Fabrication of a Repulsive-Type Magnetic Bearing Using a Novel Arrangement of Permanent Magnets for Vertical-Rotor Suspension

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***Abstract*—A repulsive-type magnetic bearing system has been fabricated in which the rotor of a vertical-shaft-type motor is levitated due to the repulsive force between two sets of permanent magnets. A novel arrangement of permanent magnets has been reported here, which has made the suspension of the rotor possible. The system is planned to be applied for pumping milks and other related products in the New Zealand dairy industry.**

***Index Terms*—Circular disk, dairy industry, magnetic bearing, permanent magnet, repulsive type, rotor suspension.**

I. Introduction

In a repulsive-type magnetic bearing system, usually the rotor is levitated by the repulsive forces between stator and rotor permanent magnets. The system is unstable in nature. The controlled electromagnet is used to keep the rotor in the desired position. The repulsive magnetic bearing system has the advantages of using a smaller number of electromagnets and simplified control scheme compared to an active magnetic bearing system. The advantages of using a magnetic bearing system compared to mechanical bearing in high-speed motors are long life, frictionless and lubrication free operation, feasible operation at high speed, etc. Many research papers have been published on magnetic bearings using permanent magnets [1]–[2]. But the satisfactory performance of this type of magnetic bearing is strongly dependent on the characteristics of the permanent magnet and its configuration in the bearing system. Two repulsive magnetic bearing systems using permanent magnets for the levitation were fabricated a few years back [3]–[4], and their levitation and control performance were compared. Due to aging and/or as both the magnets are repelling each other, there will be demagnetization of the permanent magnet, resulting in the field distribution along the magnet's periphery nonuniform, and this will affect the performance of the bearing system [5].

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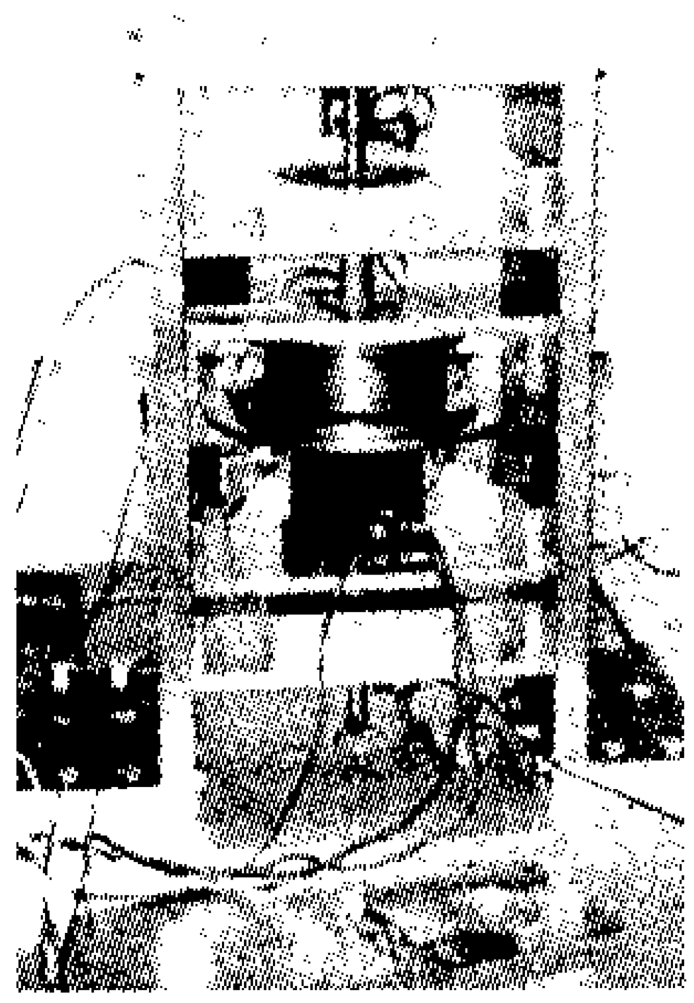

Fig. 1. Magnetic bearing for vertical shaft machine.

II. Background of the Project

The repulsive-type magnetic bearing system for the vertical shaft machine is shown in Fig. 1, and it was fabricated a few years back. The magnet used for the system was of circular configuration. This type of bearing system is stable along the radial direction but is unstable along the vertical axis.

After around five years of operation, the flux density distribution of the magnets for this system became nonuniform, which has affected its performance. The different remedial measures were reported in [5], but the best option is to replace the permanent magnets, which is a costly solution.

III. System Configuration

In this project, we aim to fabricate a repulsive-type magnetic bearing system for a vertical shaft machine using a novel arrangement of permanent magnets and also a cheaper option compared to our earlier model. Instead of using big circular magnets, many small circular permanent magnets are used which are arranged along the periphery of a circular disk made up of aluminum. The schematic arrangement of the permanent magnets in two dimension and the forces are shown in Fig. 2. Two such disks are used as shown in Fig. 3, one of which is fixed to the stator and the other fixed to the rotor shaft. They form a magnetic bearing. Two such bearings are used to levitate the rotor of the motor; the top one is shown in Fig. 4.

The thickness, number of magnets, and their arrangements is a matter of interest from stability consideration. An analytical model has been done to characterize the forces along three axes.

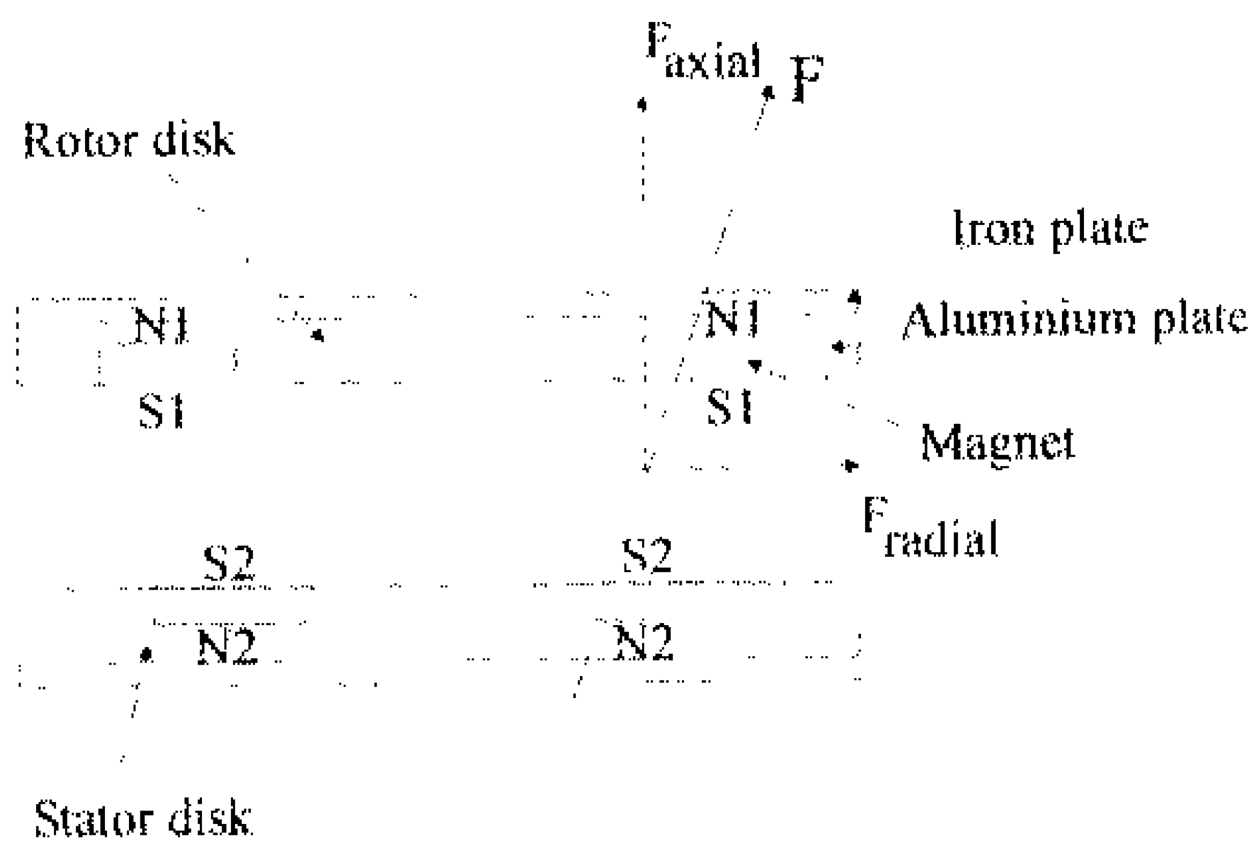

Fig. 2. Schematic representation of magnet arrangement and forces.

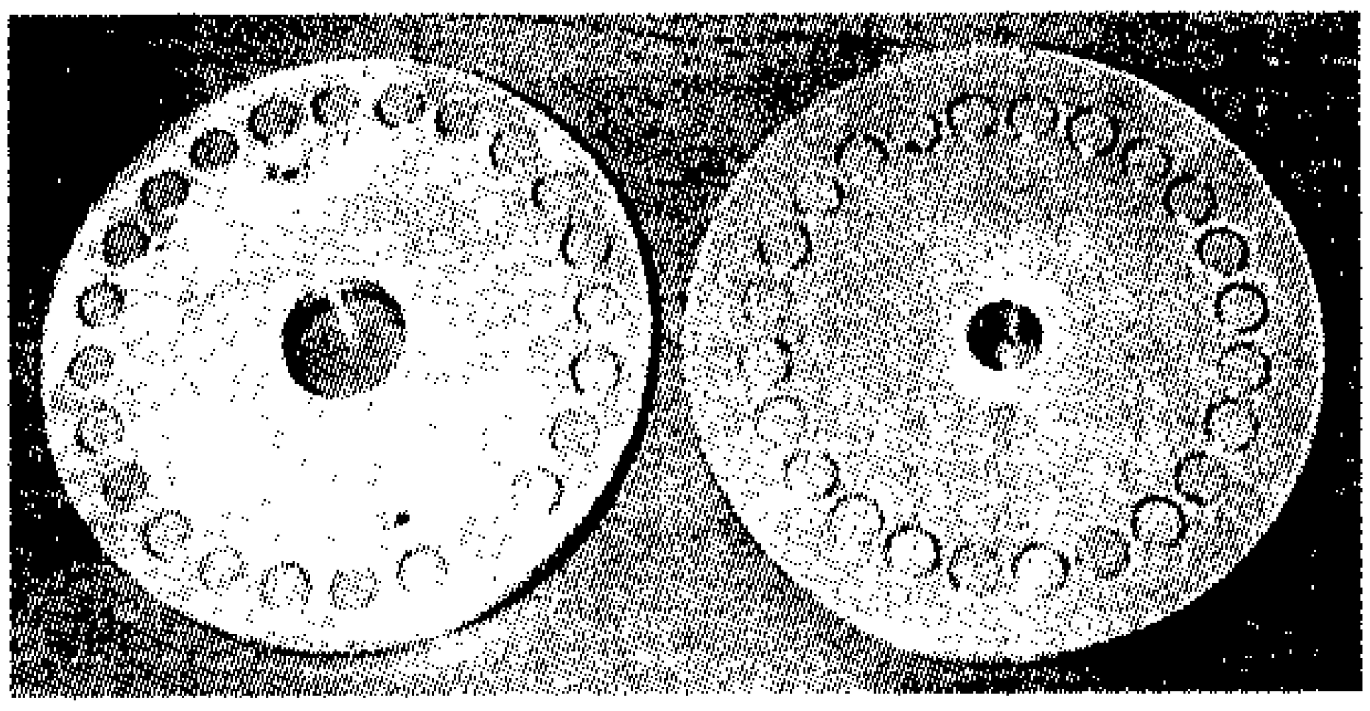

Fig. 3. Fabricated magnetic bearing.

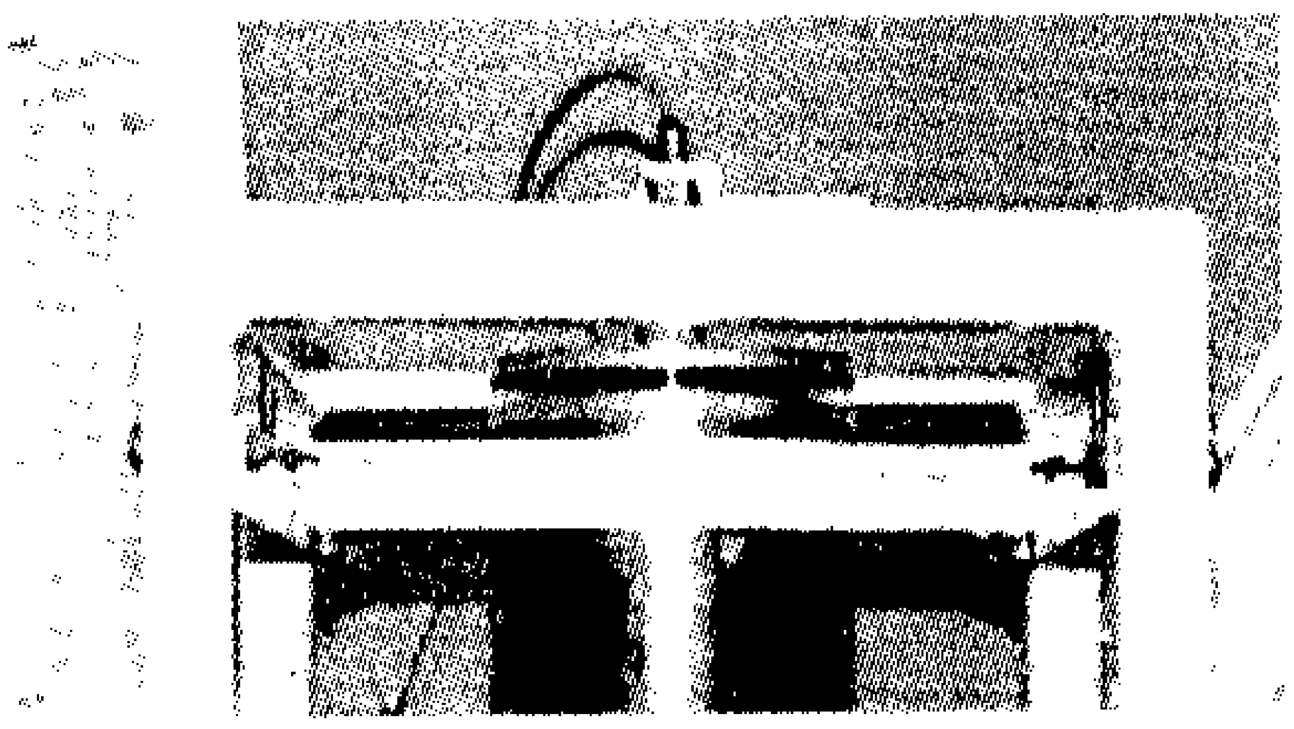

Fig. 4. Upper magnetic bearing.

The analytical expression of force between two magnet pole of intensity Q_{m1} and Q_{m2} is given by (1)

$$F = \frac{\mu_0 Q_{m1} Q_{m2}}{4\pi r_{12}^2} u_{12} \quad (1)$$

in which the intensity Q_m is given by $Q_m = H_C A$; H_C is the coercive force and A is the pole face area. It is assumed here that the pole intensity of the magnet is concentrated at the center of the magnet. The unit vector u_{12} is directed along the line joining Q_{m1} and Q_{m2}. There are four forces acting between two magnets as shown in Fig. 2. F_{N1S2} and F_{N2S1} are the attractive forces and F_{N1N2} and F_{S1S2} are the repulsive forces. The resultant force is given by the vector sum of all the forces. Table I shows the specifications of the magnet used to fabricate the system.

Fig. 5 shows the force characteristic as a function of gap distance between the two disks for different magnet thickness in

TABLE I
SPECIFICATIONS OF THE MAGNET

Make	The Magnet Source, USA
Part number	Neodymium 27H
Size	Dia = 0.375" and Thickness = 0.1"
Residual flux density	1.08 T
Coercive force	0.779 X 10^6 A/m

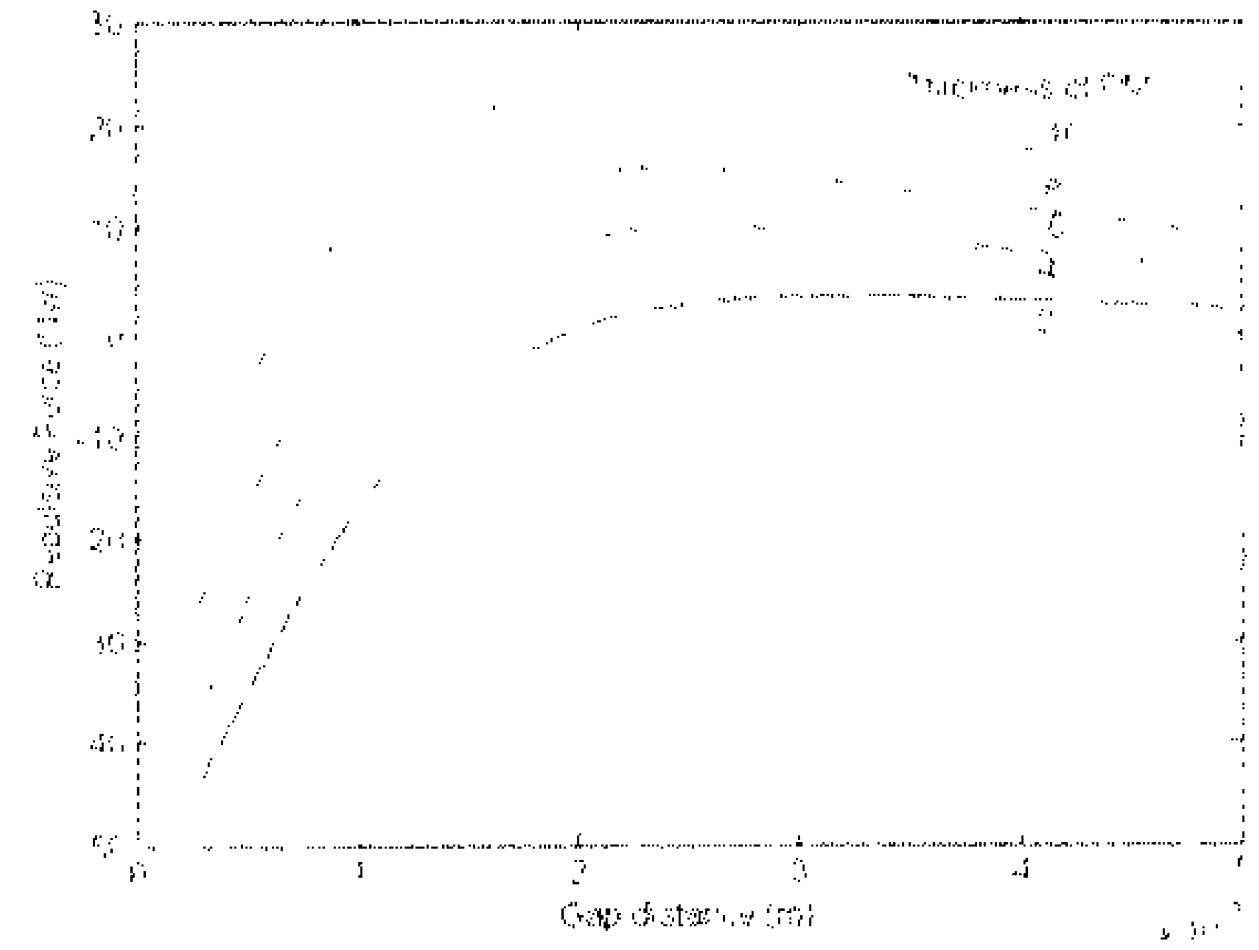

Fig. 5. Variation of repulsive force with gap distance for different PM thickness.

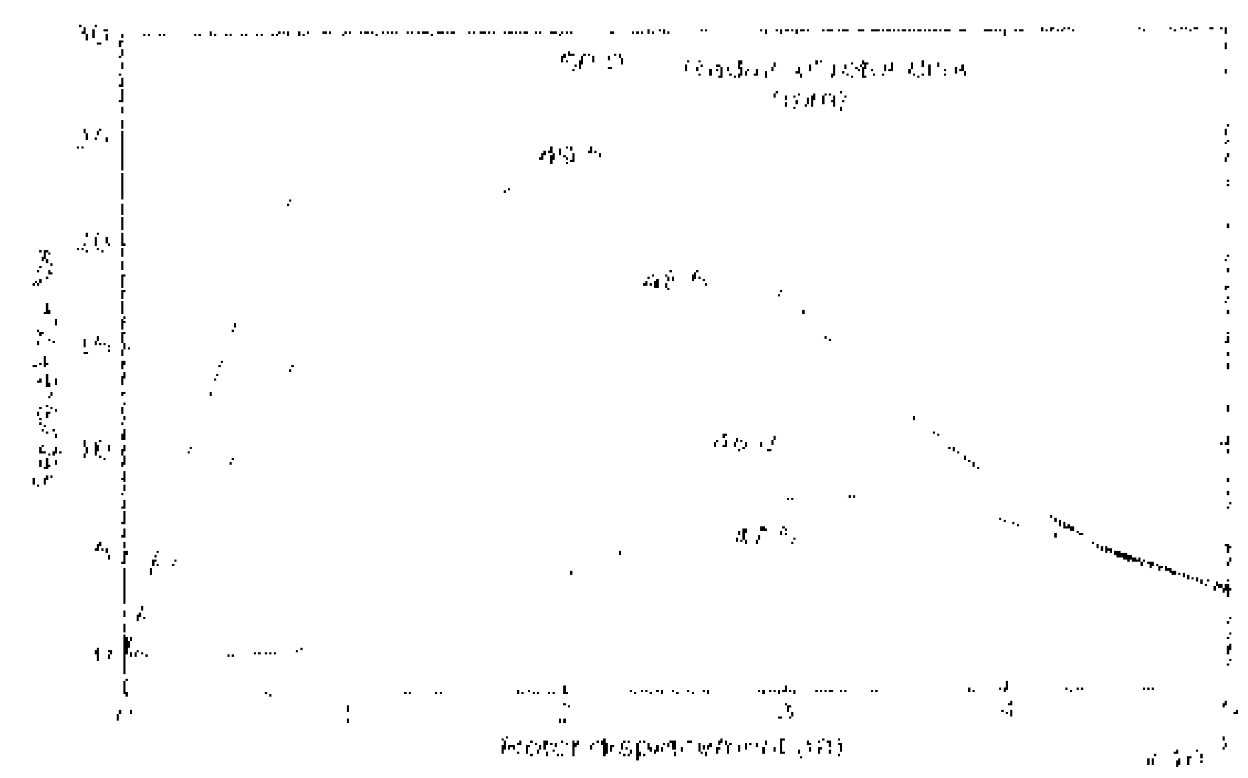

Fig. 6. Variation of repulsive force with radial displacement.

which 24 magnets are used in each disk. It is seen that the repulsive force between the disks appears when the gap between them is becoming larger than that of a certain value. So the selection of magnet thickness and the gap between the disks to be selected based on some criterion.

The distance of the center of the magnets from the disk center is 50 mm for stator disk and that of rotor disk is 47.5 mm. The selection of this parameter is explained in Fig. 6. If there is a displacement of 1 mm along the radial axis, the rotor will come back to the original central position for 47.5 mm while the other cases it will go to one extreme side.

Based on the above studies, a system has been fabricated in which 24 magnets are arranged in a circular disk separated by 15° from each other as shown in Fig. 3.

IV. ROTATIONAL CHARACTERISTIC

The repulsive force varies considerably when the rotor rotates around its axis. Fig. 7 shows the variation of repulsive force as a function of rotor movement for two different radii of rotor disk. Even though the radius of rotor permanent magnet of the fabricated system is 47.5 mm, it is seen from Fig. 7 that there

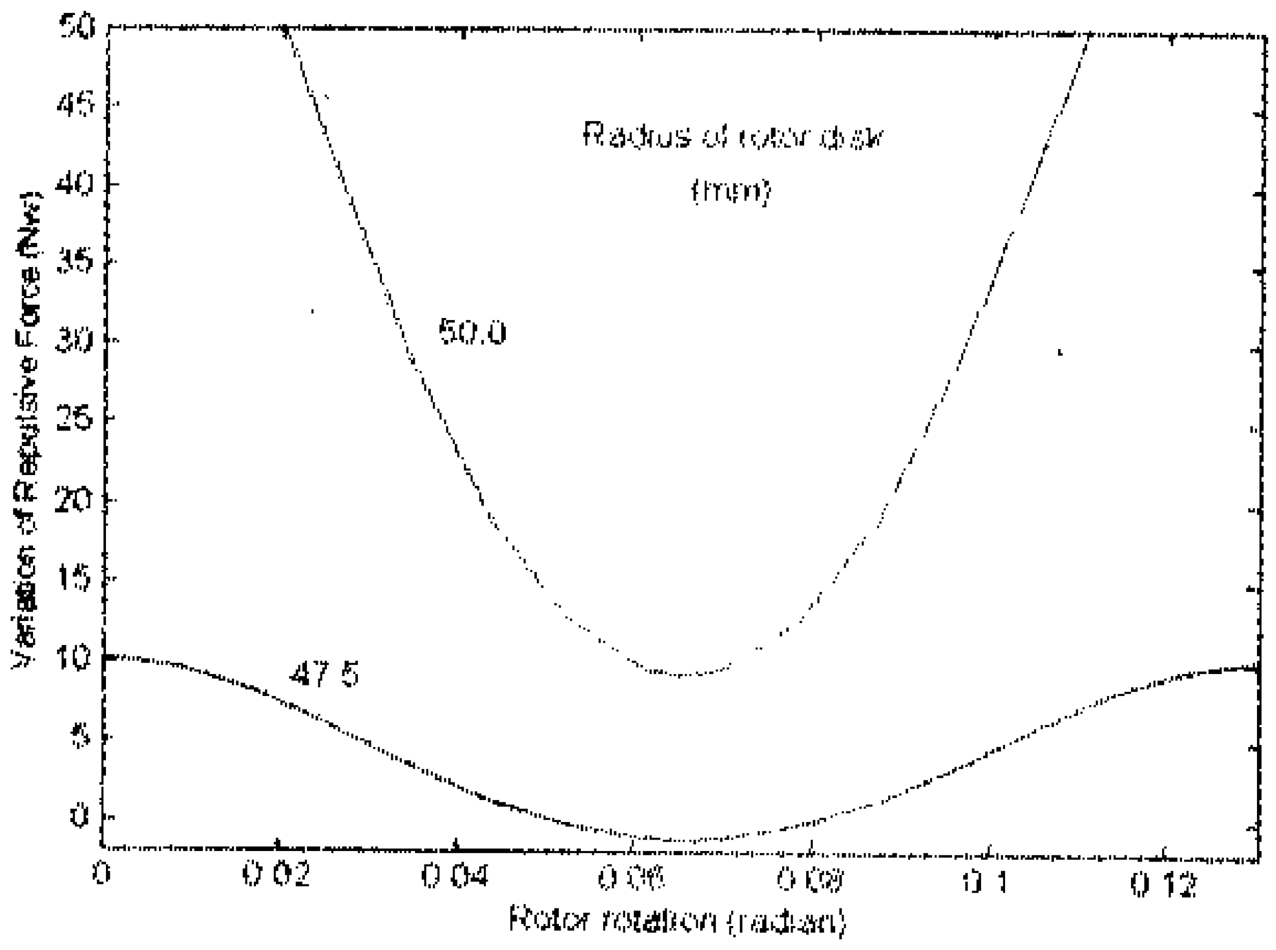

Fig. 7. Variation of repulsive force with rotor movement.

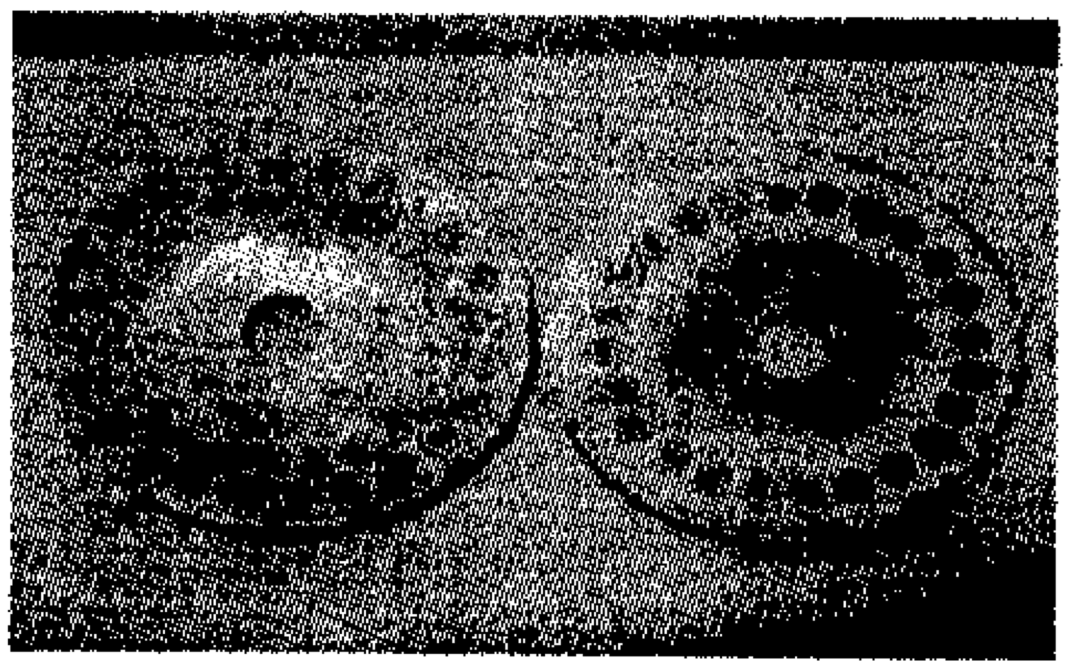

Fig. 8. Fabricated bearing with two sets of PMs in stator disk.

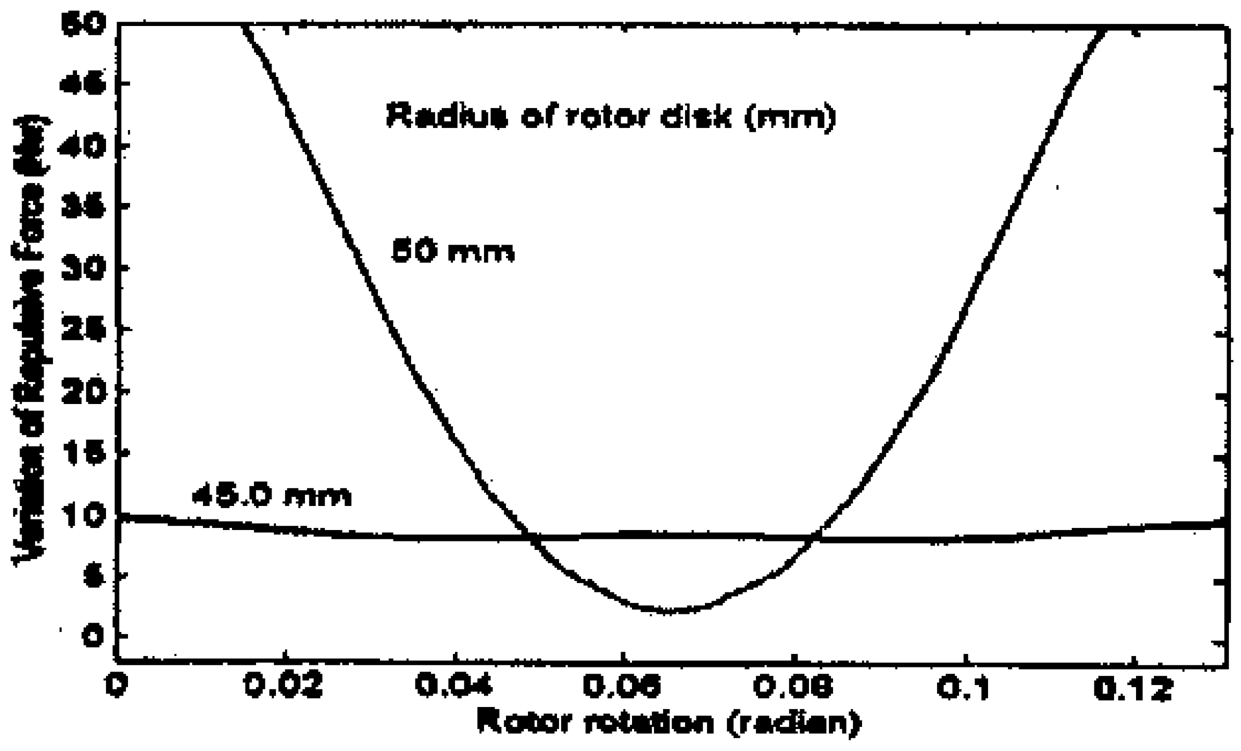

Fig. 9. Variation of repulsive force for the system shown in Fig. 8.

is a considerable change of force. This will behave as a ripple torque during the normal running condition of the rotor. In order to reduce the gravity of this problem, another set of permanent magnets is decided to be placed on the stator disk at a radius of 40 mm and is displaced by half pitch (7.5°) to that of other. The radius of the rotor disk is changed to 45 mm and the fabricated system is shown in Fig. 8. The simulated force characteristics is shown in Fig. 9. It is seen from Fig. 9 that the ripples in the force reduces to a negligible value.

V. Fabrication and Experiment

Based on the magnetic bearing as shown in Fig. 8, the complete system has been fabricated and is shown in Fig. 10. The system is unstable along the vertical direction. A controlled electromagnet has been used for controlling the rotor position along this axis. The repulsive force due to one set of magnetic bearings has been measured using available strain-gauge based force measurement rig. Fig. 11 shows the experimental repulsive force characteristics for one set of bearings and it is seen

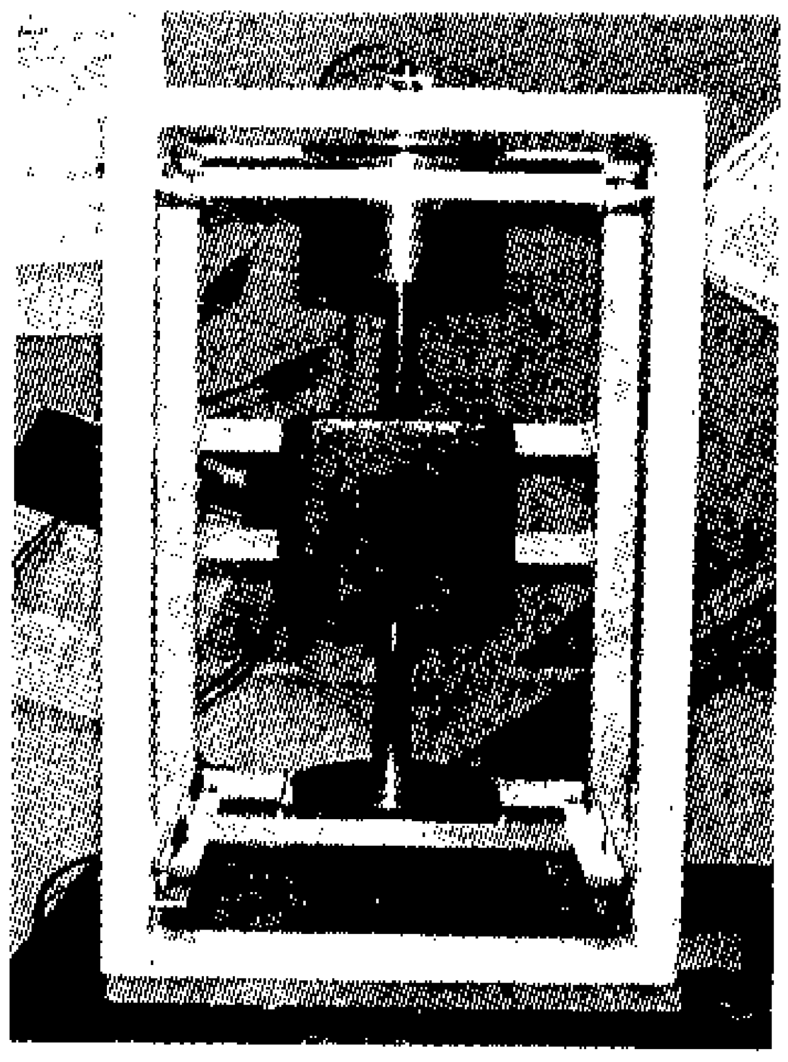

Fig. 10. Fabricated magnetic bearing system.

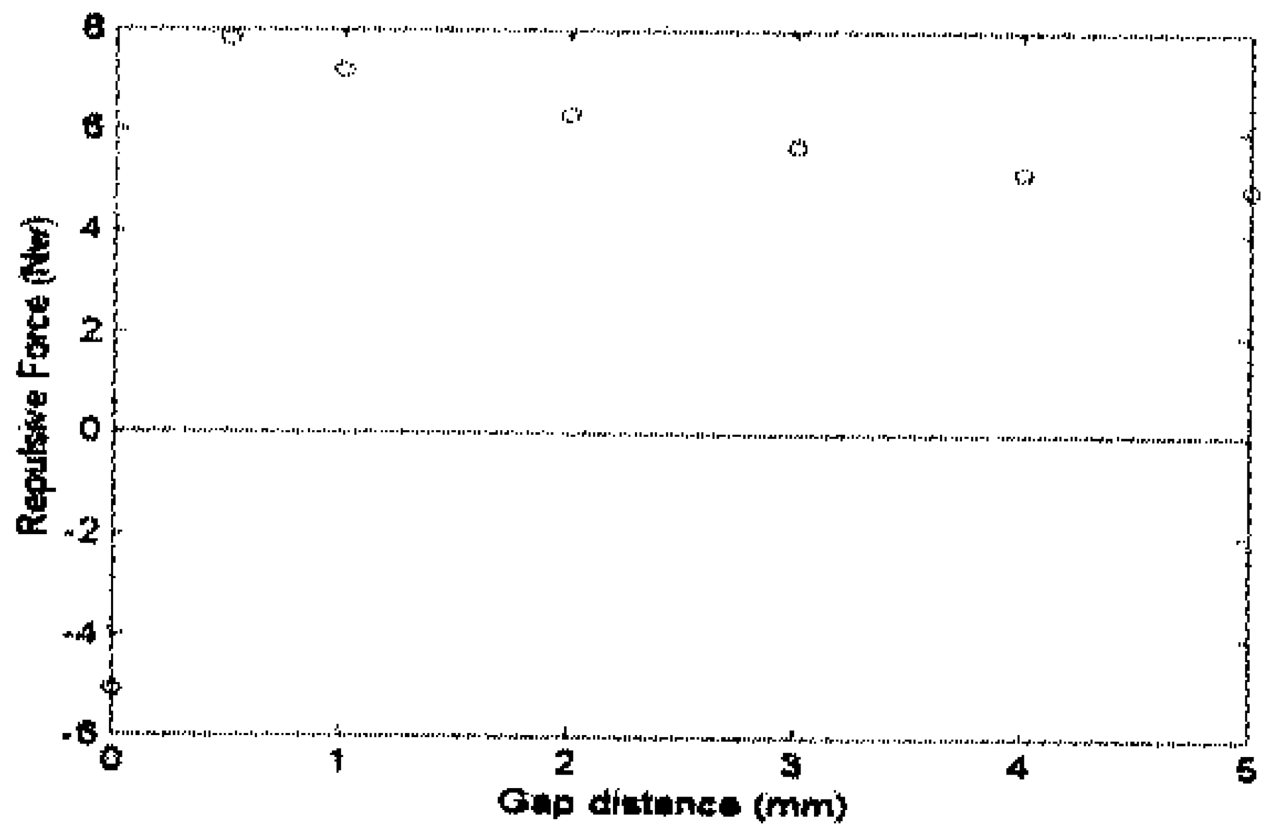

Fig. 11. Measured repulsive force characteristic.

that a total weight 1.4 kg to be levitated by both the bearings. The electromagnet is used to share a part of the weight of the rotor.

VI. Conclusion

A prototype model of a repulsive-type magnetic bearing system using a novel arrangement of permanent magnets has been fabricated. Our aim is to make this magnetic bearing system useful to dairy industries. Since New Zealand is very strong in the dairy industry, this system will find a suitable application for pumping milk and other such products in which a dirt-free, clean-room atmosphere is required. By providing magnetic bearing, it is possible to achieve that, and to get rid of the sensors, a sensorless scheme has been planned to be implemented in near future.

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