N93-27573

163499

p- 7

AN AC-ELECTROMAGNETIC BEARING FOR FLYWHEEL ENERGY STORAGE IN SPACE*

Jorgen L. Nikolajsen
Texas A&M University
College Station, Texas

SUMMARY

A repulsive type AC-electromagnetic bearing has been developed and tested. It was conceived on the basis of the so-called Magnetic River suspension for high-speed trains. The appearance of the bearing is similar to the traditional DC-type electromagnetic bearing but the operating principle is different. The magnets are fed with alternating current instead of direct current and the rotor is fitted with a conducting sleeve (e.g. aluminum) instead of a ferromagnetic sleeve. The repulsion is due to induction of eddy-currents in the conducting sleeve.

The bearing is inherently stable and requires no feedback control. It provides support in five degrees of freedom such that a short rotor may be fully supported by a single bearing. These capabilities have been demonstrated experimentally. On the down side, the load carrying capacity and the damping obtained so far have been quite low compared to the DC-type bearing. Also, significant heating of the conducting sleeve has been experienced.

The AC-bearing is essentially a modified induction motor and there are strong indications that it can be run both as a motor and as a generator with no commutator requirements. It is therefore considered to be a good candidate for support of energy storage flywheels in space.

INTRODUCTION

A new type of electromagnetic bearing, called the Eddy-Current Bearing, has been developed based on the so-called Electromagnetic River Suspension for high-speed ground transportation vehicles. See Eastham & Laithwaite [1]. The Magnetic River is shown in Figure 1. Suspension is achieved by repulsion between a set of AC-electromagnets and an aluminum plate.

---

*This work is supported by the Turbomachinery Research Consortium. Rig hardware was donated by International Minerals & Chemicals Corporation and by Magnetic Bearings Incorporated.

PRECEDING PAGE BLANK NOT FILMED

316 INTENTIONALLY BLANK

The repulsion is due to induction of eddy-currents in the plate. The Eddy-Current Bearing is simply a circular version of the Magnetic River as shown in Figure 2. This bearing was first proposed by Nikolajsen [2] in 1986.

Work on other types of AC-electromagnetic bearings has been reported by Bolton [3] in 1974, Iskierka [4] and [5] in 1984 and Connor & Tichy [6] in 1987.

Based on the reported work on the Magnetic River Suspension (see references quoted in Ref. [2]) the Eddy-Current Bearing was expected to have some unique capabilities which would make it a prime candidate for flywheel energy storage systems: (1) a single bearing would be sufficient to fully support the flywheel, (2) the bearing would be inherently stable with no need for a feedback control system, and (3) the bearing would have motoring and generating capabilities in addition to the support capabilities. The current paper reports on the experimental verification of capabilities (1) and (2). Verification of capability (3) is in progress.

THE PROTOTYPE BEARING

Analytical studies of a practical Eddy-Current Bearing design are difficult due to the three-dimensional interactions between the primary electromagnetic field set up by the magnets and the secondary field due to the eddy-currents in the conducting sleeve. It was therefore decided to base the prototype bearing design solely on the reported behavior of the Magnetic River suspension (see references quoted in Ref. [2]). This approach was expected to lead to a design with far from optimum capabilities but at least possessing the basic characteristics to be verified as mentioned in the Introduction.

Four U-shaped electromagnets are spaced 90° apart in a star formation to form a 4 inch diameter bearing as shown in Figures 2, 3, and 4. The magnets are mounted in a nonmagnetic stainless steel housing. The magnet cores are made of grain-oriented 0.014 inch laminations with a saturation flux density of about 2 Tesla. The coils have 58 turns each to achieve a peak flux density of about 1.5 Tesla. The inductance of two coils mounted on one core was measured to be about 3.2×10^{-3} Henry.

Each of the four magnets has an electric circuit as shown in Figure 5. Power is supplied from a 115V 60 Hz single phase outlet. The power is adjusted by means of the variable transformer. The variable capacitor is used to adjust the power factor to reduce the power requirements to cover only the I^2R losses in the coil and in the conducting sleeve. The result is that a large current circulates between the capacitor and the coil while a relatively small current is drawn from the supply. The variable capacitor consists of a bank of 13 250μF oil-filled capacitors in parallel which can be switched in and out of the circuit independently. Fine-tuning of the power factor is therefore not possible but the reactive power can be reduced sufficiently to permit the experimentation with the available equipment. It was generally found that 11 to 13 capacitors needed to be switched in to minimize the supply current.
The rotor to be levitated was an aluminum sleeve 6 inches long with an outer diameter of 3.75 inches and a weight of 2lb. 5oz.

EXPERIMENTS

The first two attempts to levitate the rotor were unsuccessful. The first problem was an underestimation of the coil inductance resulting in coils with too many turns and magnets with insufficient flux density. The second problem was a lack of stability of the rotor. It would oscillate radially and bounce off the bearing surfaces at close to the power frequency. The problem was solved by slightly reducing the outer diameter of the rotor. A likely explanation is that the rotor on its magnetic support had a natural frequency near 60 Hz which got excited by the 60 Hz magnetic flux oscillations.

The rotor was thereafter levitated successfully confirming the inherent stability of the bearing and the five degree-of-freedom support capability. During levitation, the current drawn from the power supply of each magnet was of the order of 10A at 50 VAC. The magnet currents were of the order of 50A with the highest current in the bottom magnet.

The supply current was limited to 18A by the variable transformers. Within that limit, a maximum weight of about 4lb could be levitated with the bottom magnet current at 68A with a supply current of 16.5 A at 65 VAC. The side and top magnet currents were about 30 A with supply currents of about 10 A at 15 VAC. The corresponding maximum thrust capability was about 5oz. The power loss in the sleeve was calculated to be about 800W. Within a few minutes the sleeve got too hot to be hand held whereas the magnets remained cool with only a slight temperature increase to be felt. An increase in supply current to one circuit would result in a similar current in the other circuits indicating strong mutual inductance between the magnet's coils.

The thrust capability could be increased significantly by using a shorter sleeve but the radial support capability would then decrease. The radial support capability could be increased significantly by using a longer sleeve but thrust stability would then be lost and the sleeve would try to exit the bearing.

The stiffness of the support was quite low as indicated by natural frequencies of the order of 1Hz for the levitated sleeve. The sleeve vibrations would also take a long time to die out indicating that the damping is very low.

However, for flywheel energy storage applications in space, the high power loss in the sleeve is considered to be the most serious problem. Efforts are continuing to resolve it. It has been speculated that both the high power loss and the low lift capacity may be due to concentration of the eddy-current in 8 spots directly below the 8 magnet poles. It is likely that a design closer to a conventional motor will be needed to ensure adequate efficiency for flywheel energy storage.

PROPOSED FLYWHEEL CONCEPT

Figure 6 shows an example of how the Eddy-Current Bearing may be utilized in a flywheel energy storage system. The bearing has been inverted and supports the inside rim of the flywheel. During charging and discharging, the bearing acts as an induction motor and as an induction generator respectively. The system is completely maintenance free. Two identical counter-rotating flywheels may be needed to cancel the reaction torque during energy transfer.

CONCLUSIONS

The reported experimental investigations have led to the following conclusions:

1. The Eddy-Current Bearing provides rotor support in five degrees of freedom: radial support and moment support in the horizontal and vertical directions plus thrust support in the axial direction. A single bearing is therefore sufficient to fully support a short rotor.

2. The Eddy-Current Bearing is inherently stable and does not require feedback control.

3. The damping capacity of the Eddy-Current Bearing appears to be low and is probably insufficient for most applications. Additional damping may be provided by a conventional eddy-current damper.

4. The I^2R loss in the rotor sleeve due to the eddy-currents is significant. Further work is needed to reduce this loss.

5. The unique capabilities of the Eddy-Current Bearing, demonstrated by this investigation, makes it a potential candidate for use in space based flywheel energy storage systems.

REFERENCES

1. Eastham, J.F., and Laithwaite, E.G., "Linear Induction Motors as Electromagnetic Rivers", Proc. IEE, Vol. 121, No. 10, 1974, pp. 1099-1108.

2. Nikolajsen, J.L., "A Magnetic Bearing Based on Eddy-Current Repulsion", NASA CP 2443, Rotordyn. Instab. Probl. in Hi-Perfom. Turbomach., 1986, pp. 461-465.

3. Bolton, H., "An Electromagnetic Bearing" IEE CP 120, Linear Electr. Machines, London, 1974, pp. 45-50.

4. Iskierka, S., "Influence of Irregularities of Exciting Current Density Distribution on Induction Bearing Work", Acta Technica Csav, No. 5, 1984, pp. 572-582.

5. Iskierka, S., "Analysis of an Induction Bearing by the Finite Element Method", Archiv fur Electrotechnik, Vol. 67, 1984, pp. 375-380.

6. Connor, K.A., and Tichy, J.A., "Analysis of an Eddy-Current Journal Bearing", ASME Pap. 87-Trib-10, 1987, p.7.

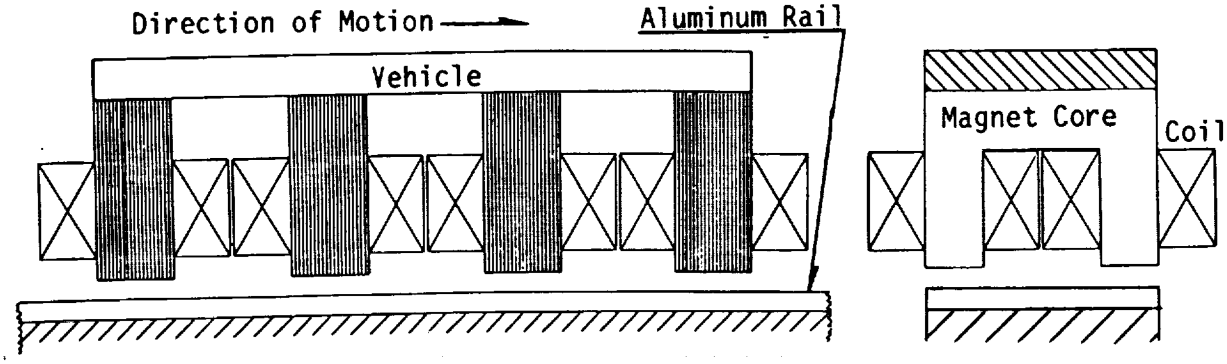

Figure 1 The Magnetic River Suspension (Schematic)

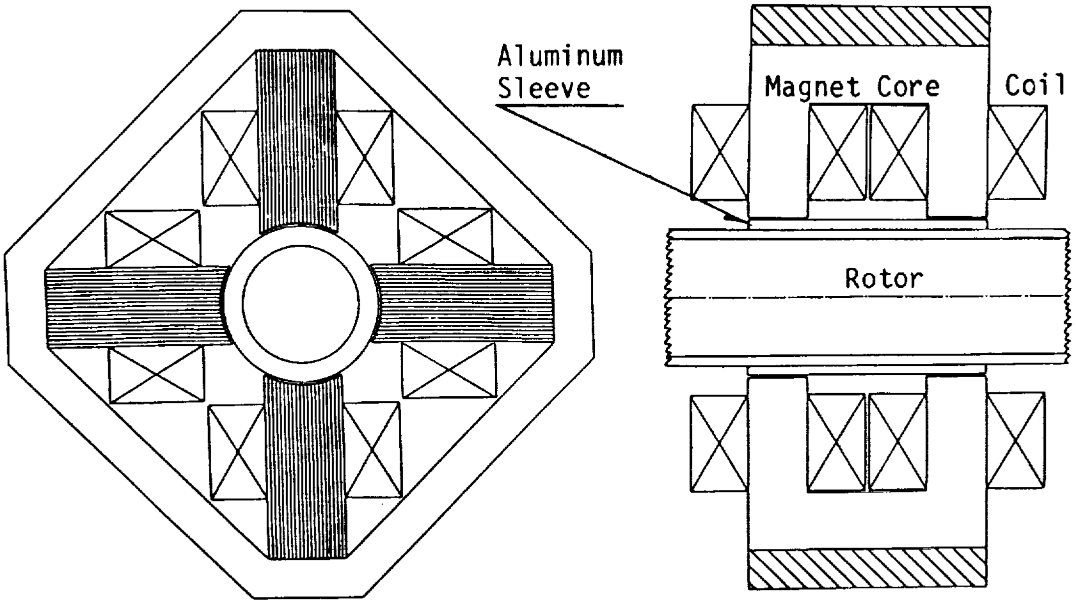

Figure 2 The Eddy-Current Bearing (Schematic)

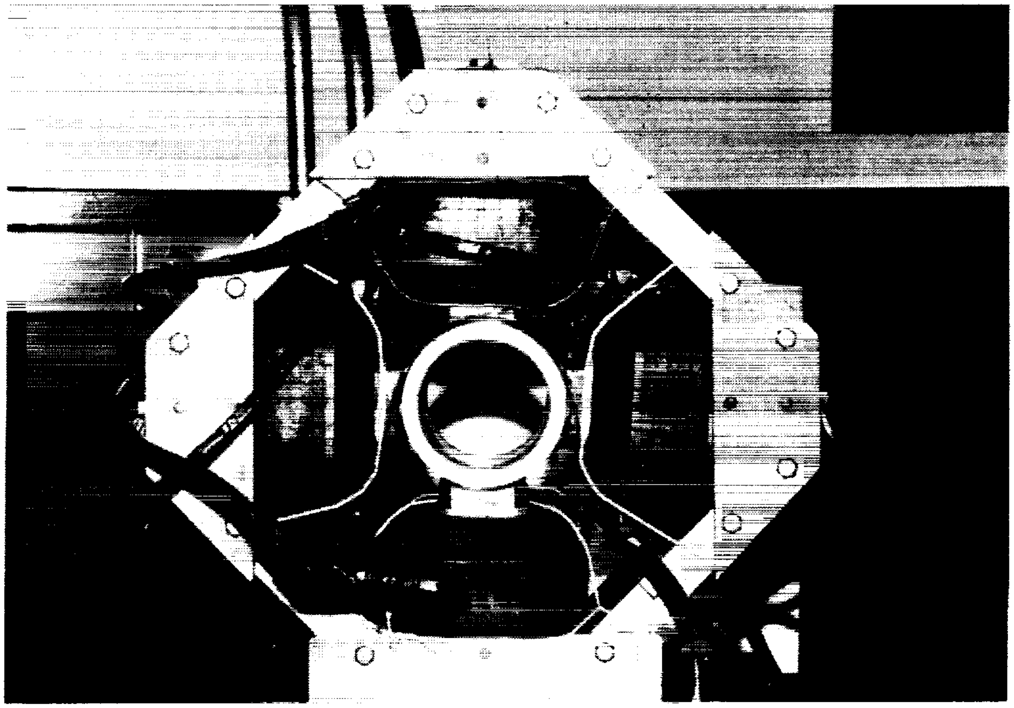

Figure 3 The Eddy-Current Bearing

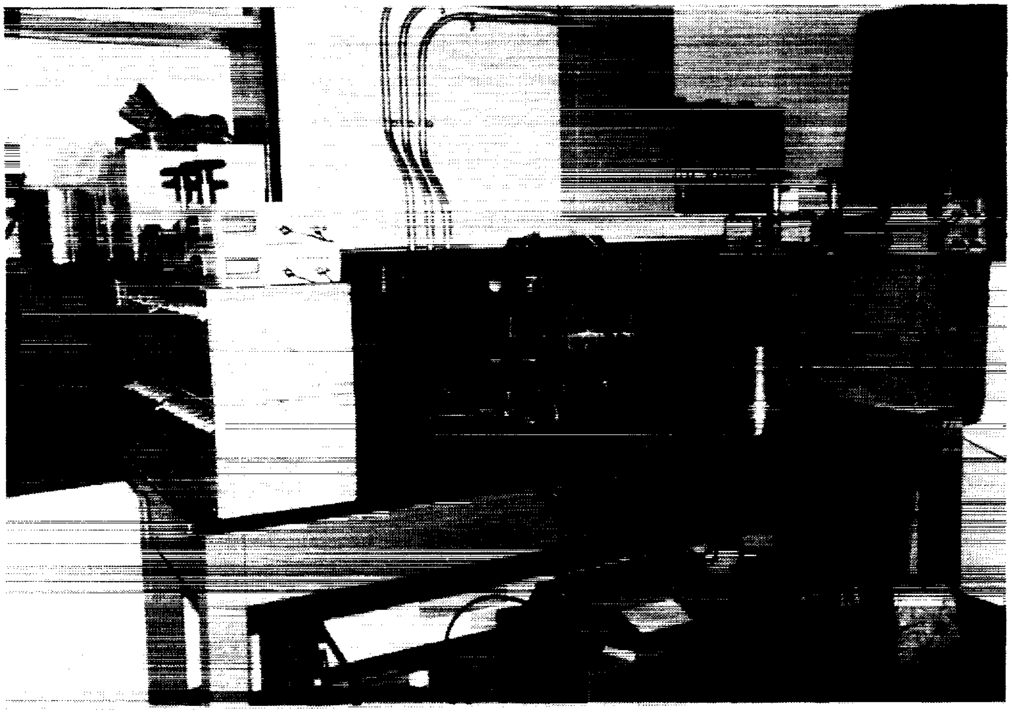

Figure 4 The Eddy-Current Bearing Rig

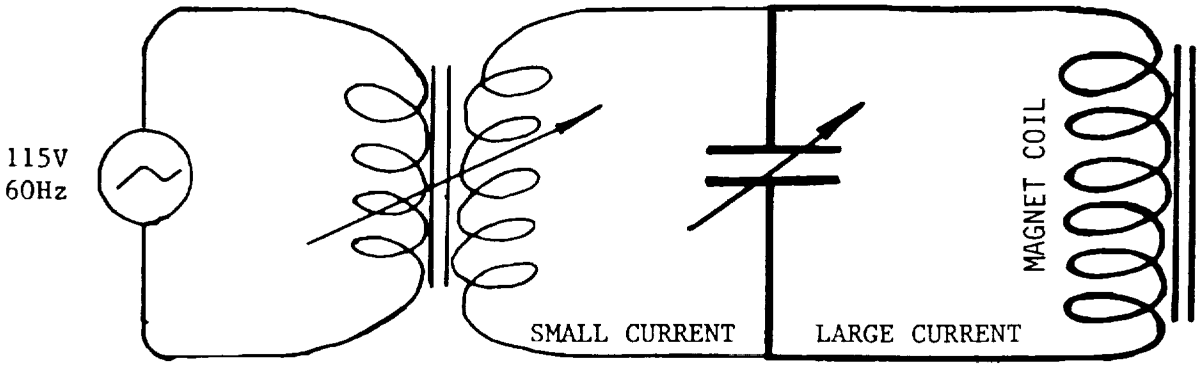

Figure 5 Magnet Circuit Diagram

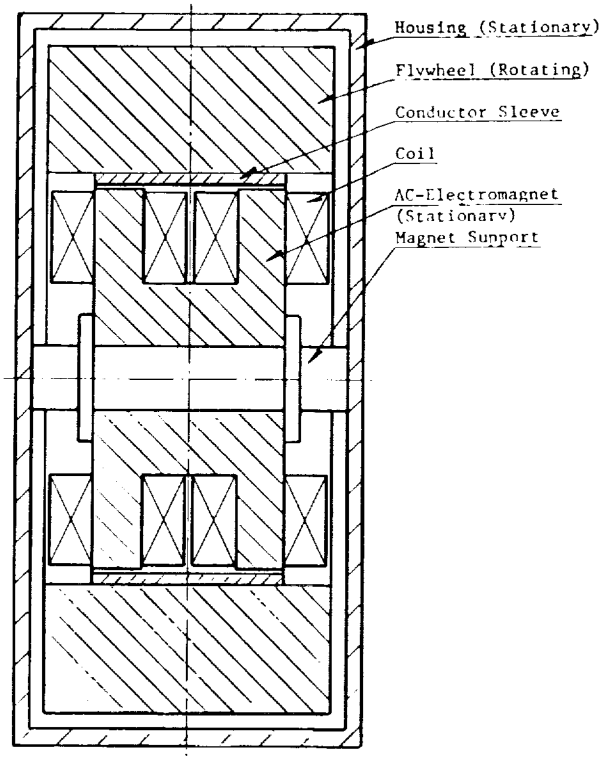

Figure 6 Proposed Energy Storage Flywheel Principle