CONSTRUCTION OF THE ACTIVE MAGNETIC BEARING CONTROL SYSTEM

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Abstract: This paper talks about the design of active magnetic bearing control system. The main design issues are proposed and discussed. The discussion covers the control system requirements, selecting the main components, and proposes the own solution. Finally, the designed prototype is shown and its concept is verified by an experiment utilizing current control loops at their maximal capacity and electromagnetic interference is observed.

Keywords: AMB, Active Magnetic Bearing, Control System, ARM, Digital Signal Processing

1   INTRODUCTION

High speed electrical machines are the current state-of-the-art in the electric motor and drives department. With the growing demand on drives with higher rotational speeds, it is also going with growing demands on the mechanical design of such machines additionally on their bearings. The conventional mechanical bearings are insufficient at high rotational speeds. There are basically two possible substitutions of a mechanical bearing. First of them are hydrodynamic bearings having disadvantages such as low dynamics and damping capability. The second type is magnetic bearings. In magnetic bearing systems, the rotor desired position is kept by a type of electromagnetic force. In this article is proposed a concept of active magnetic bearing system. The system is still being developed, its current control capability is only one radial bearing but thanks to its modular concept it will be extended to control the whole high-speed rotational machine with two radial and one axial bearing.
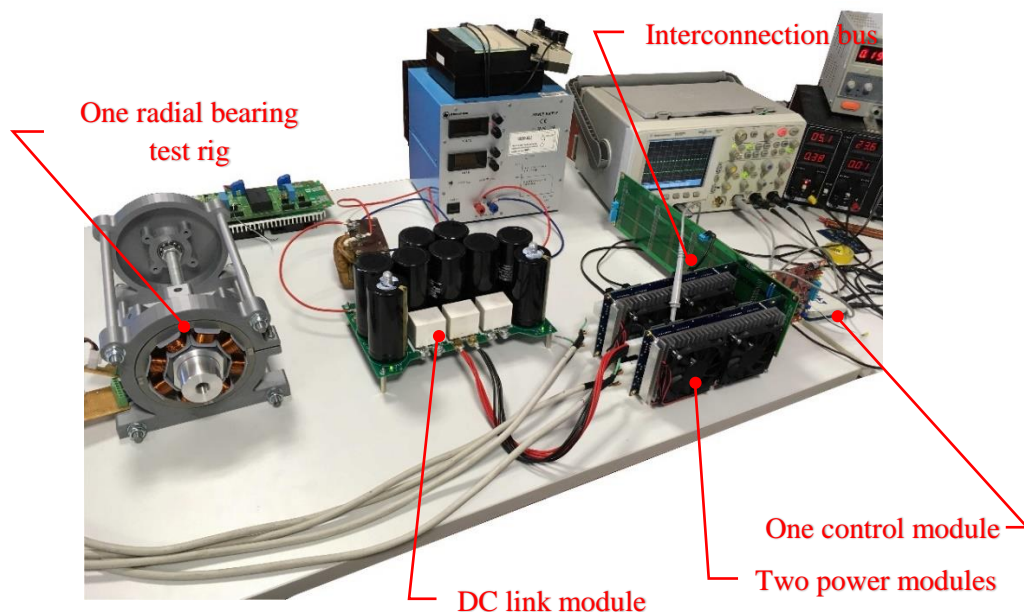
Figure 1: test rig overview

2 DEFINITION OF A PROBLEM

Active magnetic bearing is a complex electromechanical system performing a task with five degrees of freedom position control. As apparent from Figure 2 the rotor position could be defined in Cartesian system by five axes: x_1, y_1 controlled by radial bearing 1; x_2, y_2 controlled radial bearing 2, and finally z controlled by the axial so-called thrust magnetic bearing. The system complexity becomes higher when realized that control of the position in one axis is done by so-called differential actuators. The differential actuators are two opposite electromagnets, see Figure 3, biased together producing the desired forces used to adjust the position of the rotor in the respective axis. The principle and advantages of a differential actuator are explained in [1] and [2]. Substantial fact for design of the control system is that the differential actuator contains two coils energized by two different currents. That means to control the rotor position in five axis with five differential actuators, literally it is required to control ten different electrical currents. By recommendation from experienced colleagues from other universities, the bandwidth of the position control should be at least 10 kHz. To guarantee the proper performance and dynamics of the position control loops, the subsequent current control loops have to be at least by one order faster than the position loop. Those requirements define the performance of the system, which has to be able to control ten currents in the 10 μs window and five positions in the 100 μs window.
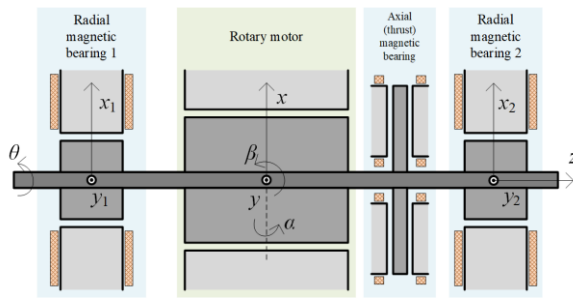

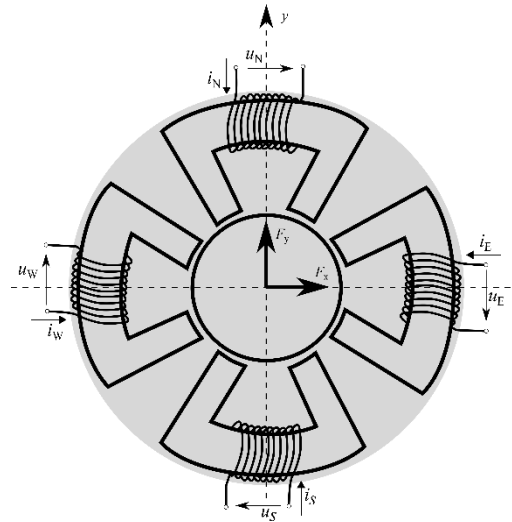**Figure 2:** AMB system radial section view

Figure 3: radial bearing, axial section view

3 SYSTEM CONCEPT

Regarding to the system complexity mentioned in Chapter 2, it was a big issue how to design such a large system. Respecting the low experience with AMB systems, the most familiar concept is exposed to be a modular system. In that way, there are two main types of modules in the system, see Figure 4. First of them is the power module. Each power module is capable to drive one differential actuator, so the final count of these modules is five. The second module type is a control board. At the first iteration, one control board is designed to be capable to drive two differential actuators of one radial bearing. All control system modules are connected using an interconnection bus, which is a bare PCB attached by PCIe connectors, so the control and power modules are tightly interconnected between each other to ensure the robustness of the whole system.

The interconnection bus arranges three auxiliary power supply buses. The 24 V power supplying bus is designed to supply the SKF eddy current sensors, whose detailed description is introduced in the next chapter. The 5 V power supply is for MCUs power supply and current sensing. The separate power supply 12 V is for the power MOSFETs driving circuit, because it is expected to be burdened by electromagnetic interference. There is also no common ground between the modules to avoid electromagnetic interference. The switching and analogue signals are guided differentially, which is

a cheaper way than, for example, optically as proposed here [3]. The main power supply was calculated to be approximately 50 VDC and is connected separately from the DC link module.
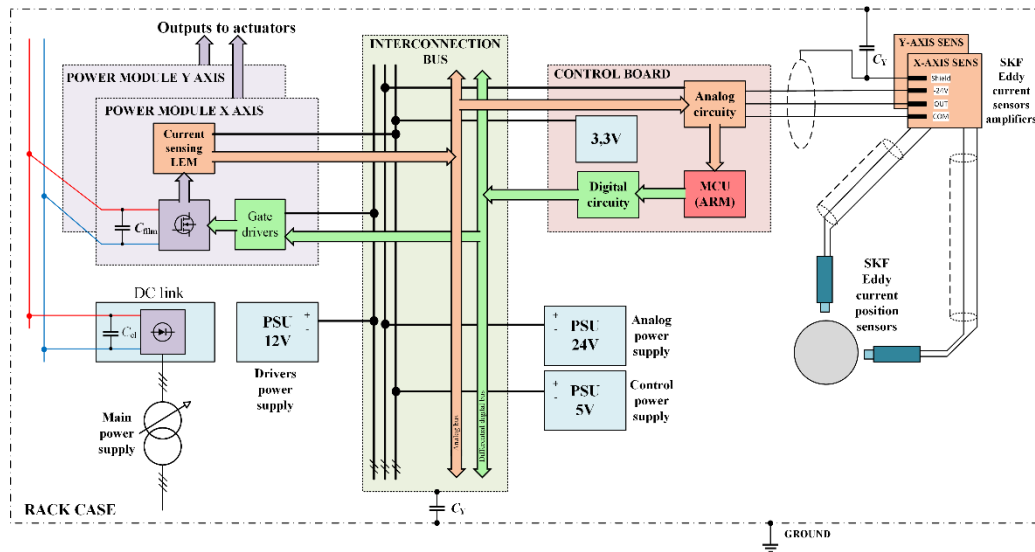

Figure 4: Overall system conception block schematic

3.1 CONTROL UNIT

There are several options which control unit to choose for such a complex system. The goal of this project is to make a stand-alone embedded system, which is compact and ready for practical use. Therefore, there are probably three options – PLC, FPGA, or Microcontroller. PLC control system for such application is not applicable in general because the majority of PLCs on the market haven't got such fast sampling periods as is desired for this application and moreover the programming languages of PLCs are not suitable for performing complex sequential algorithms. The FPGAs are more powerful, but the implementation of a sequential algorithm is complicated and finally it is not a cheap way by means of HW costs. Therefore, the most possible option for choosing a control unit is a microcontroller. As proposed in Chapter 2, AMB system has the character of fast digital signal processing tasks. The market offers for these applications so-called digital signal processors, such as Texas Instruments DSPs with C2000 cores used for example here [3]. However, it is commonly known that DSPs with Harvard architecture are going to be outdated in the near future which is proven, for example by NXP's (Freescale) termination these microcontrollers production. The DSP product lines are being substituted by a new architecture ARM Cortex-M core designed also for digital signal processing. Therefore, this kind of microcontroller was chosen, specifically STM32G4 product family. This microcontroller offers similar power of the floating-point core with a set of DSP instructions, peripherals with similar parameters, e.g. High-Resolution Timer (HRTIM) for generating up to 12 PWM signals, with maximal resolution 184 ps, 5×12-bit AD sigma-delta convertors or specific DSP peripherals - CORDIC for trigonometric functions acceleration and FMAC filter mathematical accelerator for implementation of digital HW filters.

3.2 POWER STAGE

There are plenty of articles describing advanced topologies of AMB power stages, such as shared-bridge convertors published at [4], [5] or [6]. This topology saves the count of the switching components but increases the drive algorithm complexity and brings challenges on the current caring capacity of the shared-phase leg which can be easily broken due to high current stress. Furthermore, this topology doesn't respect the selected modular conception, because all switching components need to be close together. Therefore, the traditional topology of power convertor has been chosen to feed every single coil by a half-bridge.
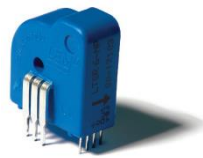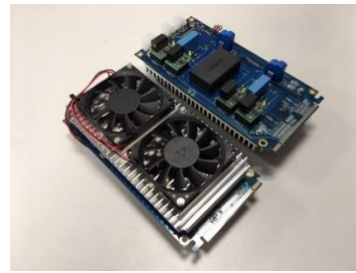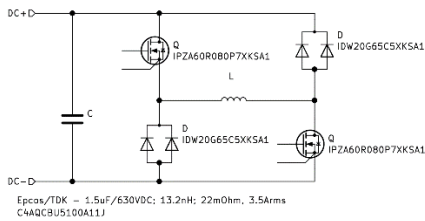
Figure 5: topology of a single converter   **Figure 6:** two power modules (2 half bridges in each)

By means of the high frequency bandwidth of the current loop, also high PWM frequency needs to be introduced. To decrease the switching power losses and electromagnetic interference, novel semiconductor technology *SiC* power switches are employed, see Figure 5.

### 3.3   SENSING OF PHYSICAL VARIABLES IN THE SYSTEM

To enable high stiffness and damping of the bearings the axis position has to be sampled very precisely. The traditional inductive position sensors are insufficient for this job, because of its low bandwidth around 1 kHz. As proposed in Chapter 2, the position sensor optimal bandwidth is 10 kHz. A little research has been done to select proper position sensors. The following sensor covers our technical requirements: Micro-Epsilon offering capacitive sensors capaNCDT series and SKF offering CMSS eddy current position sensors. However, only SKF sensor fulfil also our financial budget requirements. The force of the actuators is strongly dependant on the coil currents, so the current also has to be sampled at comparatively high resolution and high bandwidth 100 kHz at least. Finally the following sensors are employed in the system (Table 1).

Current sensor	Position sensor
LEM Current Transducer LTSR 15-NP	SKF CMSS 75-LM1
Hall effect	Eddy currents
Nominal RMS current 15 A Frequency bandwidth 200 kHz Output voltage $2.5 \pm (0.625 \times I_p/I_{pn})$	Measurement range 0.25 to 2.25 mm Scale factor 7.87 V/mm Frequency response DC to 10 kHz Linear characteristic ±25μm for 5 m cable length

Table 1: presentation of selected physical sensors

4   EXPERIMENTAL RESULTS

For verification of the designed system functionality and robustness following experiment was performed. Two different actuators were energized in different instants approximately to 12 A, which is the full current capacity and mutual interference was observed. Experiment result very well, as apparent from Figure 7, there is no recognizable interference in the instant energizing second coil by full current step (time 10 ms). The data was acquired from the microcontroller by specialized routine via serial port and visualized in MATLAB.
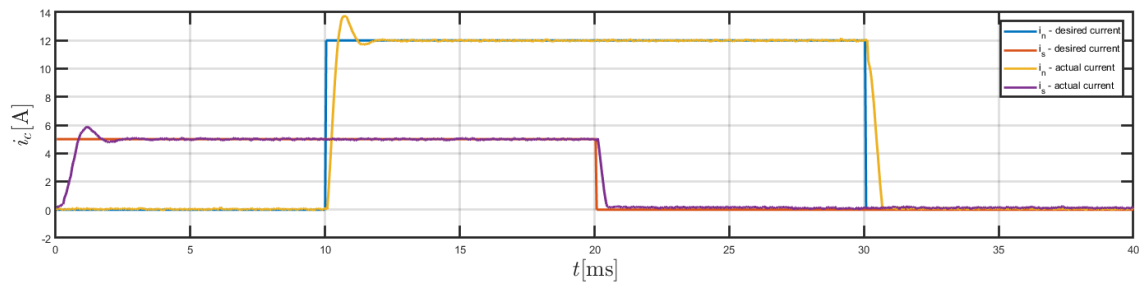
Figure 7: experimental result, current loop interreference robustness

5   CONCLUSION

In this article was presented the concept and design of the active magnetic bearings control system and several issues were discussed and explained. As a verification of system functionality an experiment was performed and shown its results. The project is in stage that hardware layer can be considered as finalized and tested. Actual work is software development, which can be divided into two main layers. First of them is low level layer covering peripheral configuration and using of hardware abilities of the MCU together with PWM generation and PID current control loop design. This part could be also considered as finalized. Second high-level software layer will be about the position sensing and control, which will be definitely covered in future work and publications

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