CHAPTER 1

Introduction and Literature Review

1.1 Introduction

The Active Magnetic Bearing (AMB) is a device that uses electromagnetic forces to support a rotor without mechanical contact. The AMB offers many advantages compared to fluid film and rolling element bearings, such as no wear, the ability to operate in high temperature environments, and no contamination of the working fluid due to the absence of a lubricant in the system. By monitoring the position of the shaft and changing the dynamics of the system accordingly, the AMB keeps the rotor in a desired position. This unique feature has broadened the applications of AMBs and now they can be considered not only as a main support bearing in a machine but also as dampers for vibration control. This thesis presents the results of a study investigating the use of AMBs as dampers to reduce nonsynchronous vibrations in a rotor-bearing system.

Lateral vibrations due to response to unbalance are the most common problem experienced by spinning rotors, producing synchronous (same frequency as rotating speed) vibrations. This problem and active solution methods addressing it have been studied in great extension. Kasarda (1988) used an AMB as damper to reduce vibrations on first and second modes.

Vibration problems, usually unrelated to unbalance, represent another kind of problem for turbomachinery in which the rotor vibrates at nonsynchronous (other than rotating speed) frequencies. Nonsynchronous vibrations can be subsynchronous, when the frequency is lower than the rotational speed of the shaft, supersynchronous, when the frequency is higher than the rotational speed of the shaft, or a combination of both. One of the most harrowing of rotor vibration scenarios is the case of rotor instability causing subsynchronous vibrations. The onset mechanisms of subsynchronous vibrations are related to a great diversity of destabilizing forces, some of them not well understood yet, and therefore, special attention must be paid to this type of vibration. While considerable literature exists on analyzing, predicting and implementing passive techniques for reducing vibrations due to rotor instability, no publications on active control of this phenomena exists. Active control through AMBs stands as a promising solution for the prevention of this type of vibration problem.

In this research, the effectiveness of an active magnetic damper in solving subsynchronous vibration problems is evaluated in two rotor kit configurations. A single-disk flexible rotor and a three-disk flexible rotor are utilized for experimental testing of the concept for comparison with theoretical predictions. Accordingly, some design guidelines are presented.

1.2 Literature Review

A great amount of literature exists related to Rotordynamic instabilities, Active Magnetic Bearings (AMBs) and Active Magnetic Dampers (AMDs). The following sections address state-of-the-art in each of these major research areas.

1.2.1 Instability in Rotating Machinery

Rotordynamic instability is a phenomenon in which a rotor whirls at frequencies lower than rotational speed (subsynchronous frequencies). The instability starts at a certain speed known as onset of instability or stability threshold and begins to grow quickly as the rotor speed increases.

In the past, rotordynamic instability problems were not very common. However, in the last few decades, the appearance of rotordynamic instability has increased due to the development of turbomachines rotating at supercritical speeds, having more stages to manage higher pressures, and closer seals clearances for increased efficiency, designed to meet industry challenging requirements.

To date, many kinds of instabilities have been identified. These include oil whirl and oil whip due to fluid forces in hydrodynamic bearings. Aerodynamic instabilities caused by the effect of forces due to variations in the blade-tip clearances in axial flow compressors were quantified by Alford (1965). Wachel (1975) described the cases of load dependent instability observed in three centrifugal compressors. One of the compressors presented a small subsynchronous amplitude when running at 11,000 RPM and when the load was increased, the instability was triggered preventing the compressor to reach the design discharge pressure.

Design specifications suggest that a rotor can operate with acceptable levels of instability as they do with acceptable levels of imbalance. Kirk (1985) describes an acceptance specification for centrifugal compressors that requires that the average subsynchronous vibration level be bounded and below 40% of the overall vibration specification.

Mathematical modeling has been performed allowing the development of computer programs that predict the threshold of instability and often allow the designer to change the rotor-bearing system characteristics to avoid the appearance of instabilities within the operational range of the machine. Kirk and Miller (1977) studied the influence that high-pressure oil seals have on turbo-compressors stability, introducing some design guidelines to avoid the appearance of subsynchronous vibrations. Kirk (1985) developed a reliable compressor design taking into account the interaction of labyrinth seals with the rotor and addressed the importance of the design of labyrinth seal clearances to enhance stability. However, limitations associated with the models and understanding of other instability mechanisms results in the periodic building of turbomachines which exhibit unstable behavior even though they have passed full speed, no-load shop tests before being installed for operation.

In addition, some rotors may require increased seal clearances to achieve satisfactory operation, from the stability point of view, with a consequent decrease on efficiency. The development of a reliable technique to damp subsynchronous vibration could reduce or eliminate this trade-off, resulting in the design of more efficient machinery.

The above establishes the importance of the evaluation of mechanisms to damp subsynchronous vibrations. In this matter, Active Magnetic Dampers stand as a very promising solution.

1.2.2 Functional Principles and Applications of AMBs

Shown in Figure 1.1 is one quadrant of a radial AMB consisting of a position sensor, a controller, a power amplifier and an electromagnetic actuator. For operation, the sensor measures the position of the shaft and the measured signal is sent to the controller where it is processed and then, the signal is amplified and fed as a current into the coils of the magnet, generating an electromagnetic field that keeps the shaft in a desired position. The strength of the magnetic field will depend on the air gap between the shaft and the magnet and the dynamics of the system including the design of the controller. Some of the advantages that make the AMB an attractive device are:

- No mechanical contact between the shaft and the magnetic bearing
- Active control capability, the position of the rotor can be continuously monitored and adjusted, if necessary, to achieve optimal performance
- Oil free system, no lubrication is required, resulting in no contamination of the working fluid and capability of operation at higher temperatures.
- Lower maintenance costs due to the absence of undesired wear and vibration.

Up to date, AMBs have been successfully used in diverse types of applications. Hustak, et. al (1985) demonstrated the capability of an AMB system to support a flexible turbo-compressor rotor. Baloh, et. al. (1996) developed electromagnetic radial and thrust bearings for an artificial heart. Kasarda (2000) discusses numerous other commercial and research applications.

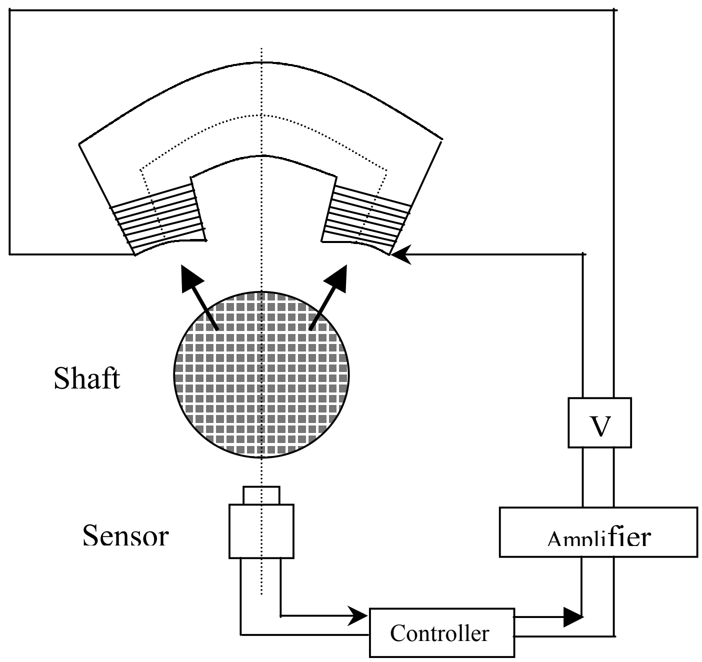

Figure 1.1: Magnetic levitation principle

1.2.3 Active Magnetic Dampers (AMDs)

Advanced control technology has made possible the use of AMBs to adjust the dynamics (stiffness and damping) of a rotor system, based on constant monitoring of the position of the shaft, this fact has introduced the concept of Active Magnetic Dampers (AMD), which are generally AMBs with no static load capacity, placed in a machine for vibration control purposes.

A good deal of research has been conducted in this area. Schweitzer (1985) demonstrated, analytically and experimentally, that a considerable reduction of the resonance amplitudes could be achieved using active damping in flexible beams and in flexible rotors supported in conventional bearings. Kasarda (1988) reported that significant reductions of up to 88% in synchronous vibrations on the first and second mode were attained experimentally placing an electromagnetic damper in a rotor simulating the dynamics of a turbomachine. Kasarda (1988) demonstrated that the location of the damper in the rotor plays an important role in its effectiveness based on rotor mode shape.

Kasarda (1988) suggested the evaluation of the effectiveness of an electromagnetic damper in solving subsynchronous vibration problem but very little work has been conducted in this area. The goal of the present thesis is to determine the effectiveness of an AMD to solve subsynchronous vibration problems, such as these caused by instability mechanisms, in a flexible rotor.