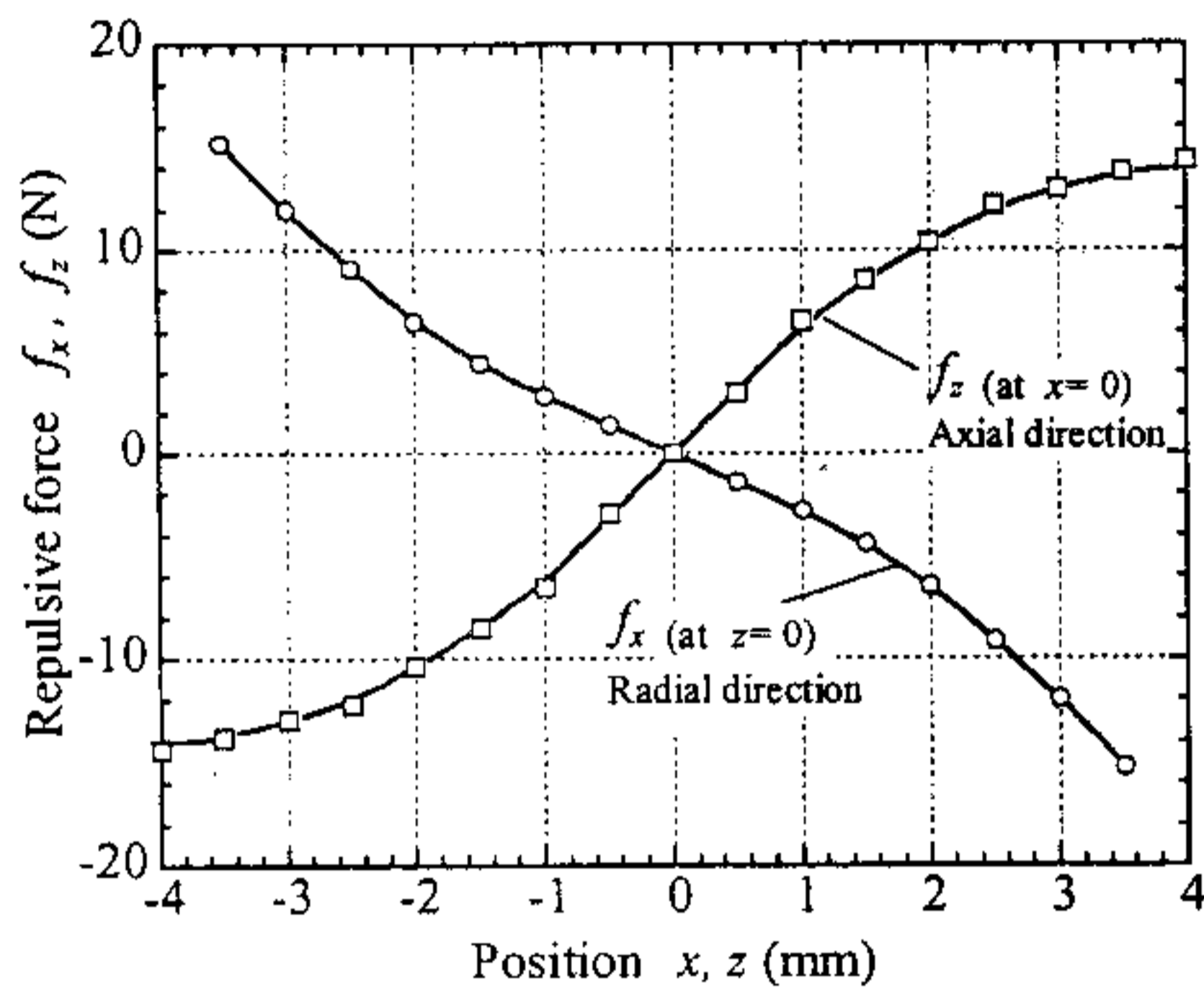


Fig. 2 Characteristics of the repulsive forces along the axial and radial directions.

Table 1 Standard parameters of a passive magnetic levitation unit

Levitor mass	0.110	kg
Shaft length	280	mm
Shaft diameter	14	mm
Total length	340	mm
Total width	40	mm
Rotor PM dimensions	12 $\phi$ mm $\times$ 7 $\phi$ mm $\times$ 6 mm	
Stator PM dimensions	26 $\phi$ mm $\times$ 20 $\phi$ mm $\times$ 6 mm	
Withstand load	15.5	N
Radial stiffness at operating point	2830	N/m
Natural frequency	25.5	Hz

around 0.11 kg, the shaft length is 280 mm, and the gap length between the rotor and stator magnet is 4 mm.

## 2.2 Characteristics and conveyance methods

One of the fundamental and important characteristics is repulsive force between the rotor magnet and the stator magnet. Characteristics of the repulsive forces per unit

along the axial and radial directions are shown in Fig. 2. A negative gradient, which contribute to passive stability, in the radial direction and a zero-force point in the axial direction exist simultaneously at  $x = 0$  and  $z = 0$ . The axial positioning screws are installed to maintain the operating point near this point of intersection as shown in Fig. 2. A natural frequency of the levitator is calculated from the relationship between the radial stiffness and the levitator mass, and the calculated value is around 25 Hz[7]. A withstand load of the levitator is around 15.5 N with the shaft falling 3.5 mm. Basic parameters of the passive magnetic levitation unit are summarized in Table 1. Since the levitator shaft is not contact in the conveyance direction ( $x$ -axis) and the vertical direction ( $y$ -axis) unlike the conventional mechanical conveyor, neither the vertical drag force nor breaking torque to the levitator occurs at all mechanically. In addition, the levitator shaft has both the soft stiffness along the vertical direction and the easy rotation by negligible friction at an edge of the levitator shaft. For these reasons, the conveyance method utilizing oscillation and/or rotation is expected.

## 3. CONFIGURATION OF A PERMANENT MAGNET REPULSIVE TYPE CONVEYOR AND CONVEYANCE TESTS

### 3.1 Conveyor system by oscillation and rotation mixed mode

In order to use the above features effectively, the method of generating oscillation and rotation to the levitator shaft is proposed. A new unit configuration with four electromagnets is shown in Fig. 3. Two electromagnets per permanent magnet section are configured with a phase shift of 90 degrees spatially in order to change the magnetic field distribution around this section. Fig. 4 shows the path of an excitation current in each electromagnet. Two-phase sinusoidal ac voltage is produced by a VVVF power supply and a

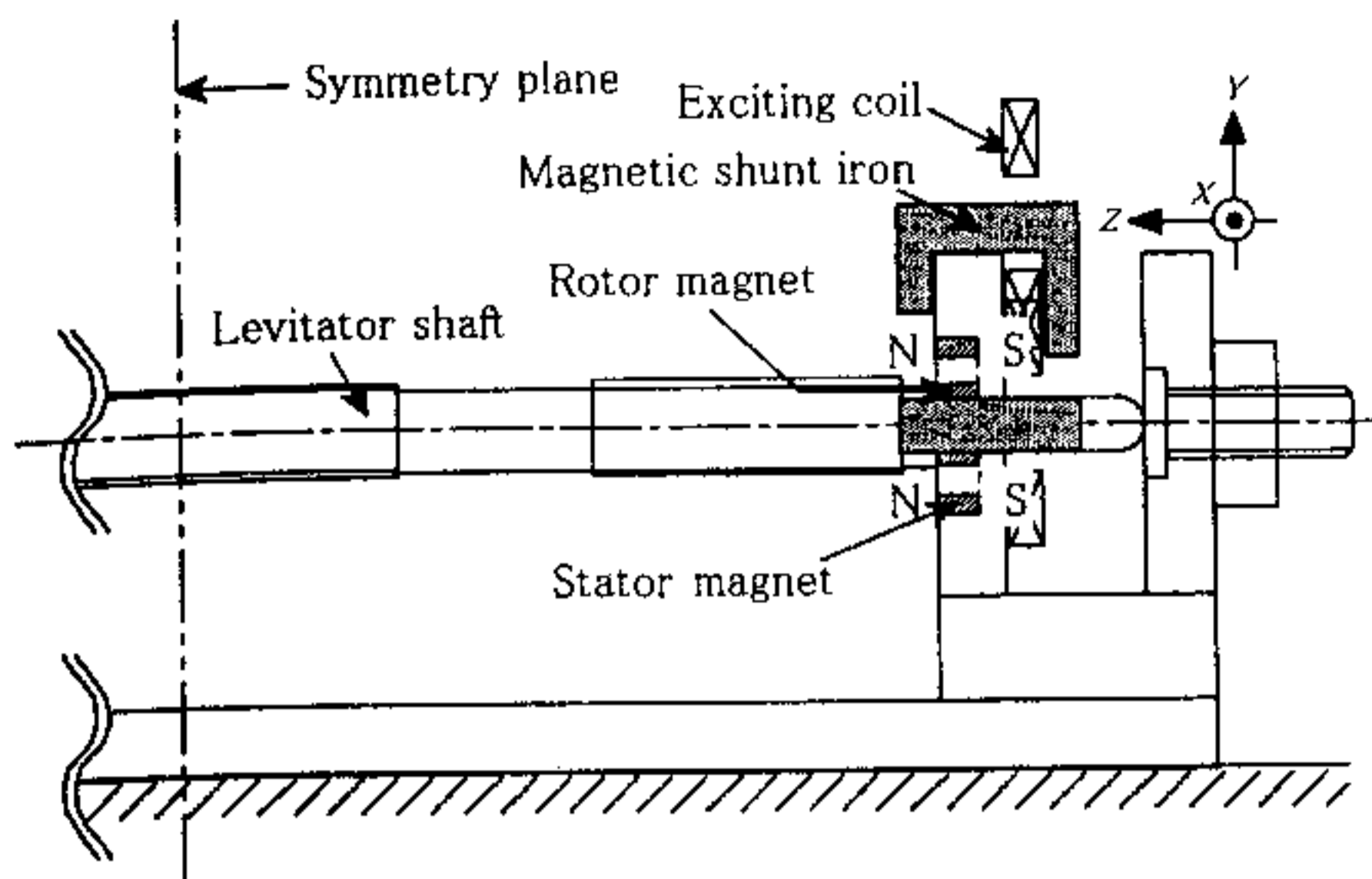


Fig. 3 Configuration of the passive magnetic levitation unit with four electromagnets.

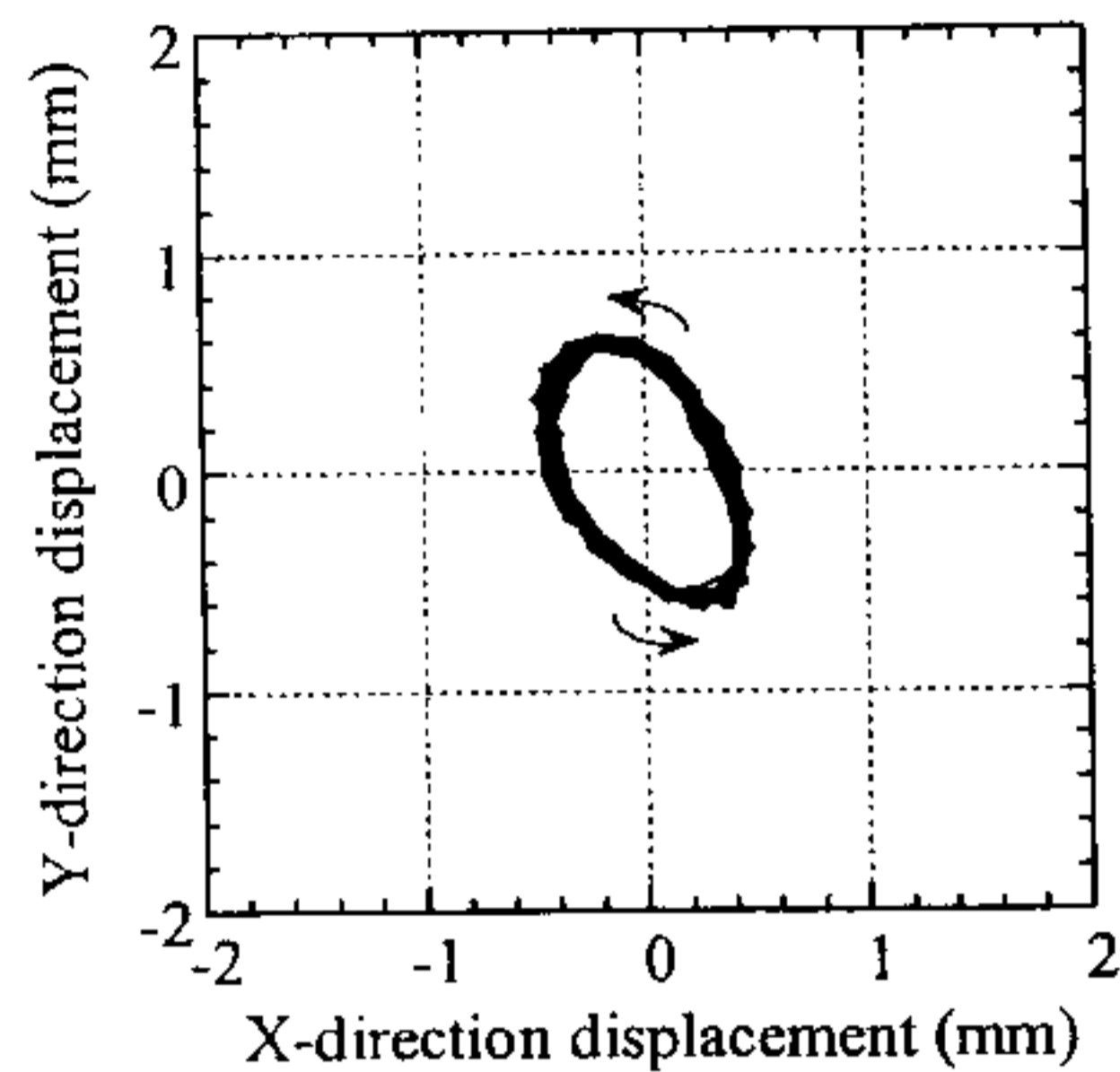


Fig. 5 Trajectory of the levitator shaft.

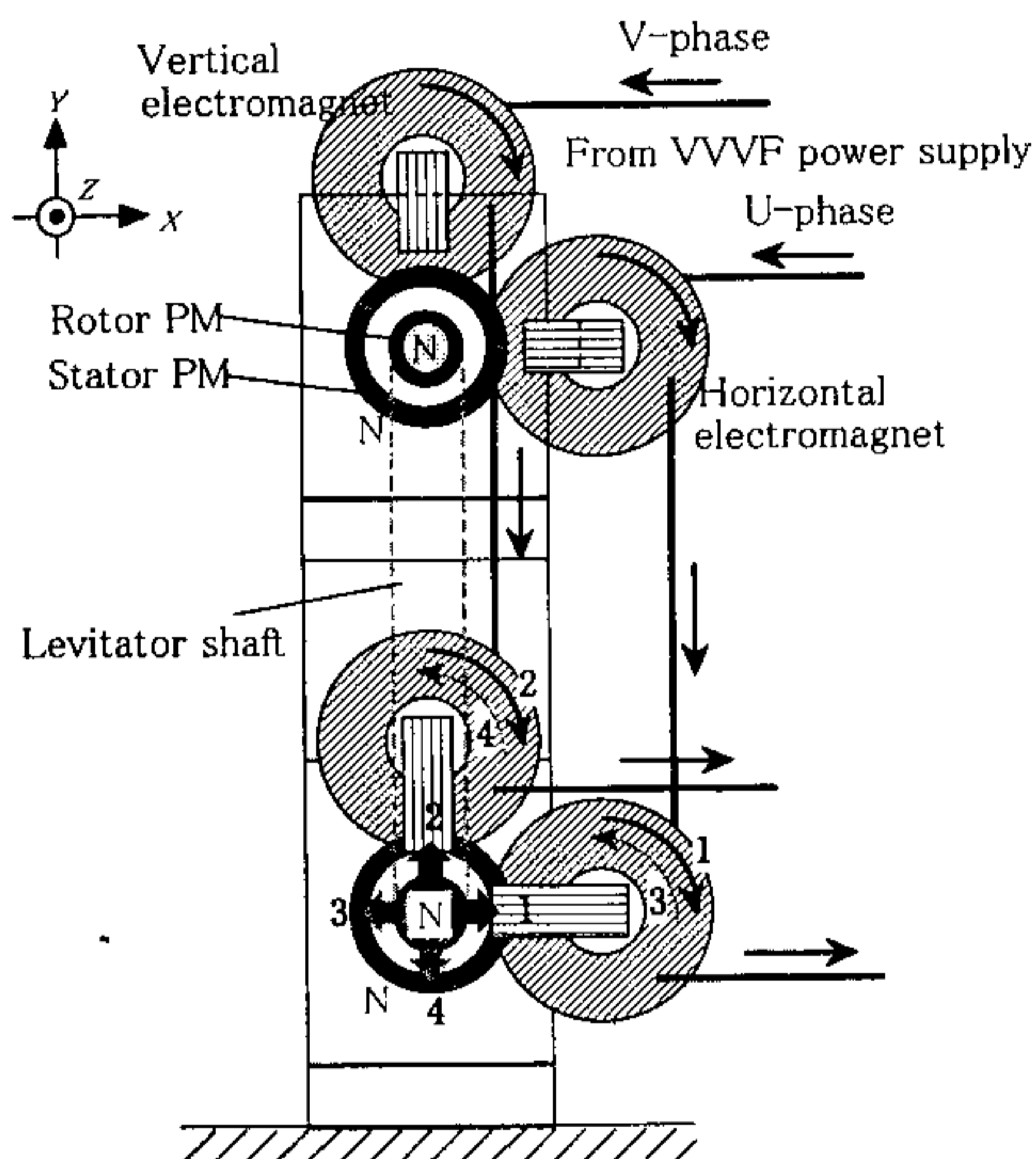


Fig. 4 Schematic drawing of current path in a unit.

phase controller. U-phase voltage, which leads 90 degrees from V-phase voltage, is applied to two horizontal coils connected in series. V-phase voltage is applied to two vertical coils in the same way.

Fig. 5 shows the orbit of the levitator shaft, which oscillates around 25 Hz in an excitation frequency. An elliptical orbit is obtained by having given with both the spatial and time phase-shift. The levitator shaft rotates counterclockwise when excitation currents flow in order of 1 to 4 in Fig. 4. Since the friction of an edge of the shaft is negligible small, the shaft rotates with

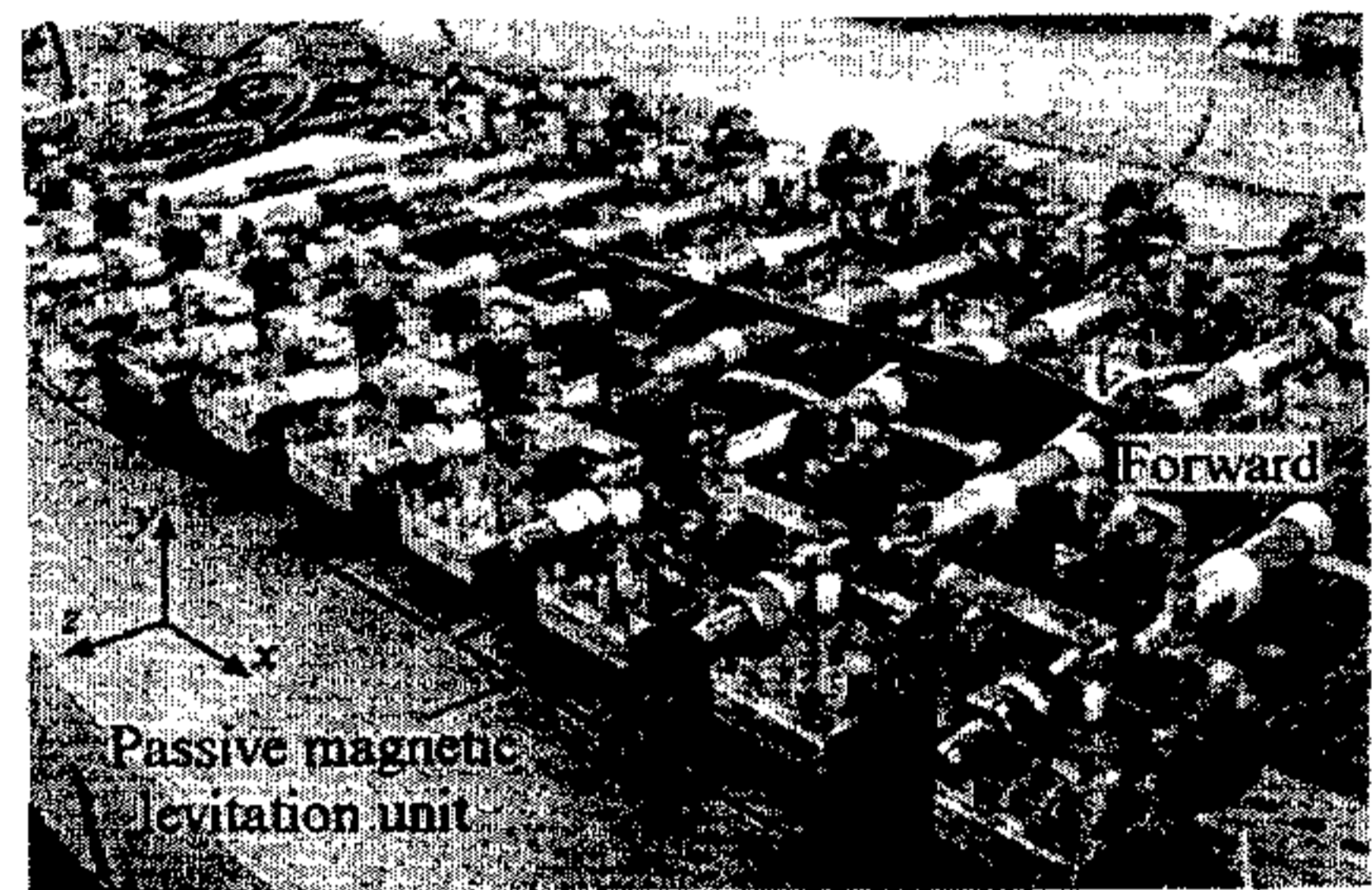


Fig. 6 Configuration of the permanent magnet repulsive type conveyor for oscillation and rotation mixed mode.

translational motion to the radial direction and does not bend in itself.

A repulsive type conveyor system for oscillation and rotation mixed mode is composed by putting nine units in order as shown in Fig. 6. A pitch between the levitators is 75 mm at equal intervals. All the levitator shafts oscillate and rotate synchronously by connecting the coils in each direction in series. Naturally, all shafts draw an elliptical orbit rhythmically as shown in Fig.5. When U-phase current and V-phase current are replaced, all shafts rotate to an opposite direction.

The characteristics of conveyance velocity by oscillation and rotation mixed mode are shown in Fig. 7. A light sponge sheet, which dimensions are 250 mm × 160 mm × 10 mm, was used as the object on the shafts. It turns out clearly that the maximum velocity is about 0.1 m/s and the conveyance velocity is not stabilized. Since the number of the levitator shaft in contact with the sheet

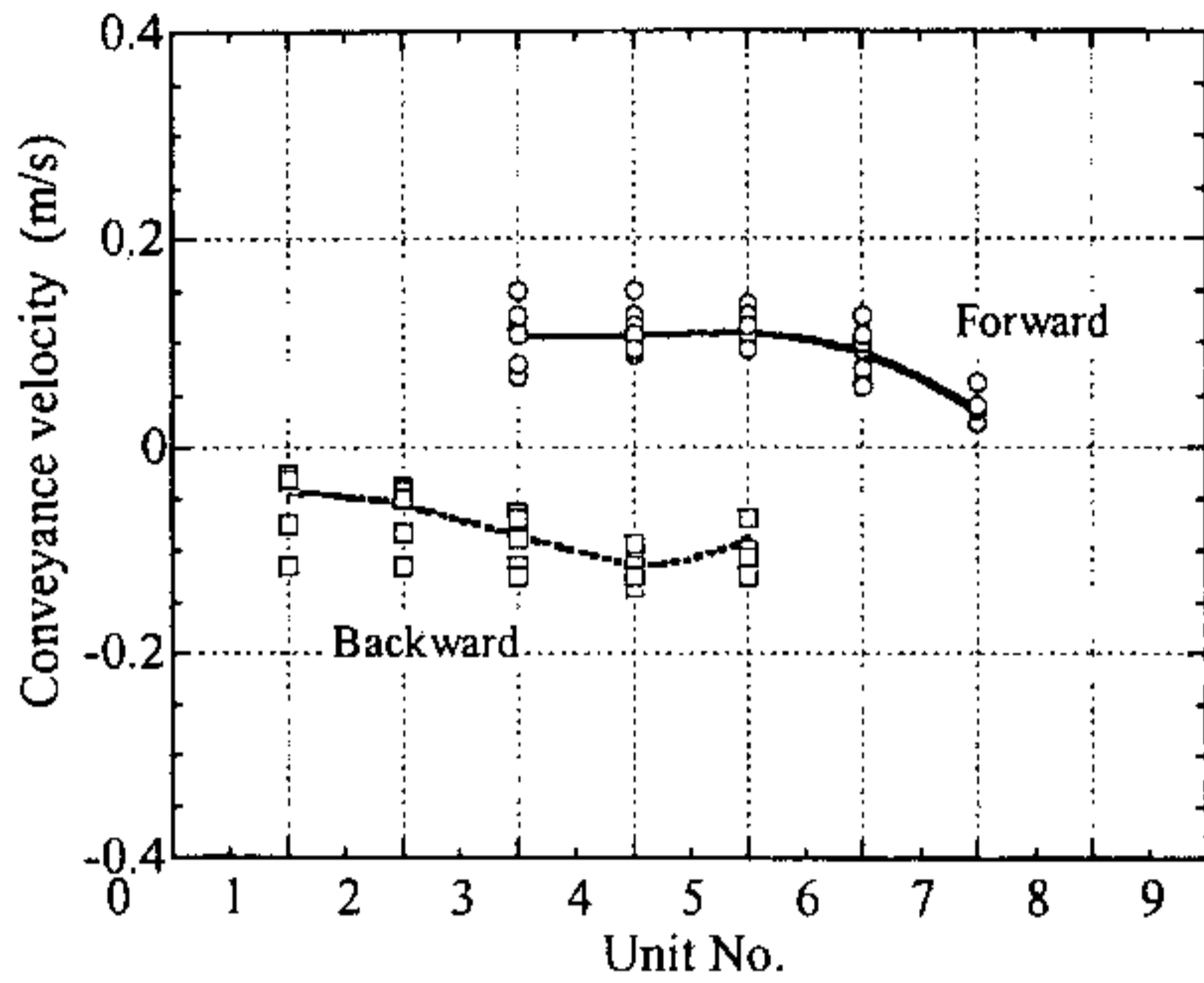


Fig. 7 Characteristics of the conveyance velocity between units.

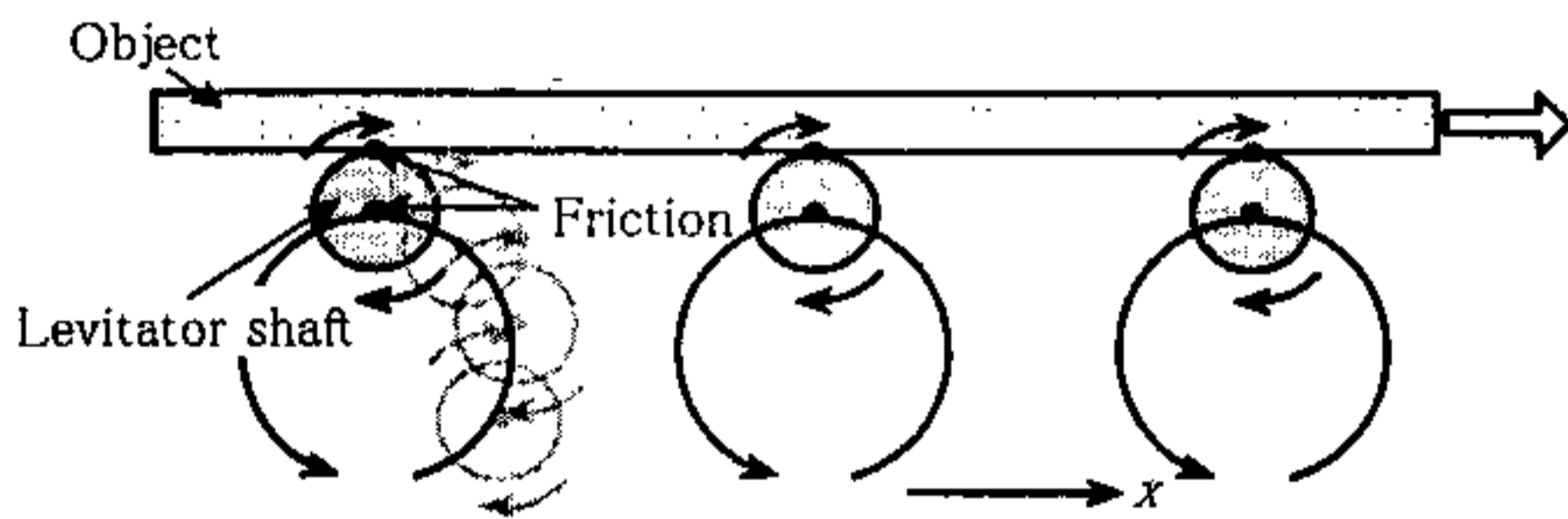
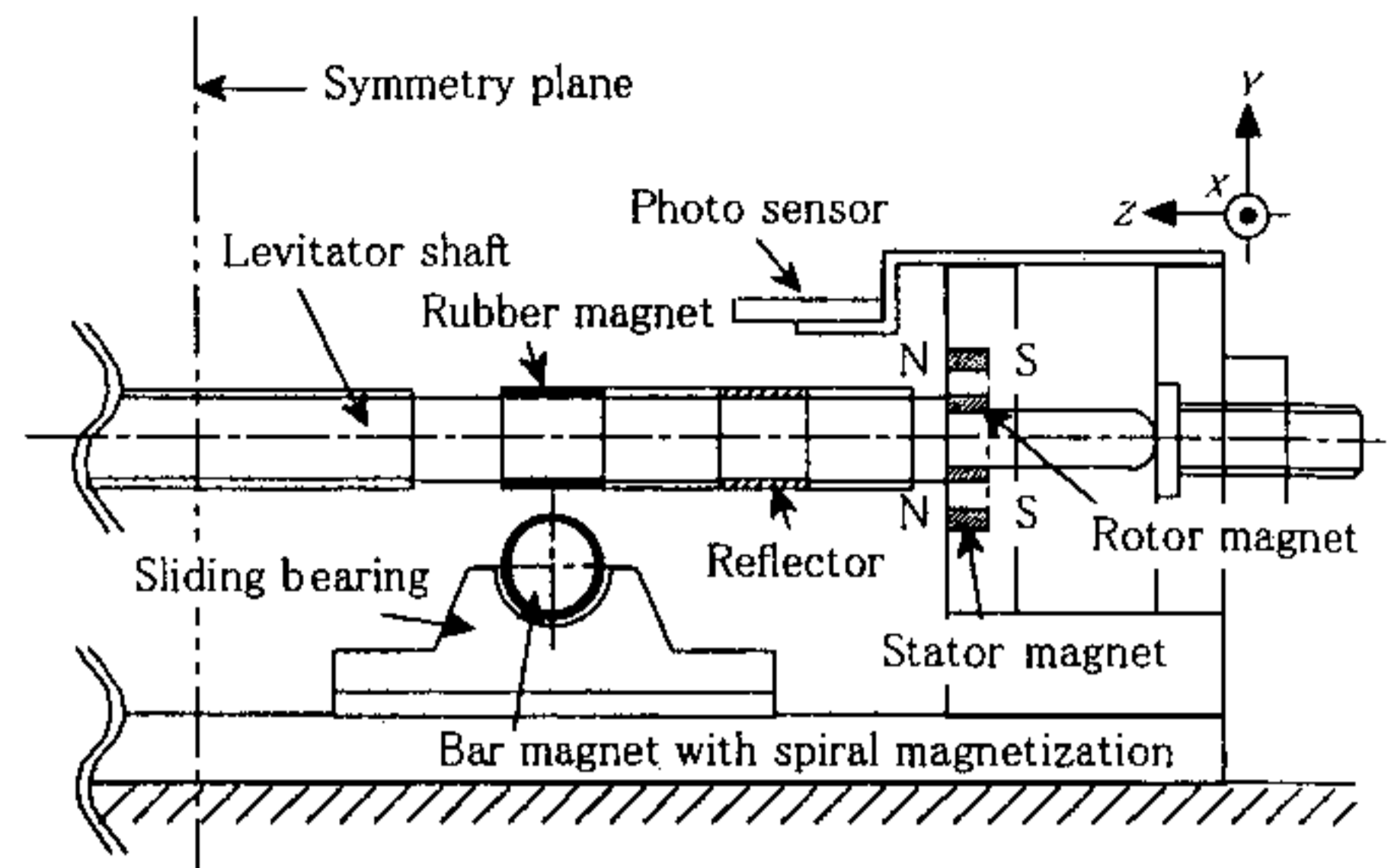


Fig. 8 Principle of operation in oscillation and rotation mixed mode.

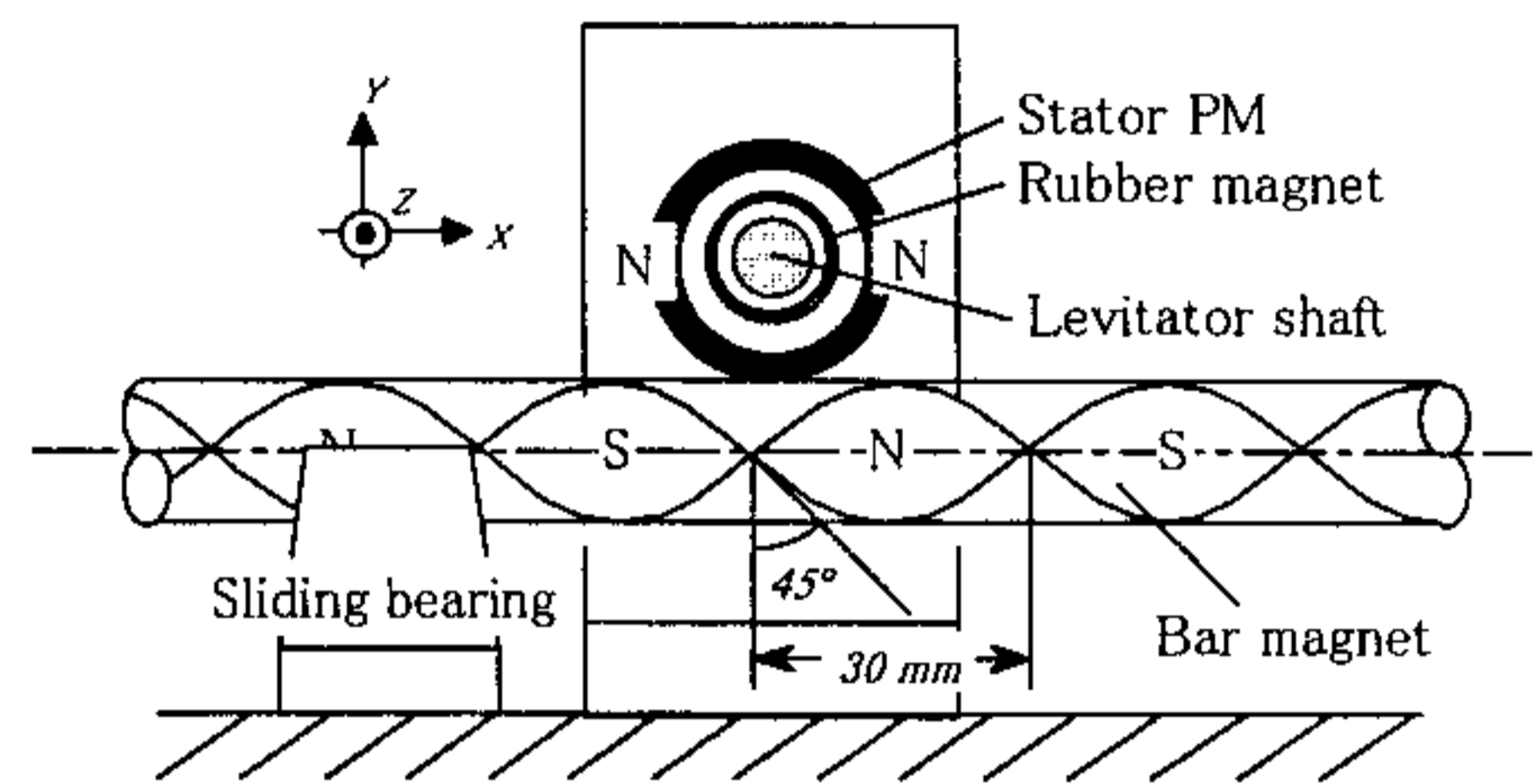
decreases, conveyance velocity also decreases. When two phase ac current flows in the direction as shown in Fig. 4, all levitator shafts rotate counterclockwise and the object moves forward. Namely, the levitator shaft itself rotates clockwise owing to the existence of a slight friction on an edge, and so the object move forward at last with the frictional force received from the surface of the shaft as shown in Fig. 8. In addition, from the point for which the natural frequency of the levitator shaft depends on the object weight, there are severe restrictions to magnitude and weight of the object.

### 3.2 Conveyor system by rotation mode

Conveyor system by rotation mode is proposed as another driving method of the levitator shaft. Figs. 9 (a) and 9(b) show the configuration of the passive magnetic levitation unit with a magnetic gear. The magnetic gear, which consists of a four-pole cylindrical rubber magnet and a bar magnet with spiral magnetization, is similar to the structure of a worm gear. The four-pole rubber magnet is put on the levitator shaft at 60 mm distance from the permanent magnet section. The bar magnet located just under the rubber magnet is supported by several sliding bearings mechanically. The bar magnet is



(a) Front view of the set-up



(b) Side view of the set-up

Fig. 9 Configuration of the passive magnetic levitation unit with magnetic worm gear.

magnetized spirally with 45 degrees lead angle and 3 mm pole pitch. When the bar magnet rotates, a shifting magnetic field is formed between the bar magnet and the rubber magnets, and so torque is transmitted to a levitator shafts. A photo sensor and a reflector are installed to detect the conveyance velocity as shown in Fig. 9(a).

Fig. 10 shows the conveyor structure, which inserts two bar magnets under the eight levitator shafts. Actually, two bar magnets are connected to a variable speed motor through the combination of timing belts and pulleys. This system was carefully fabricated so that the phase connection of all magnetic poles used for the magnetic gear may be adjusted. A pitch between units is 100 mm at equal intervals. Conveyance test was carried out by changing the sample weight up to 1.5 kgf (14.7 N) on a tray. The dimension of the tray is 300 mm × 8 mm × 15 mm, the weight is 44 gf (0.43 N), and so the tray always straddles on three levitator shafts. A bottom edge of the tray is ground so that it may not hit on the following levitator shaft.

Fig. 11 shows an experimental result of no-load test. It turns out that the levitator shafts synchronize completely.

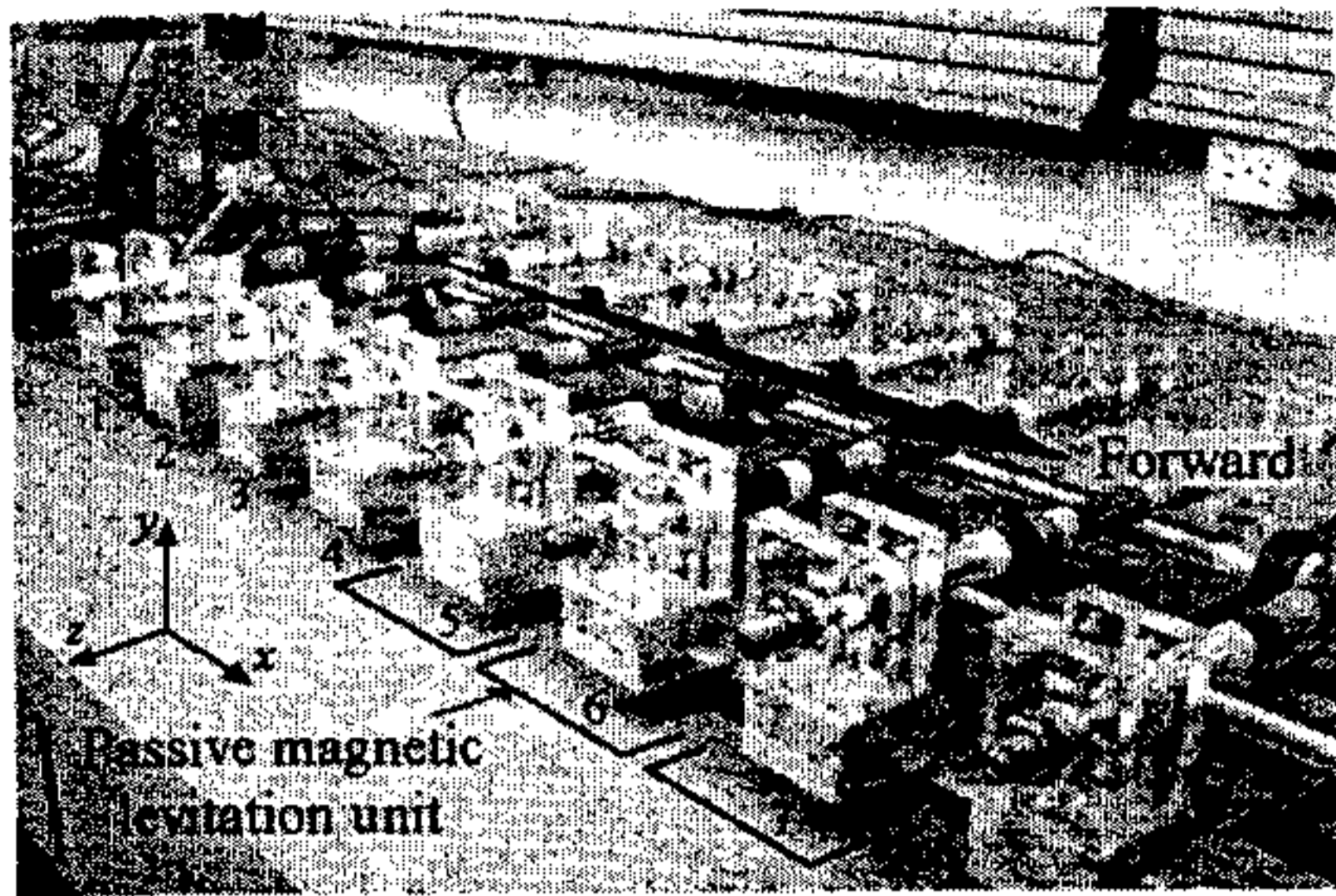


Fig. 10 Configuration of the permanent magnet repulsive type conveyor for rotation mode.

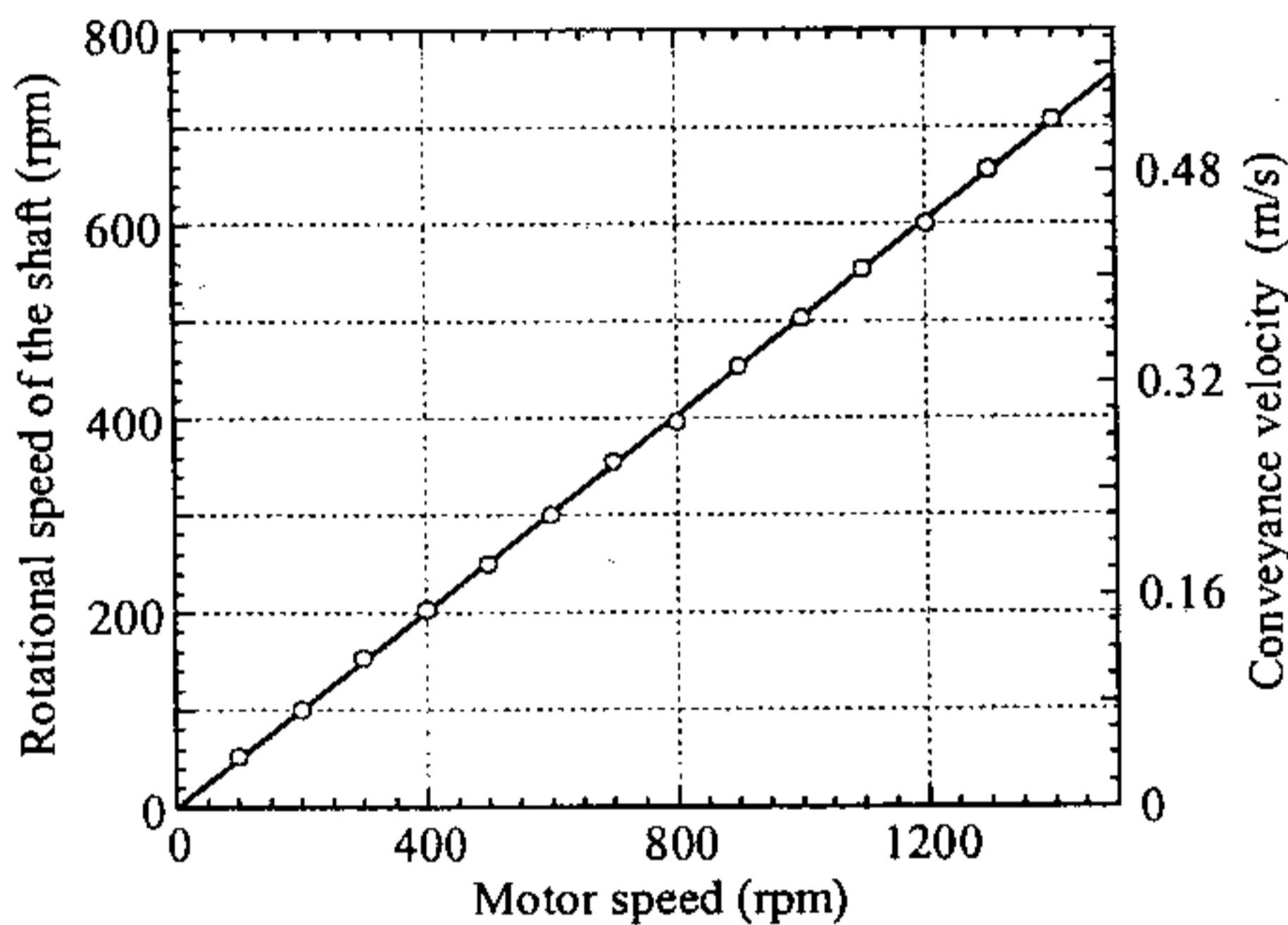


Fig. 11 No-load characteristics.

up to a maximum rotational speed of bar magnets, and the maximum conveyance velocity (i.e., the peripheral velocity of the shaft) is around 0.61 m/s. Fig. 12 shows the relationship between the allowance weight and the conveyance velocity. An air-gap between the rubber magnet and the bar magnet was set up by three kinds of distance in Fig. 12. This result indicates that the maximum loading weight and the maximum conveyance velocity in a 3.7 mm gap are around 15 N and 0.61 m/s, respectively. In the case of a large gap, even if a light sample is carried on the shaft, the levitator shafts cause step out. On the other hand, in the case of a small gap, though a light sample is carried on at the maximum velocity, the gap decreases with the increase of a sample mass, and the levitator shaft contacts bar magnets at last. In order to utilize the gap between the rotor and stator permanent magnets effectively, the gap between rubber magnets and bar magnets should be set up about the same as it.

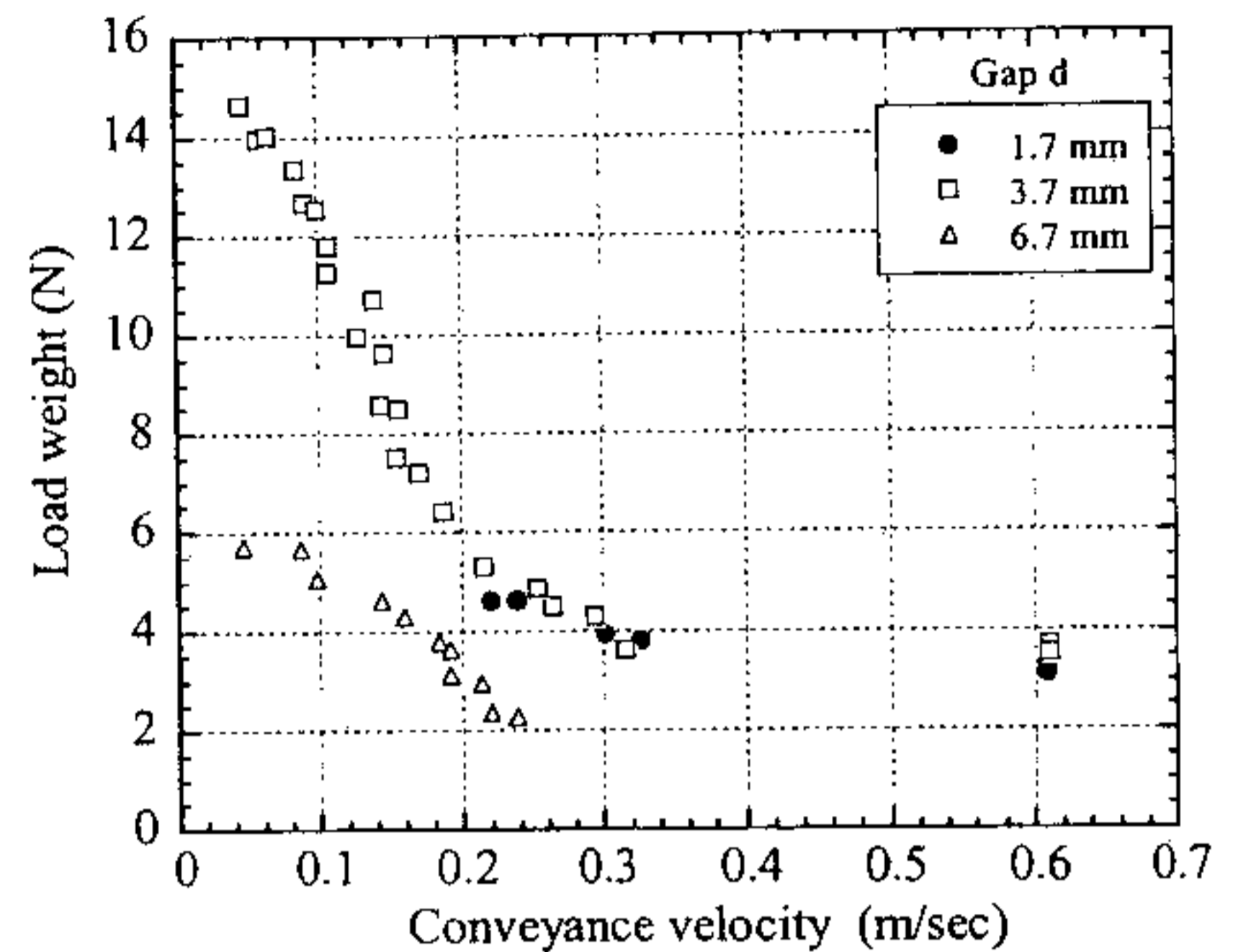


Fig. 12 Characteristics of allowance weight vs. conveyance velocity.

#### 4. CONCLUSIONS

The passive magnetic repulsive type conveyor system with the features of soft levitation and easy rotation has been reported as a new application of the repulsive type magnetic bearing in this paper. Taking these features into consideration, the conveyor structures about two kinds of conveyance modes have been proposed, and the conveyance tests for both structures were carried out. In particular, the high-speed and constant conveyance velocity was achieved in the conveyor structure by rotation mode. Whenever an object is conveyed on the conveyor, the levitator shafts go down to the vertical direction. On the basis of this point, mass detection of an object, fractionation, and an active control of shafts are due to be performed by detecting the position of shafts.

#### 5. ACKNOWLEDGEMENT

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