17th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2013, Istanbul, Turkey, 10-11 September 2013

ELASTIC ROTOR CONTROL USING ACTIVE MAGNETIC BEARING SYSTEM

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ABSTRACT
This paper represent introduction in research of elastic rotor control using active magnetic bearing system (AMB). Through literature citations paper gives insight in history of active magnetic bearings and their main advantages and disadvantages. Also paper gives basic work principle of AMB with special reference on control of elastic rotor using this system. The paper also considers one of the common problem of AMB suspension of elastic rotors i.e. non-collocation problem and gives review of different solution techniques. At the end, paper gives an overview of future research in this field.
Keywords: Active magnetic bearings (AMB), control, regulation, elastic rotor.

1. INTRODUCTION

Active magnetic bearings generate forces through magnetic fields. There is no contact between bearing and rotor, and this permits operation with no lubrication and no mechanical wear. A special advantage of these unique bearings is that the rotor dynamics can be controlled actively through the bearings. As a consequence, these properties allow novel designs, high speeds with the possibility of active vibration control, high power density, operation with no mechanical wear, less maintenance and therefore lower costs. Examples for actual application fields for magnetic bearings are [1]:

- vacuum techniques
- turbo machinery
- machine tools, electric drives, and energy storing flywheels
- instruments in space and physics
- non-contacting suspensions for micro-techniques
- identification and testing equipment in rotor dynamics
- vibration isolation

Thanks to their physical principle, magnetic bearings have some unique and very interesting properties [3], [4]:

- Magnetic bearings work without any mechanical contact. Therefore, the bearings will have a long life with much reduced maintenance and with low bearing losses. Since no lubrication is required, processes will not be contaminated, which constitutes another important advantage over conventional bearing technologies. AMB systems can also work in harsh environments or in a vacuum.

- The reduced maintenance and the possibility for omission of the complete lubrication system lead to considerable cost reductions.

- The rotational speed is only limited by the strength of the rotor material (centrifugal forces). Peripheral speeds of 300 m/s are a standard in state of-the-art AMB applications, a value not reachable by most other bearings.

- The electromagnetic bearing is an active element which enables accurate shaft positioning and which makes its integration into process control very easy. The vibrations of a rotor can be actively damped. It is also possible to let the rotor rotate about its principal axis of inertia to cancel the dynamic forces caused by the unbalance.

- Due to their built-in sensors and actuators AMB systems are perfectly suited for not only positioning and levitation of a rotor but also for serving additional purposes such as monitoring, preventive maintenance or system identification. These important features are possible without the need for any additional instrumentation.

2. FUNCTIONAL PRINCIPLE OF AMB

Generating contact free magnetic field forces by actively controlling the dynamics of an electromagnet is the principle which is actually used most often among the magnetic suspensions. It is important to notice that if we have dynamic part in mechanical system, it is impossible to achieve stable levitation and control it using only permanent magnets.

The basic functional principle of an AMB can be briefly described as follows (Figure 1). The system itself is inherently unstable. This instability is caused by the attractive forces of the electromagnets. Therefore, active control of the magnets is necessary. For this, a sensor measures the displacement x of the supported rotor. A controller, nowadays most often a digital controller on the basis of a signal processor or microprocessor, uses the sensor information to derive an appropriate control signal *u*. This control signal is amplified by a power amplifier to drive the control current in the coil. The coil current together with the ferromagnetic material in the path of the coil causes a magnetic force to act on the rotor. The electromagnetic force has to be calculated by the controller in such a way, that the rotor remains in its predefined and stable hovering position. Basically, the control operates in such a way that, when the rotor moves down, the sensor produces a displacement signal which leads to an increase in the control current. The increasing electromagnetic force then pulls the rotor back to its nominal position [2].

Of course, during the technical realization is always necessary to use multiple AMB for the control of a shaft, usually two radial and one axial bearing. It is important to emphasize that we do not need one controller and one power amplifier for each bearing separately. It is possible to maintain control over multiple bearings with only one controller and one power amplifier. In technical sense, this represents a system of active magnetic bearings (AMBs).

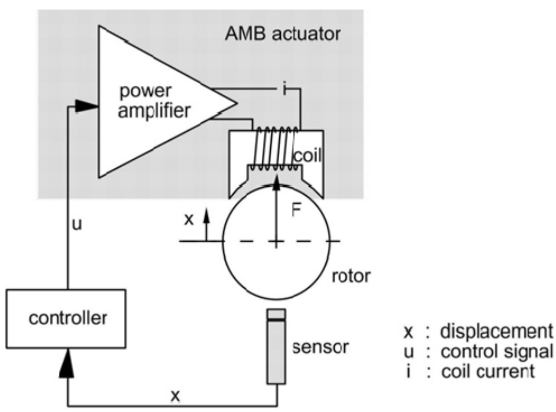

Figure 1. Basic principle of an active magnetic bearing (AMB)

3. DIFFERENT METHODS TO CONTROL ELASTIC ROTOR USING ACTIVE MAGNETIC BEARING SYSTEM

There are two reasons why flexible systems present more of a challenge to the control system designer than does a rigid rotor. The first is the simple matter that a flexible rotor has a much wider mechanical bandwidth than does a rigid rotor. This means that the mechanical response to high frequency forcing is much larger for a flexible rotor than for a rigid rotor and, as a result, the dynamic behavior of the feedback controller at high frequencies is much more important for flexible rotors than for rigid rotors. The second reason is that, when the sensors and actuators are not collocated axially along the rotor, there will always be flexible modes with a node between a sensor-actuator pair. If these modes have frequencies within the bandwidth of the controller, then they pose special dynamics problems for the system. Both of these issues must be attended to either explicitly or implicitly in the design of an AMB controller for a flexible rotor [1]. Every rotation system must have properties such as robustness, stability and reliability for good control of rotor on different rotation speeds. It is easy to achieve these properties using PID regulators if rotor does not exceed critical rotational speeds, in this case for modeling this kind of system it is possible to apply point masses or rigid body model. If rotor runs in area near critical rotation speeds, for its control it is necessary to use some of advanced algorithms, which takes in consideration elastic shaft natural frequency. At these frequencies rotor achieves elevated vibration amplitude, because of that it is important to predict and monitor system behavior in terms of resonance. This research is obligatory for all rotors operate above first shaft critical speed [5].

Most important and until today most used methods for rotor control using AMB are: PID controllers, H_∞ method [1], $\mu - synthesis$ [6], LQG (*Linear Quadratic Gaussian*) method, Nonlinear sliding method, SPOC-D algorithm, etc. Because of lack of space, functional work principle of these methods is not explained in this paper. Paper only gives some of advantages and disadvantages of these methods and their application possibilities.

- **PID controllers**

With H_∞ method and $\mu - synthesis$, PID controllers have biggest potential for use in field of AMB elastic rotor systems. With PID controllers it is possible to achieve robustness, but in the same time only decentralized control is possible. Decentralized control doesn’t take in consideration non-collocation of actuators and sensors [5]. Regulators obtained using this control method usually don’t take in consideration special requirements of complex systems and therefore can’t guarantee their stability. In order to improve efficiency of these regulators, they are usually extended with low pass filters which can remove measurements noise and improve robustness and with notch filters which can prevent appearance of higher vibration forms. Except that, if is necessary to take in consideration non-collocation of sensors and actuators, stability of the system is still low. In order to overcome the disadvantages of long manual adjusting, because systematic toll for this purpose still don't exist, and in order to prevent appearance of some elastic forms, a lot of research are focused to extend the standard PID controller with advanced method of control like LQG, H_∞ and $\mu - synthesis$. The goal is to achieve a more efficient setting and to implement method with which will be possible to achieve stable response in the shortest possible time and in different operating conditions [5].

- **H_∞ method and μ synthesis**

First usage of H_∞ method was around 1990. This method have two approaches. First approach is based on design of transfer functions and second one is based on signals. If design is implement in open circle, then method which is usually used, is so called Glover-McFarlane H_∞ method, this method can be used in field of AMB. In another hand, design of transfer function in closed loop leads to H_∞ method of *mixed sensitivity*. A lot of papers for implementation of this method rely on use two functions, which are determined based on empirical assumptions. H_∞ approach based on signals is very effective method for systems with more variables, but impractical due to the need to manually adjust many weight function. Taking in consideration that this usually means that stability will be harder to achieve and that system will lose some of its properties, a lot of research is directed toward modern approaches of adjusting, like neural nets, genetic algorithm or special optimization methods, for example LMI (*Linear Matrix Inequality*). Except that it is necessary to pay attention to the fact that, during implementation of H_∞ method, some of numerical problems can occur, as a consequence of complex system dynamic. Unlike PID controllers, in which settings of parameters can be carried out iteratively in a real system, to design robust controllers it is necessary to be familiar with the model of the system. Because of this, properties of controller depend on accuracy of the model. Because, it is impossible to achieve the model which will accurately describes the corresponding real system in all phases of concepts, H_∞ method and μ – synthesis allowing to take in consideration errors of the system (modeling error, changing of system parameters, etc) directly in design process of controller. On this way it is possible to build controller which is robust on uncertainty which are considered in the process of its modeling [5], [7].

- **LQG (*Linear Quadratic Gaussian*) method**

The biggest disadvantages of this method is in the fact that this method is based on initial model of the system, so this mean that this method don't take in consideration changes in the system which can occur during time. Because of this, LQR method gives optimal results only in conditions from the beginning of controller design process.

- **Nonlinear sliding mode method,**

A lot of research is done around this method. The main advantage of the method lies in a significant reduction in power consumption. This method has the potential for promising applications in the future, but it requires further research related to unresolved issues for preventing appearance of weakly damped elastic forms.

In addition to the above methods, recently there are a lot of attempts to develop robust PID controller. It is possible to use *Augmented Lagrangian Particle Swarm Optimization* (ALPSW) method in this controller. Analysis is based on simultaneously satisfying multiple criteria from H_∞ method, which are difficult to resolve using computers and existing methods. Taking in consideration that ALPSW is stochastic method, this is just one of the attempts. Further research is needed to improve convergence.

4. CONCLUSION

The paper gives a brief insight into the AMB technology and possibility of their applications. Paper also gives most important advantages and disadvantages of this technology. Also the paper was succeed to present complexity of elastic rotor control using AMB systems, by presenting currently studied methods of control. Control of flexible rotors is a very complex process and it is still focus of many researchers. Previous research has shown that for choosing an optimal control approach for elastic rotor someone has to compare characteristics of many different control strategies on considered elastic rotor system. Chosen control method has to fulfill several requirements including robustness, reliability as well as simplicity

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