An Overview of the FMECA Technology of Magnetic Bearing System

ZHANG Li [a], REN Yafeng [b], CHEN Jinping [a], LIU Jun [a], LUO Yanyan [a], ZHANG Haining [a]

[a] AVIC Qingan group., LTD, 710077 Xian, China, ZHANG Li.19871027zhangli@163.com
[b] Northwestern Polytechnical University, Xian, China

***Abstract*—Active magnetic bearing is usually applied for the intelligent device that has high running speed and huge impact in the event of a failure. It has become the research hotspot of monitoring and diagnosis technology in the field of intelligent machine. Intelligent magnetic bearing system understand the inherent state by itself, and through fault diagnosis, prediction, health management to continuously optimize and adjust itself. It is necessary to deeply study the failure mechanism of magnetic bearing system, which is helpful to develop the intelligent machine. this article mainly expounds the observed index characteristics and fault modes. Failure modes and effects criticality analysis (FMECA) is introduced to design the magnetic bearing system. The FMECA design process is to extract fault features of the best indicators or conditions, early detect and isolate faults, and predict the remaining life of the key components, finally realize the lower maintenance cost, higher safety and reliability.**

I. Paper

A. Introduction

As a very valuable unit, magnetic bearings have a series of quite new features and a variety of applications ranging from small turbo molecular pumps to large pipeline compressors[1]. In addition to functions, the safety and reliability of magnetic bearing system has become a key factor in commercial development. Because of the high speed of the magnetic bearing system and the great damage of the fault, it has always been the focus of the research on the monitoring and diagnosis technology. The application of the intelligent fault diagnosis and prediction technology can help the system to operate more safely and economically.

Now, the research on fault prediction, diagnosis and health management technology of magnetic bearing system has become one of the focuses. M and R [2]studied the failure of magnetic poles, sensors and other components, and continuously corrected the system through effective detection. M[3] diagnosed the faults in the grinding process and the wear condition of the tool by detecting the sensor signal in the spindle of the magnetic bearing. F[4] has carried out in-depth research on fault detection and correction of actuator and sensor in magnetic bearing system. The FMECA analysis of permanent magnet bearing is carried out by Tianjin University in China[5], but the whole magnetic bearing system is not analyzed. Fan Wen et al.[6] put forward a design method of magnetic bearing vibration monitoring and fault diagnosis based on LABVIEW, and applied it to vibration monitoring. Hu Yefa and others[7] applied the multi valued logic algebra method based on sequence variables to the fault diagnosis of magnetic bearing sensor. In this paper, indicator features and fault modes that can be monitored from a systematic perspective are expounded. The FMECA analysis of magnetic bearing system is studied. It helps to promote the reliability and life analysis of the system.

B. Indicator features of magnetic bearing system

Some indicator features of magnetic bearing system, such as carrying capacity, speed, temperature, voltage / current, loss and so on, are very important for the expected performance. Therefore, they should be monitored and detected, which is critical to the reliability and safety of the system.

TABLE I. INDICATOR FEATURES OF MAGNETIC BEARING SYSTEM

Features	Explaination
Load Capacity	*Load Capacity is not only to provide static force, but has a strong dynamic characteristics. Power amplifier are mostly to generate dynamic forces.*
Dynamic stiffness	*It is the relationship between electromagnetic force and current ,frequency and displacement.*
Supercritical speed	*A rotor may well have to pass one or more critical bending speeds in order to reach its operational rotation speed.*
Current/Voltage	*the maximum coil current available from the power amplifier which drives the magnetizing coil and the maximum driving voltage of the power amplifier.*
High Temperature	*In some special fields such as aircraft engines magnetic bearings need to work in high temperature environment. Also, the thermal dissipation of MB system needs to be considered.*
Losses	*The losses of MB system during operation are often rare, but they should not be ignored .In the micro system they leads to a lot of limitations.*

The features in the table are both the limiting features of the design and the fault characteristics of the state detection. For example, displacement $x(t)$ is measured by sensors for system controlling and operation monitoring. Voltage/current or rotational speed is critical to the operation of the system and can be directly monitored. The load capacity reflects the size of the electromagnetic levitation force. it can be detected by measuring flux density through a hall sensor. The losses can cause the increase of temperature, and the ambient temperature has an important influence on the safety .Therefore, the monitoring of temperature is necessary. In different application fields. MB system needs more controllable indicator features.

C. Fault mode of magnetic bearing system

The magnetic bearing system is a mechanical and electrical integration system including mechanical, electrical and information processing units. Failure comes from all aspects. Failure of mechanical parts, electrical components or software may be encountered. According to the technology of fault diagnosis and health management and the research example of magnetic bearing, the potential fault range can be understood.

Software system failures generally have system crashes timeout caused by running exceptions, or version mismatch. Software problems need to be improved during the bugging phase. Electrical components may fail or signal interference, such as sensor signal interference caused by electromagnetic radiation. It may lead to excessive control of compensation. Electromagnetic compatibility design must be valued, but there is no better solution. Mechanical parts often fail to malfunction such as the crack of the rotor, the drop of the load plate etc. they have been well understood in practice. When the fault happened, the protective bearing can protect the rotor. However, there is still a sudden occurrence, rub will appear to test its life. The power off will be the most serious internal failure, standby measures should be considered.

D. FMECA study of magnetic bearing system

Modern FMECA can provide advanced algorithm to extract the best fault characteristics or Indicator features, and predict the remaining useful life of key components[8]. Therefore, it is necessary to carry out FMECA design of system level and sort out the failure modes, causes and seriousness of the system. FMECA design often uses a spreadsheet with an explanatory module. Complex tools are also used such as rule-based expert system and decision trees.

A FMECA design must identify the failure mode which is classified according to severity, occurrence probability and testability. The following are the classification of severity on failure modes.

a) Catastrophic, it may lead to death, major injury or total loss of equipment.
b) Critical, it may cause serious damage and equipment damage.
c) Weak, it may cause minor damage and equipment damage or system performance degradation.
d) Tiny, it does not cause damage or equipment damage. However, if there is no maintenance or regular maintenance, it may cause a device failure.

Probability of occurrence can be divided into four categories, respectively, is easy, possible, accidental and never. they differ in the average time between failures(MTBF). The testability is that a feature in specific fault mode can be detected by the sensor. Therefore, failure modes that cannot be measured are not included.

According to the FMECA method MB system is analyzed. The following table 2 gives the key components of the failure mode, fault reason, severity, probability and so on.

In the direction of the system, the more the number of components, the worse the reliability of MB system and the higher the frequency of failure. Table 2 also helps to study the template for diagnostic algorithms. The failure physical mechanism of MB system is fully understood.

TABLE II. FMECA OF MB SYSTEM

System	Component	fault mode	Reason	Severity	Probability	Testabi	Measures
MB System	Power Amplifier	Failure	Current overload/ Ambient temperature(High or low)	possible	Critical	Yes	Duplicate configuration
	Displacement Sensor	Failure	Measured surface damage/ Electronic circuit failure	possible	Critical	Yes	Duplicate configuration
	MB coil	Failure	Coil insulation failure	accidental	Weak	No	Regular inspection
	Control system	Failure	Control algorithm is not suitable for new conditions	possible	Critical	No	Robust control
	Rotor	Rotor rub	vibration at sub-synchronous and higher harmonic frequencies	accidental	Critical	Yes	Controller compensation
		Cracked rotor	vibration at the synchronous frequency	accidental	Catastrophic	Yes	Replace material
		Rotor contact	contact with the rotor when faults occur	possible	Critical	Yes	Replace Auxiliary bearings
	Power supply	Power off	External power outage	accidental	Catastrophic	Yes	Standby pewer

E. Block diagram of MB system with reliability

MB system is a series system. If a core component fails , the operation will be affected or damaged. Fig.1 indicates Block diagram of the five-degree-of-freedom MB system with reliability(includes two radial magnetic bearings(RMB) and a thrust magnetic bearing(TMB)). The core components are duplicated or redundant designed is beneficial to the reliability for MB system. But, it increases the complexity.

There is a hypothesis that the failure probability of the same part within the same semicircle in the same working mode is consistent, for example, the failure probability of sensor in Fig.1 is the same. Based on this series model , the failure probability of the system is simplified and the scheme of the fault problem becomes simpler. In Fig.1 the power supply is the only one, the part that is circled by the dotted line can be used as a subsystem that is also a typical tandem model. If TMB and RMB have the same failure probability, then three subsystems will be consistent. The failure probability of the system is that three times of failure probability in the subsystem multiply the power supply and the rotor. Since the control software is the same, its value needs to be rooted in three square. Based on the above assumptions , the FMECA design of MB system is also simplified.

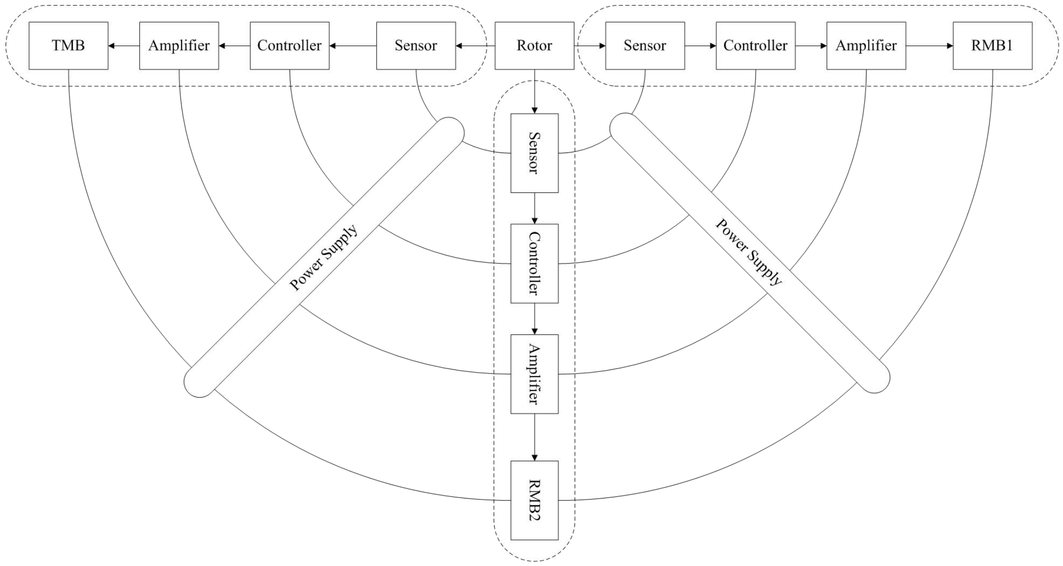

Figure 1. Block diagram of the five-degree-of-freedom MB system with reliability

F. *Life evaluation of MB system*

The life evaluation of MB system can be validated by accelerated test . But in this field, system-wide lifetime data is scarce, and can be not accumulated entirely through the lifetime test of the whole system. Therefore it is suitable for MB system to adopt the core unit evaluation method, named as the shortest life method of core device.

Obviously Fig.1 shows the core components of the system including MB, rotor, sensor, controller, etc. The analysis of subsystem reflects the life of the MB system. Controller and power amplifier in subsystems can be individually integrated and replaced when designed. So, it is more important to evaluate the life of magnetic bearings and shaft. Because of no friction and no contact, the life of MB is more than other bearings, generally more than 10 years. The life of shaft is affected by rotational speed, material and load.

G. *Conclusion*

By analyzing the fault mode, the cause of the fault and the characteristic of the magnetic bearing system, the FMECA of the magnetic bearing system is further designed to understand the potential fault range. This is conducive to the stable operation and higher reliability of the system, and also lays the foundation for the intellectualized development of the magnetic bearing system.

REFERENCES

[1] G.Schweitzer, H.Maslen. Magnetic Bearing-Theory, Design, and Application to Rational Machinery,2009.

[2] M.Aenis,R.Nordmann..Fault Diagnosis in Rotating Machinery using Active Magnetic Bearing.8th internet.Sympos.on Magnetic Bearings,Mito, Japan,2002.

[3] M.K.Mueller.On-line-Process Monitoring in High Speed Milling with an Active Magnetic Bearing Spindle.PHD thesis,ETH Zurich,2002.

[4] F.Loesch.Detection and Correction of Actuator and Sensor Faults in Active Magnetic Bearing Systems. 8th internet.Sympos.on Magnetic Bearings,Mito,Japan,2002.

[5] Yao Jiangwei.A Study on the Failure Mode and Accelerated Life Test of the Permanent Magnetic Bearing in Rotating Machine. PHD thesis,Tianjin University,2004.

[6] Fan Wen,Sun Dongmei,Yuan Qian.Design of Vibration Monitoring and Fault Dignosis System of Magnetic Bearing Based on LabVIEW.Instrument Technique and Sensor,2016.

[7] Zhou Zude,Ku Shaoping,Hu Yefa.Study on Fault Diagnosis of the Multi-Sensors of Magnetic Bearings.China Mechanical Engineering,2005.

[8] G.Vachtsevanos.Intelligent Fault Diagnosis and Prognosis for Engineering Systems,2006.