Overview on Various Types of AMBs & their Respective Potential for Applications

Hannes Bleuler [a]

[a] EPFL Lausanne, LSRO-IMT, CH 1015, Lausanne, Switzerland, hannes.bleuler@epfl.ch

***Abstract*—Many different types of magnetic bearings are known since a long time: "Active" and "passive", "electrodynamic", "electromagnetic", "hybrid" etc. Certain types have found many applications and others none. A recent successful realization of a complex system (a momentum reaction sphere) based on a Lorentz-force type of bearing will be presented in more detail and the potential of as yet unexploited types of magnetic bearings will be briefly discussed.**

I. BASIC TYPES OF MAGNETIC BEARINGS

A. *Introduction*

Since Earnshaw's 1842 investigation [1], it is known that magnetic forces alone cannot provide contact-free levitation in all degrees of freedom. It is only in the 1930'ies that practical ways to overcome this fundamental limit are beginning to be reported [2], essentially through the application of stabilizing feedback control. After 1945, especially through the activities of Jesse Beams [3], and, later, of many others, solutions to the problem of magnetic levitation are realized, although some of them have been kept confidential for evident military reasons. Nevertheless, the complete picture of available solutions is well known since many years. These solutions are listed below. However, many potentially interesting types of magnetic levitations have still not found practical applications. This is the issue to be addressed in this contribution.

B. *"Physical" Classification*

The classification of magnetic bearing types follows naturally from the physical mechanism of achieving magnetic force. A first distinction concerns the two basically different mechanisms types of magnetic forces, i.e. forces on moving charge (Lorentz force) and forces on magnetic material (related to energy of the magnetic field). At a fundamental level, both effects are identical, namely the consequence of Einstein's special theory of relativity on electrical charge. From a practical point of view, the two effects are however significantly different (the effects of moving charges of magnetic materials being reduced to material properties).

So at the beginning of the classification, there are the two groups of Lorentz force devices and reluctance force devices.

Lorentz force is perpendicular to the magnetic flux and to the current, depending linearly of the current. Reluctance force is in direction of the magnetic flux and essentially proportional to the square of the current. In each of the two main families, finer distinctions lead naturally to an exhaustive list of the fundamental magnetic levitation types. This is illustrated in Figure 1. In the **first group, Lorentz Force devices**, the energy in the magnetic field remains constant and force is linear with the current, as it results from the vector cross-product of magnetic flux and charge velocity. No magnetic material is involved (except for field enhancement).

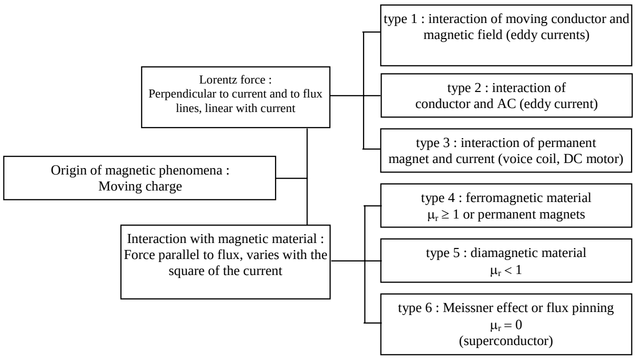

Figure 1. Fundamental types of magnetic levitation. While interactions of type 1 to 3 are all used for electric motors, they are (yet) seldom to be found in magnetic bearings. Technical realizations of magnetic bearings are almost exclusively of type 4

In the **second group**, **electromagnetic devices or devices involving magnetic material**, force is calculated not as a cross product of field vector and current vector, but from an energy integral over the volume filled by magnetic flux. Force is normal to the surface of magnetic material and (in case currents are involved and in first approximation) proportional to the square of electric current. Permanent magnet devices and superconducting devices also fall into this broad category.

C. *"Engineering" Classification, Current applications*

Parallel to this "physical" classification, technical criteria allow an overview based on more application oriented considerations. This will include criteria such as "active" or "passive" bearings, sensorless (or "self-sensing") bearings, permanent magnet bearings, bearingless motors, gyroscopically stabilized bearings etc. We will not attempt a classification along such criteria in this paper, we just would like to draw the attention to the fact that there exists a rich body of publications, not always available on internet, on the most various types of technical solutions to the magnetic levitation challenge. As a representative example, the full body of the 14 ISMB symposia offers quite a complete picture of the work done in the last 26 years.

From the six fundamental magnetic bearing types in Fig. 1, present realizations almost exclusively concentrate on type four (electromagnetic) bearings. In the next section, a recent successful realization of a type three (Lorentz force) bearing will therefore be briefly presented.

II. EXAMPLE: A REACTION SPHERE FOR SATTELITE ATTITUDE CONTROL

We would like to present here a challenging project of an unusual type of magnetic bearing which has very recently achieved levitation. It concerns a momentum sphere for satellite attitude control, and involves several partners (essentially CSEM, EPFL, ESA, Maxon Motors). After several years of work (and a number of publications), the project is far from over, but an important milestone has been reached very recently (too late for inclusion as a full paper in this Symposium). Nevertheless, references can be found under [5].

The realization of a truly spherical momentum rotor, controllable around all spatial axes of rotation, is a serious technical challenge. The problem has been solved with an ironless stator of 20 coils arranged on the vertices of a dodecahedron. The rotor is a complex assembly of (Nd-Fe) permanent magnets with 4 pole-pairs in a cubic arrangement.

The stator (diameter 20 cm) is shown open in fig. 2.

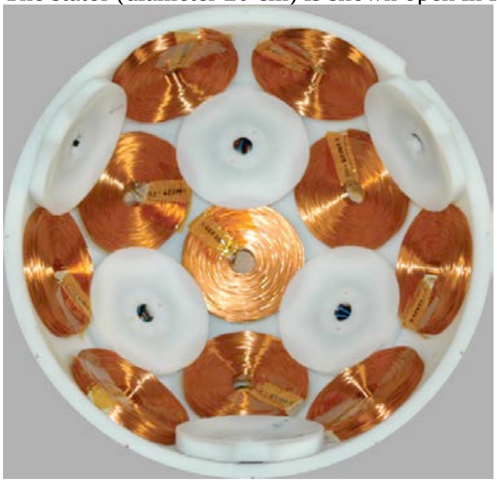

Figure 2 Stator (ironless) for a spherical momentum rotor of 20 cm diameter. Half of the 20 stator coils, arranged at the vertices of a regular dodecahedron, can be seen. The rotor consists of a sphere with Nd-Fe-B magnet shells in a 4 pole-pair arrangement, oriented as the vertices of a cube.

This system has recently been levitated successfully and rotated up to 12 rpm, work continues after this first operation. It is described in the publications and the PhD thesis of Leopoldo Rossini, of EPFL [7,8]

III. APPLICATION POTENTIAL OF OTHER TYPES OF MAGNETIC BEARINGS

As illustrated with this application example, magnetic bearing types other than controlled electromagnetic bearings still hold a promising potential for future applications. Among these I would like to mention three bearing types.

1 Superconducting rotor bearings (e.g. [6]). At the 10th ISMB Symposium, engineers from Siemens have presented a magnet an industrial magnetic bearing prototype based on high temperature superconductors. The fundamental technical hurdles seem to have been overcome and I could imaginefurther applications for this type of bearings, perhaps in situations where a high degree of reliability is essential, or in connection with high TC generators.

2 Passive Bearings with eddy current stabilization. This type of bearing has been presented at ISMB 9 (2004) in Lexington, KY [9]. It has the potential of energy-free levitation at room temperature. Losses are only proportional to deviations from rotational symmetry and of course to air friction. This makes it suitable for stationary flywheel energy storage. The problems to be overcome seem concentrated on the mechanical design and the behavior of high-velocity flywheels.

3 Diamagnetic bearings. As to now, a few exotic experiments for flow meter or vacuum gauge have been reported, but there seems to be a potential for clean-room handling and satellite attitude control for small satellites, an emerging activity in space technology.

IV. CONCLUSIONS

A classification of basic magnetic bearing types shows that among six basically different principles of magnetic levitation, only one type has found widespread application up to now. Although some obvious facts explain partially this situation, it is believed that some of the unusual types of magnetic bearings could have interesting practical applications, thus opening new perspectives for magnetic bearing engineering recent example of a reaction sphere has been presented in some detail, other new application domains might be accessible by exploiting the potential of all magnetic levitation types.

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