

## A MAGNETIC BEARING BASED ON EDDY-CURRENT REPULSION

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This paper describes a new type of electromagnetic bearing, called the 'Eddy-Current Bearing,' which works by repulsion between fixed AC-electromagnets and a conducting rotor. The following advantages are expected: inherent stability, higher load carrying capacity than DC-electromagnetic bearings, simultaneous radial, angular and thrust support, motoring and generating capability, and backup mode of operation in case of primary power failure. A prototype is under construction.

## INTRODUCTION

Levitation of conducting material by AC-electromagnets, as shown in figure 1, is a well-known phenomenon. The AC-current in the magnet sets up a constantly changing magnetic field which induces eddy-currents in the conducting plate. The direction of rotation of the eddy-currents is such that the resulting secondary magnetic field will oppose the primary field. E.g., whenever a north pole is being generated in the primary field, a north pole will also be generated in the secondary field and steady repulsion will take place between the magnet and the plate. This is the basic operating principle of the Eddy-Current bearing outlined in this paper.

## BACKGROUND

AC-electromagnetic levitation of conducting material has inspired many inventions throughout this century. Some early outstanding examples are: the Foucault Railroad of 1912 (ref. 1), Anschutz-Kaempfe's gyro of 1923 (ref. 2), and Orkress' levitation of molten metal without a crucible in 1952 (ref. 3).

In the 1960's, the principle was applied in contactless suspension of high-speed ground transportation vehicles (ref. 4). Development took place in competition primarily with controlled DC-electromagnetic suspensions and cryogenic type suspensions using superconducting magnets. An excellent survey of these and other types of magnetic suspensions can be found in references 5 and 6.

The potential of the AC-electromagnetic type suspension was fully realized in 1974 when Eastham and Laithwaite presented their so-called 'Magnetic River' suspension (ref. 7). It consists of a single linear induction motor which has been adapted to provide not only stable levitation but also propulsion and guidance of itself along a conducting rail without any feedback control (fig. 2). There is even a technique available by which the 'Magnetic River' can be made to stop safely on the rail in case of power failure (ref. 8).

By their very nature, the competing suspensions have no capability for propulsion or emergency stopping. However, they remain strong contenders due to some problems with the Magnetic River which are still unresolved. The primary problem is a low power factor which appears to necessitate forced cooling of the magnets and use of heavy power-factor-correcting capacitors in order to achieve large levitation gaps (ref. 9). Also, the inherent damping in the system is apparently very light and some form of feedback control may be needed to improve it (ref. 10). Finally, analytical predictions of the performance are exceedingly difficult to make due to the complex three-dimensional interactions which take place between the primary and secondary electromagnetic fields. Thus, improvements have had to be made largely by trial-and-error experimentation based on the intuition of a few specialized engineers (ref. 7). This work has been made even more difficult by the fact that apparently minor changes in geometry have been found to produce large unexpected changes in performance. Relief finally appears to be in sight with recent developments of finite element methods intended specifically for design studies of the Magnetic River (refs. 10, 11 and 12).

### THE EDDY-CURRENT BEARING

The Eddy-Current bearing, as shown in figure 3, is made simply by bending the Magnetic River of figure 2 into a circular shape. An extensive literature survey has indicated that this has not previously been done although the possibility of doing so has previously been mentioned in reference 13 during the discussion of another electromagnetic bearing.

The many advantages of the Magnetic River suspension, as mentioned previously, are expected to translate into similar advantages of the Eddy-Current Bearing as discussed in the following sections. Also, the problem with the low power-factor in the Magnetic River is expected to diminish in the Eddy-Current bearing because the airgap is much smaller. The inherent system damping will probably remain low in the Eddy-Current bearing, but this could be compensated by use of a passive eddy-current damper (ref. 14). Finally, the recent finite element methods for the Magnetic River are expected to be applicable to design studies of the Eddy-Current bearing also. A brief discussion of each of the expected advantages of the Eddy-Current bearing is given in the following sections.

### Support and Motoring Capabilities

The Eddy-Current Bearing is expected to provide stable support in both the radial, angular, and axial directions simultaneously without any feedback control. This follows from the capability of the Magnetic River to fully support and guide itself along a rail without feedback control. Also, since the Magnetic River is essentially a linear induction motor, it has both motoring, braking and electricity generating capabilities (refs. 7, 8). The Eddy-Current Bearing is also basically an induction motor which can be expected to have those same capabilities.

## Load Capacity

The load carrying capacity per unit weight of both DC-electromagnetic and AC-electromagnetic suspensions depend on size. DC-suspensions are more efficient the smaller they are while AC-suspensions are more efficient the larger they are (ref. 15). For vehicle size suspensions, levitation gaps of over 10 inches are possible with the Magnetic River whereas controlled DC-magnet suspensions are limited to less than 1 inch airgap (ref. 16). The effect on bearing derivatives of these suspensions is not known. However, the large difference in levitation gaps indicates a potential for improved load capacity of the Eddy-Current bearing which warrants further investigation.

## Emergency Shutdown

The operating principle of the Eddy-Current bearing is such that it may be possible to continue operation after a power failure long enough to ensure safe shutdown without the need for catcher bearings. In principle, this can be done by switching to battery operated DC-power direct to the magnets. The operating principle would then change to so-called electrodynamic levitation with the eddy-currents induced by the motion of the rotor surface past a row of DC-electromagnets. This principle is used in eddy-current brakes (ref. 17) and in high-speed vehicles with superconducting magnet suspensions (ref. 18). Inherent stability is retained and the airgap is so small that a good possibility exists for generating sufficient lift with acceptable coil currents for a short time interval. The eddy-current drag will automatically decelerate the rotor and, eventually, metal contact will occur at low speed.

It is emphasized that no Eddy-Current Bearing yet exists and the capabilities suggested here remain speculation. A prototype of the bearing is currently under construction and a preliminary test program is scheduled for the summer of 1986 to determine whether further investigation is justified. A patent disclosure has been submitted and a patent search is underway.

## CONCLUDING REMARKS

A new type of magnetic bearing, called the Eddy-Current Bearing, has been introduced. It derives from a magnetic vehicle-suspension called the Magnetic River. An extensive literature survey on the Magnetic River has suggested that the Eddy-Current bearing will have a number of important advantages over existing magnetic bearings. A research program is underway to determine the extent of these advantages.

## REFERENCES

1. "Foucault and Eddy Currents put to Service," The Engineer, Vol. 114, Oct. 18, 1912, pp. 414 and 420-421.
2. Anschutz-Kaempfe, H., "On Gyroscopic Apparatus," U.S. Patent 1589039, 1923.

3. Orkress, E. C., et al., "Electromagnetic Levitation of Solids and Molten Metals," J. Phys., Vol. 23, No. 12, 1952, p. 1413.
4. Hochhausler, P., "The Magnetic Railroad," ETZ-B, Vol. 23, No. 13, 1971, pp. 311-313. (In German)
5. Jayawant, B. V., "Electromagnetic Levitation and Suspension Techniques," Edward Arnold, London, 1981.
6. Jayawant, B. V., "Electromagnetic Suspension and Levitation," IEE Proc., Vol. 129, Pt. A, No. 8, 1982, pp. 549-581.
7. Eastham, J. F., and Laithwaite, E. R., "Linear Induction Motors as Electromagnetic Rivers," Proc. IEE, Vol. 121, No. 10, 1974, pp. 1099-1108.
8. Laithwaite, E. R., "Three-Dimensional Engineering," Laithwaite, E. R. (Editor): "Transport Without Wheels," Elek Books, London, 1977, pp. 279-303.
9. Eastham, J. F., "The Magnetic River," SRC Advanced Ground Transportation Panel Meeting, London, U.K., Feb. 1978.
10. Rodger, D., and Eastham, J. F., "Dynamic Behavior of Linear Induction Machines in the Heave Mode," IEEE Trans. Vehic. Tech., Vol. VT-31, No. 2, May 1982, pp. 100-106.
11. Rajanathan, C. B., "Study of Xi-Core Transverse-Flux Plate Levitator," IEE Proc., Vol. 127, Pt. B, No. 3, May 1980, pp. 183-189.
12. Rajanathan, C. B., et al., "Finite Element Analysis of the Xi-Core Levitator," IEE Proc., Vol. 131, Pt. A, No. 1, Jan. 1984, pp. 62-66.
13. Bolton, H., "An Electromagnetic Bearing," IEE Conf. Publ. No. 120, Conf. on Linear Electric Machines, London, Oct. 1974, pp. 45-50.
14. Robinson, A. A., "Magnetically Suspended Momentum Wheel for Satellite Stabilization," IEE Conf. Publ. No. 142, 2nd Conf. Adv. Mag. Mater. & Appl., London, Sept. 1976, pp. 131-134.
15. Laithwaite, E. R., "Magnetic or Electromagnetic? The Great Divide," Electronics & Power, Vol. 19, No. 14, Aug. 1973, pp. 310-312.
16. Laithwaite, E. R., "Four Legs are Better than Two," Electrical Review, Vol. 202, No. 18, May 1978, pp. 30-31.
17. Singh, A., "Theory of Eddy-Current Brakes with Thick Rotating Disc," Proc. IEE, Vol. 124, No. 4, Apr. 1977, pp. 373-376.
18. Rhodes, R. G., and Mulhall, B. E., "Magnetic Levitation for Rail Transport," Oxford University Press, New York, 1981.

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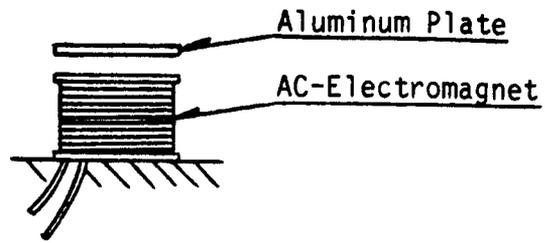


Figure 1. Electromagnetic Levitation

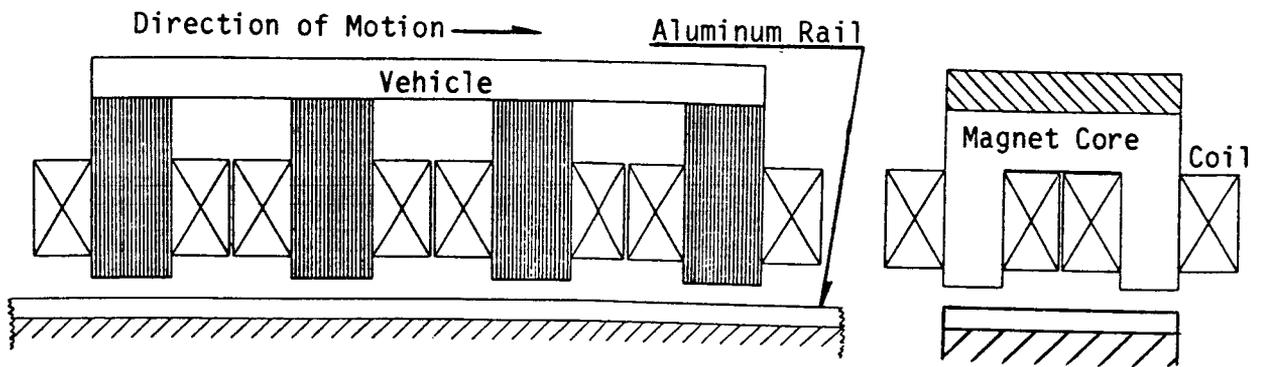


Figure 2. The Magnetic River Suspension (Schematic)

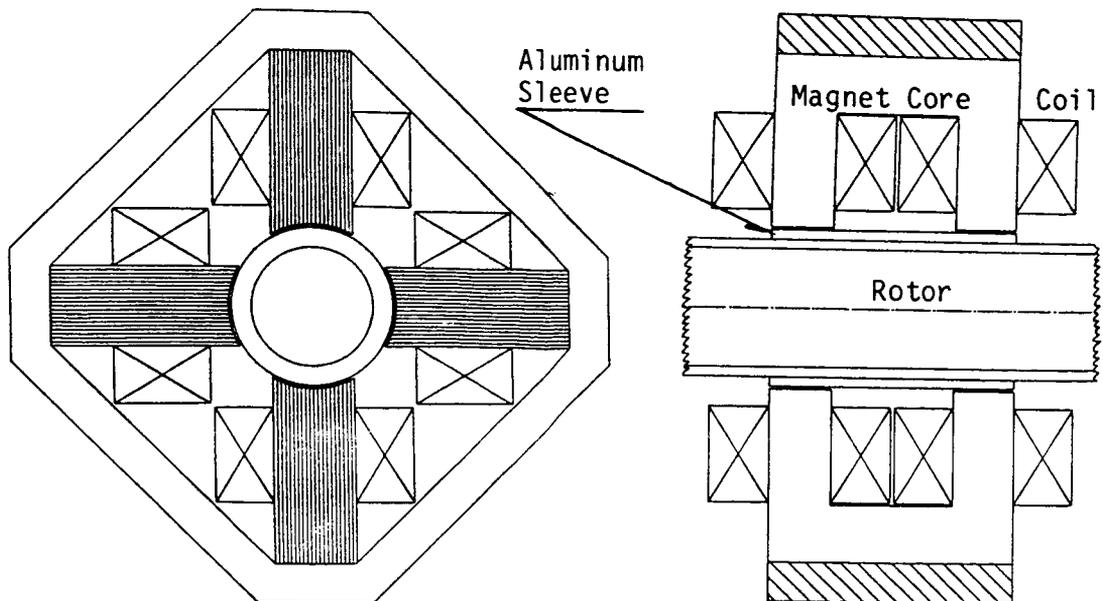


Figure 3. The Eddy-Current Bearing (Schematic)

#### ADDITIONAL BIBLIOGRAPHY FOR MAGNETIC BEARINGS

1. Eisenhaure, D.B.; and Kingsbury, E.P.: Final Report on the Development of an Advanced Flywheel Bearing Performance Model. Sandia Laboratories. SAND79-7003, 1979.
2. Eusepi, M.; Martin, L.; and Ray, A.: Application of Magnetic Suspensions and Fluid Film Bearings to Energy Storage Flywheels. Sandia Laboratories. SAND79-7007, 1979.
3. Groom, Nelson J.; Woolley, Charles T.; and Joshi, Suresh M.: Analysis and Simulation of a Magnetic Bearing Suspension System for a Laboratory Model Annular Momentum Control Device. NASA TP-1799, 1981.
4. Henrikson, Carl H.; Lyman, Joseph; and Studer, Philip A.: Magnetically Suspended Momentum Wheels for Spacecraft Stabilization. Aerospace Sciences Conference, AIAA, 1974.
5. Kirk, James A.; Studer, Philip A.; and Evans, Harold E.: Mechanical Capacitor. NASA TN-D-8185, 1976.
6. Studer, Philip A.: Magnetic Bearings for Instruments in the Space Environment. NASA TM-78048, 1978.
7. Studer, Philip A.; and Gasser, Max G.: A Bi-directional Linear Motor/Generator With Integral Magnetic Bearings for Long Lifetime Stirling Cycle Refrigerators. First Biannual Conference on Refrigeration for Cryogenic Sensors, National Bureau of Standards (NBS) (Boulder, Colorado), Oct. 1980.
8. Wilson, Meredith; and Studer, Philip A.: Linear Magnetic Bearings. Proceedings of the Fifth International Workshop on Rare Earth-Cobalt Permanent Magnets and Their Applications (Roanoke, Virginia), Paper No. V-4, June 1981.