MAGNETIC BEARINGS FOR CRYOGENIC TURBOMACHINES

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ABSTRACT

Magnetic bearings offer a number of advantages over gas bearings for the support of rotors in cryogenic turboexpanders and compressors. Their performance is relatively independent of the temperature or pressure of the process gas for a large range of conditions. Active magnetic bearing systems that use capacitive sensors have been developed for high speed compressors for use in cryogenic refrigerators. Here, the development of a magnetic bearing system for a miniature ultra high speed compressor is discussed. The magnetic bearing has demonstrated stability at rotational speeds exceeding 250,000 rpm. This paper describes the important features of the magnetic bearing and presents test results demonstrating its performance characteristics.

INTRODUCTION

This paper focuses on the development of high speed magnetic bearings for turbomachines used in cryogenic systems. The magnetic bearing work is an outgrowth of our experience with gas bearings. Over the years, we have developed turboexpanders, circulators, and compressors for cryogenic systems that vary in size from small cryocoolers for cooling of spaceborne sensors to large cryogenic refrigerators for cooling the superconducting magnets used in high energy particle accelerators. These machines use gas bearings to eliminate contamination of the process gas stream and to ensure reliable and stable high speed rotation with little or no maintenance.

Magnetic bearings offer the potential to increase the performance of present and future machines because they offer the following advantages over gas bearings: performance independence from process gas conditions, load capacity at low rotational speeds, and relative ease of fabrication. For medium sized applications, magnetic bearings in the size range of 2.5 cm (1.0 in.) to 5.0 cm (2.0 in.) have been developed for pumps and compressors and tested to rotational speeds exceeding 80,000 rpm. The development of a cryogenic vacuum compressor is currently underway. In this paper, we discuss the development of a miniature magnetic bearing for use in an ultra high speed compressor with a shaft diameter of 0.64 cm (0.25 in.) and rotational speed of about 500,000 rpm.

PRINCIPLE OF OPERATION

An active magnetic bearing is a type of position controlled servomechanism. A schematic drawing of one magnetic bearing configuration is shown in Figure 1. The bearing can be thought of as four electromagnets arranged circumferentially around the shaft. Each magnet controls the flux level for an individual quadrant of the bearing.
By individually adjusting the currents in the four coils, a radial force may be produced of a desired magnitude and direction. This magnetic force is used to control the position of the shaft. The flux emanating from a pole face is composed of two components—a DC or bias field $B_0$ that remains relatively constant, and a control component $B_c$ that varies with the shaft position.

An active control system is included for each radial axis. The system consists of the control electromagnets (actuator), a sensor for detecting radial displacements of the shaft, and control electronics which supply current to the coil in response to the error signal. One component of the control current is proportional to the shaft displacement and determines the stiffness of the bearing. Another component of the control current is proportional to the rate of change of position (velocity) of the shaft and determines the damping of the bearing. The stiffness and damping can be adjusted within a range of values via the controller electronics.

A bias flux $B_0$ is included to linearize the relationship between the control current and force. The bias field can be produced by the control electromagnets, by a separate bias coil, or by one or more permanent magnets. For large applications where resistive heating loss in the bearings is not critical, the bias field may be supplied by the control electromagnets for simplicity. However, the use of permanent magnets to supply the bias field is preferred for small and miniature applications where electrical heating would adversely affect the performance of the machine. In the absence of external loads on the shaft (such as imbalance and acceleration forces), an active magnetic bearing employing a permanent magnet can be designed to dissipate almost zero power.

MINIATURE MAGNETIC BEARING FOR AN ULTRA HIGH SPEED COMPRESSOR

Creare is developing a miniature compressor that incorporates magnetic bearings as part of a program to develop the Single Stage Reverse Brayton (SSRB) cryocooler. This is a spaceborne mechanical cryocooler capable of 5 watts of cooling at 65 K. The 0.64 cm (0.25 in.) shaft of this compressor spins at 500,000 rpm at its design point, and the 1.5 cm (0.60 in.) impeller produces about 100 watts of useful work. The nominal design parameters for this compressor are listed in Table 1.

The magnetic bearing that was conceived, built, and tested for this application is shown schematically in Figure 1 and photographically in Figure 2.