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Redundant unbalance compensation of an active magnetic bearing system

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ABSTRACT

To achieve a good running behavior of a magnetic levitated rotor, a well-developed position controller and different compensation methods are required. Two very important structures in this context are the reduction of the gyroscopic effect and the unbalance vibration. Both structures have in common that they need the angular velocity information for calculation. For industrial applications this information is normally provided by an angle sensor which is fixed on the rotor. The angle information is also necessary for the field oriented control of the electrical drive. The main drawback of external position sensors are the case of a breakdown or an error of the motor controller. Therefore, the magnetic bearing can get unstable, because no angular velocity information is provided. To overcome this problem the presented paper describes the development of a selfsensing unbalance rejection in combination with a selfsensing speed control of the motor controller. Selfsensing means in this context that no angle sensor is required for the unbalance or torque control. With such structures two redundant speed and angle information sources are available and can be used for the magnetic bearing and the motor controller without the usage of an angle sensor.

1. Introduction

In recent years, active magnetic bearings (AMB) have got increasing importance in rotating machinery, because of several attractive advantages, such as no friction losses, wearless, the ability of long-term high speed running, and the possibility to affect the mechanical properties [1,2]. They do not need lubricant and are maintenance free. A so-called active magnetic bearing generates the electro-magnetic force totally by electro magnets compared to hybrid or passive magnetic bearings. Magnetic bearings are unstable systems and they require a control structure for a stable levitation of the rotor. For closed loop operation a radial and axial position informations of AMBs are required. The position information is typically provided by external position sensors, but in the last years also sensorless position strategies were developed, like the INFORM method, which is described in [3,4]. For higher speeds, vibrations caused by mass unbalance are a common problem in magnetic bearing applications. Unbalance occurs if the principal axis of inertia of the rotor is not coincident with its axis of geometry. For real systems it is almost impossible to manufacture an ideal balanced rotor. With conventional mechanical bearings, reaction forces occur due to the unbalance [5]. These reaction forces excites unwanted vibrations at the machine housing. However, with active magnetic bearings it is possible to provide an unbalance compensation to minimize the resulting vibra-

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tion or to reduce the rotor orbit. Such an unbalance compensation allows the rotor to spin around its inertial axis. This additional component of the control structure can have the following tasks:

- Rejection of synchronous bearing forces: The synchronous bearing current is approximately a quadratic function of the rotational speed. So an upper limit of the angular velocity of an AMB is the actuator saturation caused by the unbalance force. Therefore, the aim of this compensation technique is to reject the synchronous bearing current. This can be done by making the controller "blind" for the unbalance frequency. With this unbalance control the upper limit caused by the angular velocity can be significantly increased.
- Rejection of the unbalance vibration: The aim is to reject the vibration due to the reaction forces of the unbalance and the housing. To get a suitable rejection the system requires high damping forces which can also lead to a saturation of the amplifiers. Thus, this balancing technique is a converse approach to the first one, because of the high damping instead of no gain for the unbalance frequency.

The focus of this paper is the rejection of the synchronous bearing forces and the reduction of the gyroscopic effect using redundant angular velocity information. For both structures the knowledge of the angular velocity is required. This information can be provided from the motor controller or from an unbalance observer like it was described in [6]. For the motor controller it is possible to get the speed information from an external sensor or from a sensorless method. The acceleration of the rotor is provided by a permanent magnet synchronous machine (PSM). A problem in critical applications with respect to costs, space and reliability is the rotor position sensor, which reduces the robustness of the drive considerably. In this paper, the INFORM method for sensorless torque- and speed-control down to standstill is used to realize cost effective sensorless drives for reliable transient operation [7]. With these methods two different redundant structures to estimate the speed information can be implemented in the motor controller and the magnetic bearing controller. If the magnetic bearing controller and the motor controller are connected (Fig. 1), both structures are able to use different angle or angular velocity sources for control. This leads to a high robustness of the system because it is possible to provide a stable levitation of the rotor even in the case of a damaged motor controller. With this structure, different critical conditions for the usage of the angular velocities can be defined.

For the tracking of the unbalance frequency, [8] uses an adaptive observer method. A simpler and more straightforward way was shown by [9], where a phase locked loop (PLL) was used in combination with an atan-calculation. However, the lack of this method is the atan-calculation, which shows problems regarding to measuring noise.

The contributions of the presented paper can be summarized as follows:

- A selfsensing unbalance control (no external angle sensor is required) is developed for a five degree of freedom active magnetic bearing. Thus, the magnetic bearing controller can run independent from the motor controller.
- A redundancy of the speed information is given by an unbalance observer of the magnetic bearing in combination with a sensorless motor control strategy. Therefore, no angle or speed sensor is necessary in the whole operating range.

2. Unbalance control using a two modulation step approach

A simple unbalance control technique is the insertion of a Notch filter in the feedback path. However, this method has stability problems using open loop designed filters [10]. This lack of Notch filters is eliminated by an observer-based design [11]. The observer based method requires much computing power and a very accurate plant model, which is often not preferable in industrial applications. A converse approach is an adaptive feedforward method [12,13]. This technique cannot introduce instability, if the adaption process itself is stable. However, such methods often uses complex nonlinear adaption

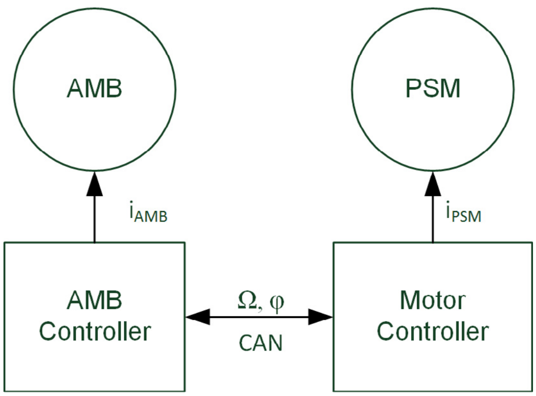

Fig. 1. Communication of the controllers.