INTEGRATED RADIAL AND AXIAL LOW COST COMPACT A.M.B.

Holger Stegemann, Frank Worlitz, Torsten Rottenbach, Armin Dörrer, Rainer Hampel
Institute of Process Technique, Automation and Measurement Technique
University of Applied Sciences Zittau/Görlitz
E-Mail: r.hampel@hs-zigr.de

ABSTRACT
Usually the rotor is levitated by one axial and two radial bearings which are arranged separately around the rotor. Often, the effective bearing length has to be limited. This is due to the requirements of the construction and the application. With respect to the rotor dynamics it is also advantageous to minimize the rotor length especially at high speed rotating machinery.

The paper describes an integrated axial-radial compact active magnetic bearing designed as a homopolar bearing. Compared with a standard bearing of similar capacity the design shows some advantages in size, losses, and costs. The arrangement combines the axial and radial capacity and the auxiliary bearing landing system compactly within one unit. Thereby, the lateral surface of the axial disk is used as rotor core for the radial bearing. The four stator cores consist of standardized lamination. The rotor is not laminated. Design, manufacturing, and testing of this bearing have been completed successfully.

The compact bearing is integrated into the new test facility MBZ120 with a complete magnetic supported rotor. The load capacity amounts to 120 N axially and to 60 N radially. The second radial bearing is also constructed as a homopolar bearing. The bearing control can be realised very simply and robustly without or with variable bias current. A special design allows different bearing positions on the rotor for vibration tests. The paper presents selected bearing test results.

INTRODUCTION
The axial length of the shaft rotating in magnetic bearings is restricted by the requirements of the application and, especially, by the critical speeds of the rotor. The motivation to develop a combined axial and radial A.M.B. was to minimize the effective bearing length. Figure 1 shows the comparison between a conventional design with two radial and one axial bearing, and the new design approach with one combined and one radial A.M.B. A high amount of space reducible by the integrated axial and radial A.M.B. is occupied by the magnetic bearings. The conventional design of comparable load capacity needs twice the space of the combined bearing. In order to have low-cost bearings it is advantageous to use homopolar bearings without lamination at the rotor. In addition the auxiliary bearings can be integrated into the combined bearing.

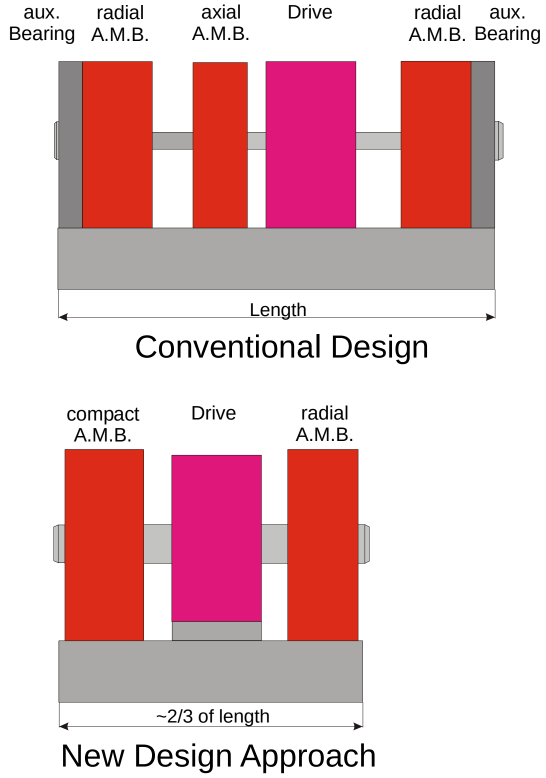

FIGURE 1: Comparision between Conventional and New Design of Magnet Suspended Rotors

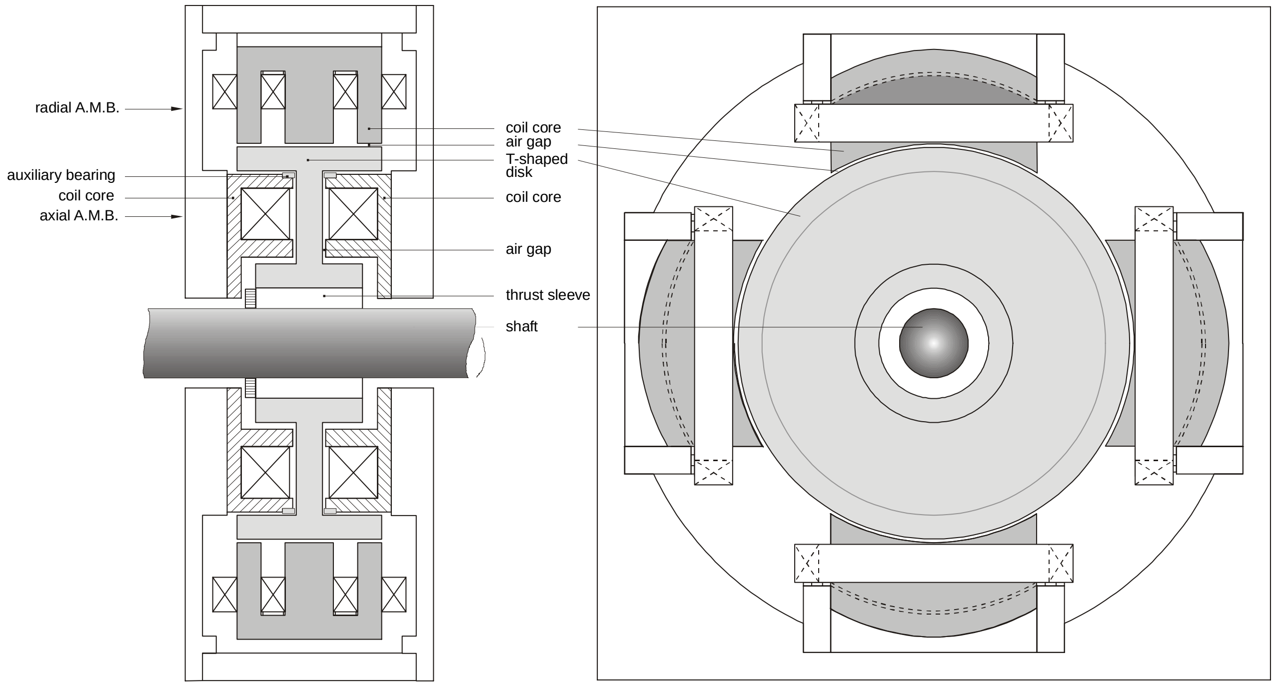

FIGURE 2: Mechanical Construction of the Compact Axial/Radial Magnetic Bearing

MECHANICAL DESIGN

The principal mechanical construction of the new design approach is shown in Figure 2. The axial bearing and the radial bearing are combined in one unit. The lateral surface of the T-shaped axial disk is used as rotor core for the radial bearing. The radial bearing is constructed as a homopolar one with a total of 4 poles. The lamination for the radial coil system consists of standard E-shaped tins. The axial coil system is realized as ring winding. The shaft (disk) is not laminated.
The axial/radial auxiliary bearing is integrated into the T-shaped disk by utilizing brass rings.
The bearing is moveable mounted on the shaft by applying a thrust sleeve.
Table 1 shows the most important parameters of the compact magnetic bearing.

PROPERTIES

Using this arrangement the space required for the magnetic bearing can be reduced. Therefore a compact construction is attainable. With respect to the rotor dynamics it is advantageous to minimize the rotor length especially at high speed rotating machinery. By increasing the magnetic surface due to the T-shaped axial disk it is possible to reduce the coil current and the number of windings at the same load capacity.
As shown by Kasamara [2] the power losses of homopolar bearings are much lower than of heteropolar bearings. In particular the power losses due to hysteresis can be reduced. Because of that these bearings are appropriate for applications with high-speed rotating machinery.
The costs for production can be reduced if the rotor lamination is omitted. At the same time a higher rotational speed is possible because of the massive shaft, but the power losses due to eddy currents are increasing.
The radial moment of inertia is increased due to the shape of the disk, therefore this design is particularly suitable for applications like fly wheel energy storage systems [1].

TABLE 1: Characteristics of the Compact Axial/Radial Magnetic Bearing

Parameter	**axial**	**radial**
airgap of magnetic bearing	1.0 mm	1.0 mm
airgap of auxiliary bearing	0.5 mm	0.5 mm
maximum current	3 A	3 A
load capacity at maximum current and equilibrium position	116 N	58 N
position stiffness at 1.5 A and equilibrium position	60 N/mm	30 N/mm
current constant at 1.5 A and equilibrium position	39 N/A	20 N/A
power losses due to windage	9 W	9 W

TEST FACILITY MBZ120

The compact axial/radial bearing has been integrated into the test facility MBZ120. Figure 3 shows the test assembly with a completely magnet suspended stiff rotor. The second radial bearing is also constructed as a homopolar bearing with a total of 4 poles and integrated auxiliary bearings. The rotor weight is 2.7 kg and the length of the shaft 250 mm. Because of the tests of variable bearing placements the diameter of the shaft constantly amounts to 20 mm. The airgaps of the second radial bearing are the same as at the compact bearing. The load capacity amounts to 28N.

The principal structure of signal processing units and the control loop are shown in Figure 4. A separate control loop exists for each magnetic bearing and each axis (decentralized control). The rotor position is measured by eddy-current sensors. After signal condition and filtering the signals are transfered to the digital controller. As controllers a DSP system or a High Speed Matrix Controller (HSMC) are utilized. The controller output signal is divided into two contrary signals. These signals are superposed by a voltage corresponding to the bias current. The bearing control can be realized without or with variable bias current. After pulse-duration modulation (PDM) the power amplifiers for the coils are controlled. The power amplifiers have a converter voltage of 30 V in the intermediate circuit. The maximum current in the coils is limited to 3 A.

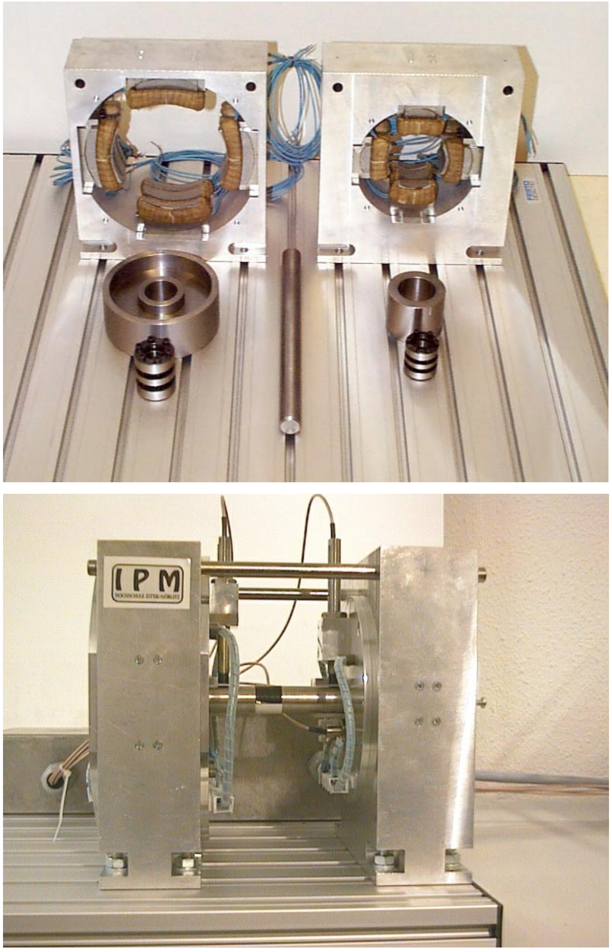

FIGURE 3: Test Facility MBZ120

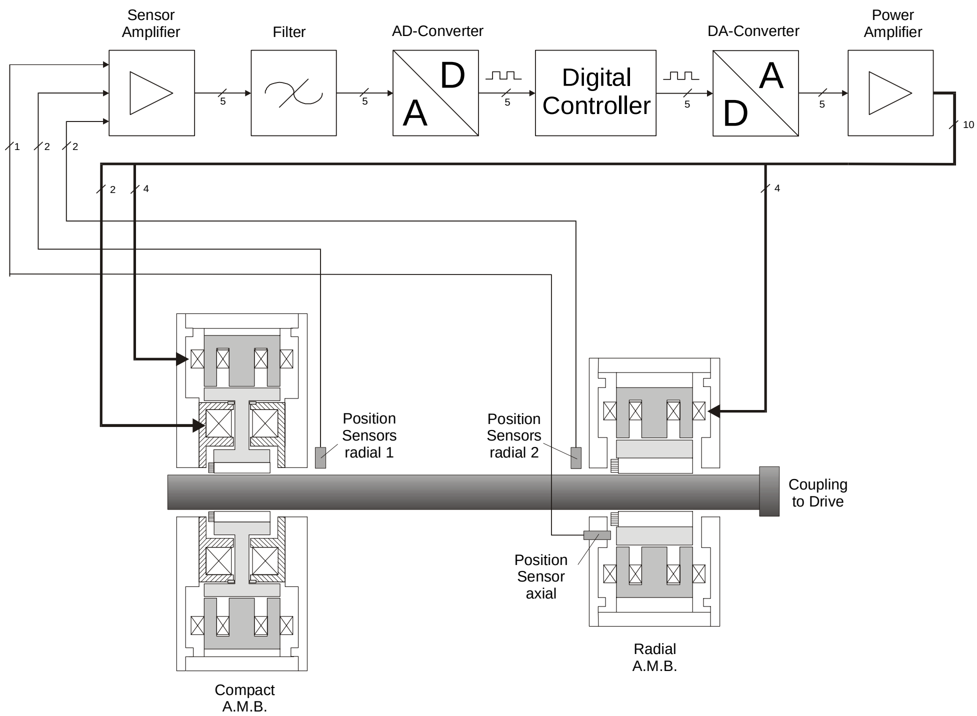

FIGURE 4: Control Loop of the Test Facility MBZ120

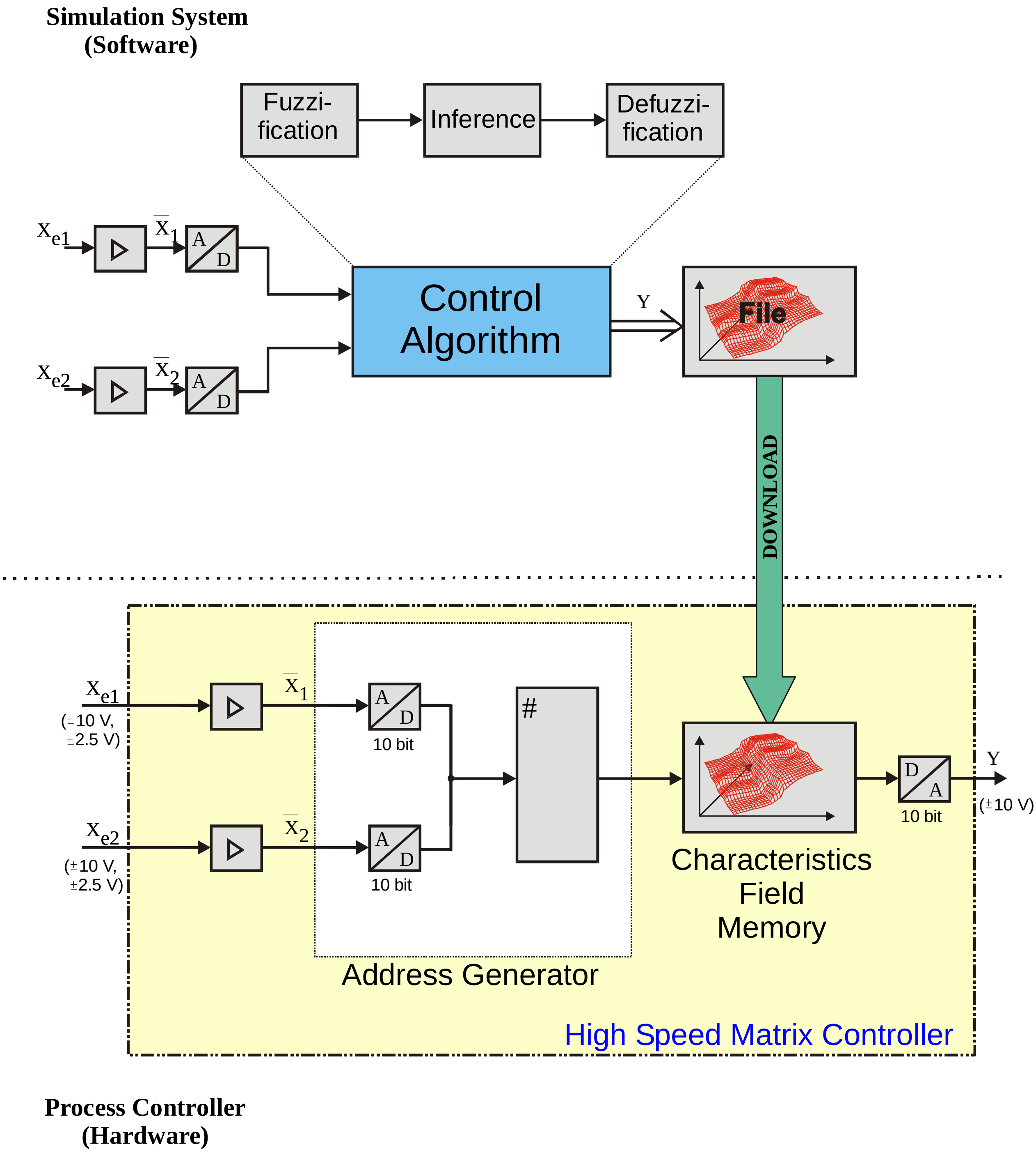

FIGURE 5: High Speed Matrix Controller

The High Speed Matrix Controller was developed at the institute especially for real time control of high dynamic processes applying complex algorithms, e.g. fuzzy control, adaptive control and compensation methods for the non-linearities in the loop [3].
With help of a simulation system the process is calculated and an optimal controller can be designed. The control algorithm is converted into a matrix as shown in Figure 5. The saved file can be downloaded to the hardware, that consist of A/D- and D/A-Converters, adress generator and memory.
The process can be controlled in a cyclic time of 200 ns independently of type and size of the control algorithm. The reliablity of such a controller is increased as no calculations are necessary in the control process. Without using a processor the costs for the digital controller can be reduced in contrast to conventional DSP systems.

RESULTS OF SELECTED EXPERIMENTS

START-UP OPERATION

At the start-up operation the shaft must be lifted from an arbitrary position in the retainer bearings to the setpoint position. A minimal overshoot and a short settling time are required. In Figure 6 the rotor position at the compact bearing with its x- and y-axis is shown during the start-up. The overshoot amounts to 75 µm in x-direction, where the weight force acts, and 125 µm in y-direction. The settling time amounts to 1.0 s in x- and to 1.5 s in y-direction.

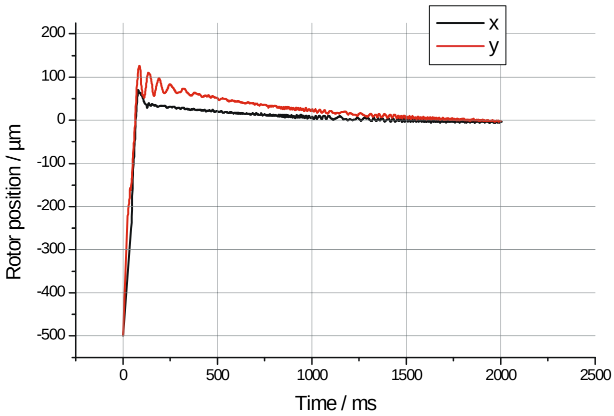

FIGURE 6: Start-up: Rotor Position at the Compact Bearing

FULL SPEED RUNNING TEST

For the test of the compact bearing at different rotational speeds the test facility MBZ120 was coupled with an external magnet suspended drive.

Figure 7 shows the measured amplitude of the rotor position in the x-axis of the compact bearing. The maximum attainable speed is 12,000 rpm restricted by the coupling. The maximum amplitude amounts to 66 µm and occurs at the critical speed of 8,400 rpm.

The power losses due to eddy currents had no significant effect on the temperature of the rotor during long time operation.

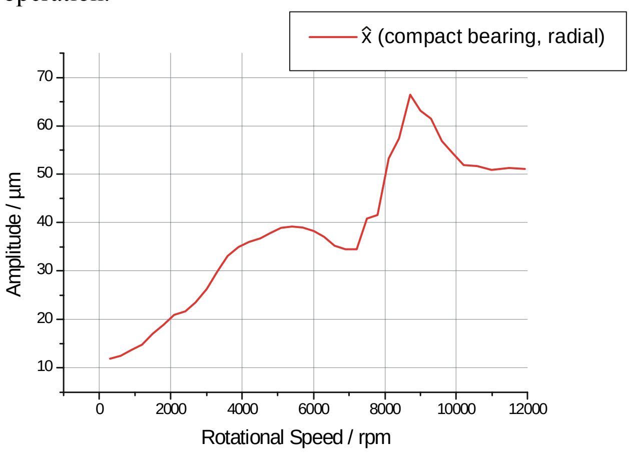

FIGURE 7: Amplitude of Rotor Position vs. Rotational Speed

LOAD MEASUREMENT

At these experiments a static external load with variable capacity acts on the rotor in positive y-direction. The measured radial bearing load in the y-axis at equilibrium position versus the measured and calculated current curves for the compact bearing is shown in Figure 8. The measured load exceeded the design load, the difference amounts to 10 N at the maximum current.

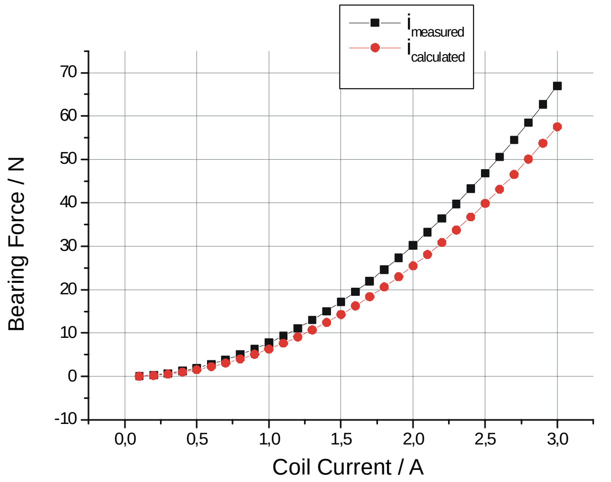

FIGURE 8: Radial Force vs. Current Characteristic for the Compact Bearing

Figure 9 shows the calculated characteristics field and the measured radial bearing force for one of the identically designed coils.

The range of rotor position is the airgap in the auxiliary bearings. The coil current is limited to 3 A due to the power amplifier. The lift out force amounts to 25 N at the maximum airgap. As shown in Figure 9, the radial bearing operates below the saturation. The calculated force correspondends with the measured data.

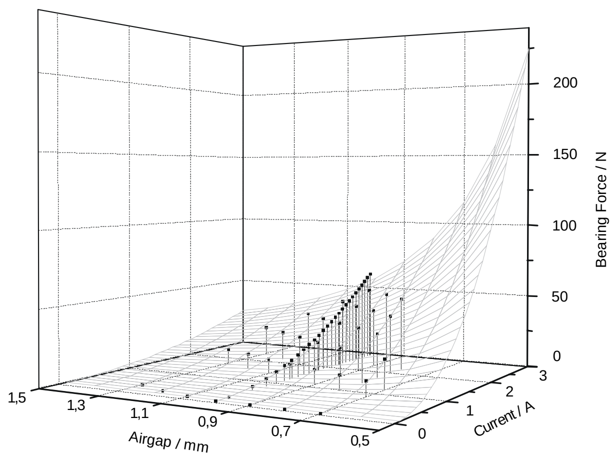

FIGURE 9: Characteristics Field of the Radial Bearing Force

CONCLUSIONS

The design, manufacture, integration and evaluation of the axial/radial compact bearing in a test facility with a full magnet suspended rotor has resulted in a successful testing under various conditions. The following conclusions regarding the design and test process can be drawn:

- Under the restriction to use low-cost bearings only the new design approach has no lamination on the rotor. The radial bearing consists only of 4 poles, a special measuring trace for the position sensors is omitted. In addition the space required for the magnetic bearing can be reduced by this compact design.
- The power losses due to hysteresis can be minimized by using a homopolar design. By increasing the magnetic surface due to the shape of the disk the coil current for the same load capacity can be reduced and, therefore, the power losses due to the windage too.
- The compact bearing is especially suitable for high-speed applications and, due to the shape of the disk, for magnet suspended fly wheels.

REFERENCES

[1]Gebrauchsmusteranmeldung G 200 05 391.4: Schwungmasseenergiespeicher mit Elektromotor-Generator (Fly Wheel Energy Storage System with Electric motor - Generator), VEAG and Institute of Process Technique, Automation an Measuring Technique Zittau, Germany, 1999/02/12

[2] Kasarda et al.: Comparision of Measured Rotor Power Losses in Homopolar and Heteropolar Magnetic Bearings, MAG '97 Industrial Conference and Exhibition on Magnetic Bearings, Alexandria, U.S.A., Aug 1997, pp. 323-334

[3] Europäische Patentanmeldung 99112101.3: Verfahren zur Regelung zeitkritischer Prozesse durch einen High Speed Matrix Controller (Control of Time-critical Processes by a High Speed Matrix Controller), Institute of Process Technique, Automation an Measuring Technique Zittau, Germany, 1999/06/23