Engineering Failure Analysis 62 (2016) 1–20

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure mode and effect analysis of passive magnetic bearing

K.P. Lijesh [a], S.M. Muzakkir [b,*], Harish Hirani [a]

[a] Mechanical Engineering Department, Indian Institute of Technology Delhi, New Delhi, India
[b] Mechanical Engineering Department, Jamia Millia Islamia, New Delhi, India

ARTICLE INFO

Article history:
Received 11 August 2015
Received in revised form 31 October 2015
Accepted 16 November 2015
Available online 17 November 2015

Keywords:
Risk Priority Number
Magnetic flux density
Finite element modeling
Modeling of cracks
Fracture of magnets
Wear

ABSTRACT

In the present research work the failure mode and effect analysis (FMEA) process is applied to identify the various possible failure modes of different configurations of passive magnetic bearings (PMB) and the corresponding effects of these failures on the bearing performance. The identified failure modes of PMBs will facilitate designer to incorporate necessary design features that would prevent the occurrence of the failure. Experiments have been conducted to determine the severity, occurrence and detection of the various failure modes. The Risk Priority Number (RPN) of each failure mode is calculated to identify high risk failures. The methods to eliminate or reduce the high-risk failure modes are proposed and experimental investigations are conducted to validate the proposed solutions.

1. Introduction

In the passive magnetic bearings (PMB) the rotor is generally levitated by the repulsive forces generated between the magnetic rings placed on both rotor and stator (as shown in Fig. 1). The unique advantage of such system is that the rotor rotates in levitated condition preventing the contact between the stator and rotor. In situations of heavy load and slow speed, like in sugar mill bearing [1] where hydrodynamic lubrication is difficult, a passive magnetic bearing is very advantageous. This reduces friction, provides zero wear and obviates the use of lubricant. The load carrying capacity of such system has increased considerably in last two decades due to the development of high strength neodymium magnets and its easy availability at relatively low cost. This has resulted in an increase in its usage in many engineering applications like molecular pumps (Yoichi and Yuji [2]), artificial heart blood pump (Qian et al. [3]), flywheel (Kumbernuss et al. [4]) *etc*. But the performance of repulsive type magnetic bearing is strongly dependent on the characteristics of the magnets and its configuration [5].

One of the main limitations of such magnets is the non-uniform magnetization of a large size neodymium material [4] and to make the situation worse, the non-uniformity of the magnetic field increases with aging under the running condition. Ohji et al. [6] studied the performance of the repulsive type magnetic bearing under the non-uniform magnetic field caused due to aging of magnet. Based on their experimental study, it was concluded that a 10% variation of magnetic flux density on the stator resulted in unwanted vibration in the system due to unbalance magnetic pull between the stator and rotor, increase in the power loss of system and shifting of rotor position from the centre [6]. Therefore, the non-uniformity of magnetic field has strong influence on the performance of the system. Another limitation of the rare earth magnets is its fragility that makes it prone to fractures [7–9] even at low level of impact [7]. One such failure has been reported by Muzakkir et al. [10] in passive magnetic bearing where crack in the 180° sector stator magnet and fracture of rotor magnets were observed. The PMBs are thus more prone to failures and there is a need

* Corresponding author.
E-mail addresses: mez108659@mech.iitd.ac.in, smmuzakkir@jmi.ac.in (S.M. Muzakkir).

http://dx.doi.org/10.1016/j.engfailanal.2015.11.033
1350-6307/

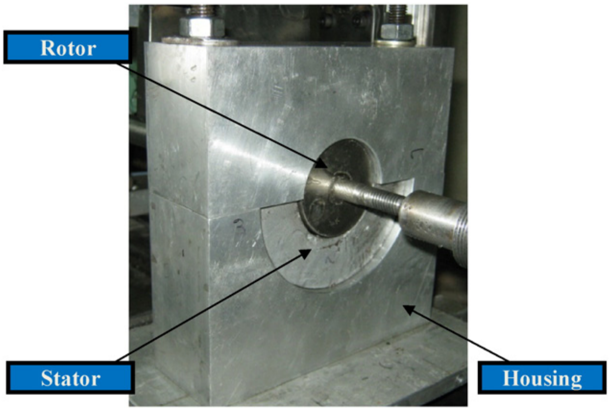

Fig. 1. Passive magnetic bearing.

to identify feasible solutions to prevent the failures. The failure mode and effect analysis (FMEA) is a widely accepted method to identify the failures and their effects on the system performance. It facilitates the designer in generating ideas for obtaining solutions for prevention of the failures [11].

The FMEA is a systematic method of identifying and preventing the failure of products [11]. The main objective of an FMEA process is to identify all the potential modes of failure of a product. The failure of a product is said to occur when it does not function as per the requirements or when the product does not fulfill the required performance objectives. Each identifiable and distinguishable manner in which a product fails is known as its failure mode. Each failure mode affects the product performance, safety, economy, reliability and has a potential to result into a catastrophic failure. Therefore, each potential effect has a relative risk associated with it. The FMEA process is a way to identify the failures, effects, and risks within a process or product, and then eliminate or reduce them [11]. As per authors knowledge there have not been any work reported in literatures of FMEA on PMB.

Various possible failure modes of passive magnetic bearings and their severity, occurrence and detection have been discussed in detail in the present research work. The severity of the failure mode has been evaluated by performing experiments in the developed experimental setup. The Risk Priority Number (RPN) of the each failure mode was estimated and then utilized in ranking the failures. The methods to eliminate or reduce the high-risk failure modes were proposed and experimental investigations are conducted to validate the proposed solutions.

2. FMEA procedure for passive magnetic bearings

In the FMEA, it is required to identify the various failure modes of PMBs and determine their severity, their possible means of detection and their effects on the performance. Since a PMB consists of several components, there is a need to identify the failure mode of each component and then determine the interrelationship between failures of various components of PMB. FMEA is an efficient tool that provides a systematic procedure to identify and categorize the various failure modes so that a designer is able to prevent them under actual operating use.

In FMEA, it is essential to study the system for which the failure has to be reduced. Then the various components of the system which are prone to failure are to be identified. These failures have to be categorized based on their severity, occurrence and its

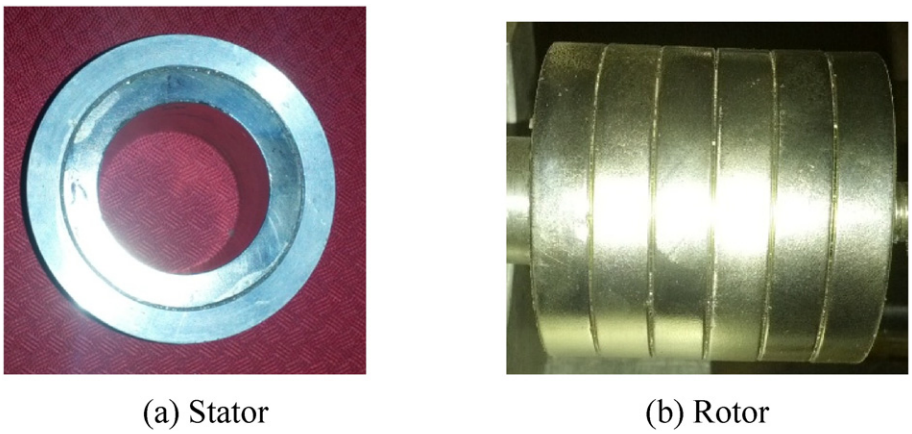

Fig. 2. Configuration 1: full ring stator and its rotor.