

Available online at www.sciencedirect.com**ScienceDirect**

Procedia Engineering 144 (2016) 810 – 816

**Procedia
Engineering**www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

Design and Analysis of a Radial Active Magnetic Bearing for Vibration Control

Gaurav Kumar^a, Madhurjya Dev Choudhury^a, Sivaramakrishnan Natesan^a, Karuna Kalita^{a,*}

^a Department of Mechanical Engineering, IIT Guwahati, Guwahati-781039, India

Abstract

Vibration caused by rotor unbalance is one of the most pertinent problems facing the rotating machines, including electrical motors and turbo machinery among others. Thus vibration attenuation has become very essential in improving the overall performance of such machines. In this paper, a 12-pole radial Active Magnetic Bearing (AMB), using AC excitation has been proposed to counteract the unbalance. Here a switching variation of AMB teeth excitation currents is implemented to generate a rotating force, synchronous with the rotor unbalance but in opposite direction.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the organizing committee of ICOVP 2015

Keywords: vibration control; rotor; unbalance; AMB

1. Introduction

Active Magnetic Bearing (AMB) is being extensively used in many rotating machine applications, mainly because of their non-contact motion control characteristics and related advantages as compared with various passive control schemes. Many researchers have exploited the capability of producing a controllable electromagnetic force by AMB, among them Nickolajsen et al. [4] in 1979 introduced their use for vibration damping. Later many authors have worked for vibration suppression using AMB [3,5,7]. They have demonstrated the use of AMB as between-bearings to introduce damping and stiffness into the system and compensate for rotor unbalance such that the magnitude of vibration can be minimized, their focus have been on suppressing the vibration by changing the pole currents based on position feedback.

* Corresponding author. Tel.: +91-361-2582680.

E-mail address: karuna.kalita@iitg.ernet.in

The present paper proposes a force production technique to generate a rotating control force in-order to counteract any unbalance with the help of a 12-pole radial AMB. Here the controlling force to negate the rotor unbalance has been generated by implementing a switching variation of the bearing pole control currents, which has been achieved by utilizing an AC supply. The switching is executed in such a way that a rotating force is generated by the AMB which is synchronous with the unbalanced force and whose direction can be controlled by changing the phase of the AC supply. The electromagnetic design of the proposed model has been developed and verified using FEA (Finite element analysis) software OPERA 2D.

2. Electromagnetic Design of AMB

The design of the radial AMB has been developed by calculating the dimensions of the actuator parameters based on the initial design criteria like the maximum load capacity, air gap, and number of poles. Various analytical equations made available in [1,2,6] are utilized for calculating these parameters. Fig. 1 shows the design methodology adopted in developing the model.

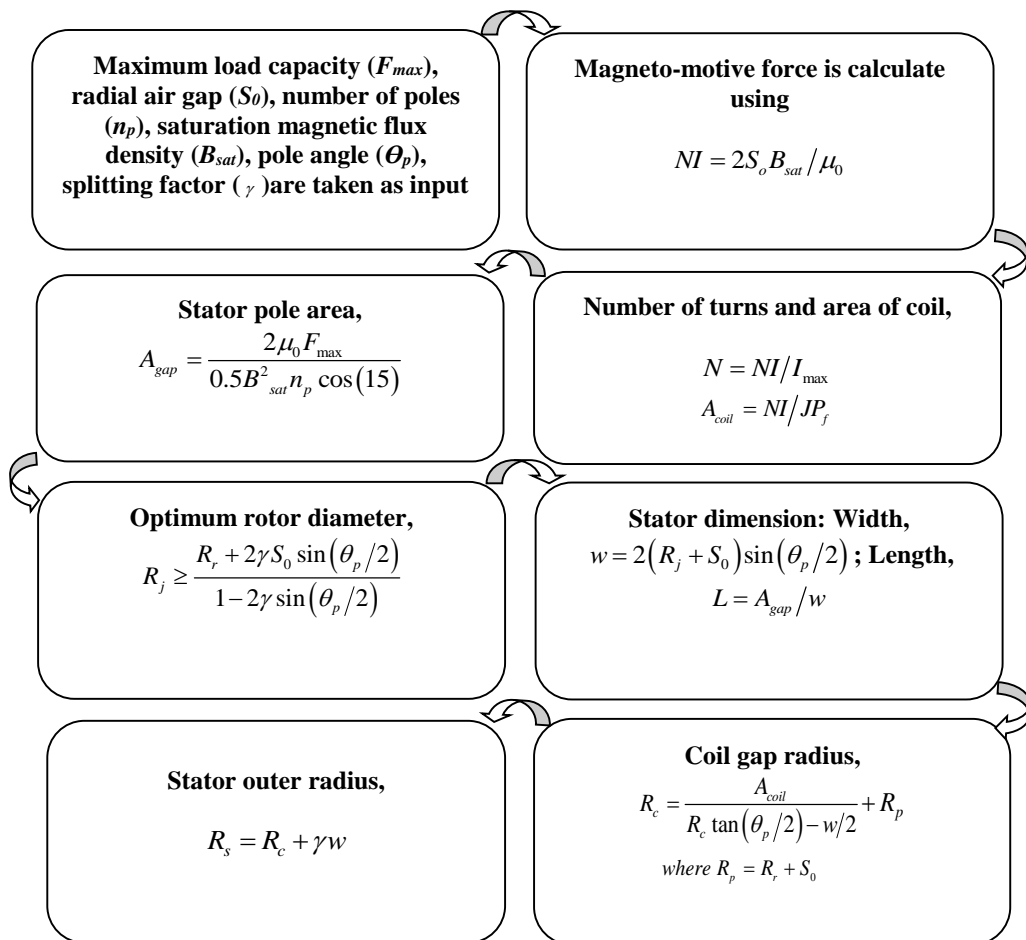


Fig. 1. Flow chart depicting the design methodology.

Based on the methodology applied, the calculated dimensions of various parameters are shown in the table below,

Table 1. Calculated dimensions of the radial AMB.

Dimension	Value
Number of turns of coil, n_p	120
Iron ratio	0.5
Air gap, S_o	1 mm
Radius of shaft, R_r	25 mm
Radius of rotor, R_j	40 mm
Width of the pole tooth, w	10 mm
Coil area for windings, A_{coil}	247.57436 mm ²
Coil space radius, R_c	78.34 mm
Outer radius of stator, R_s	89 mm
Stator tooth area, A	350 mm ²

3. Generation of Revolving Force

The purpose of this study is the generation of a revolving force to counteract an unbalance force. So the calculation of lateral force to support the rotor has not been discussed, only the idea of generation of revolving force and its calculation has been presented. Fig.2 represents a schematic diagram of a Rotor- AMB system, which is coupled with a motor, which drives the system. Generally a rotor is designed in such a way that its first critical speed lies above the operating speed and hence the rotor whirls in 1st mode during its normal operation due to unbalance present in the system, as shown in Fig. 2.

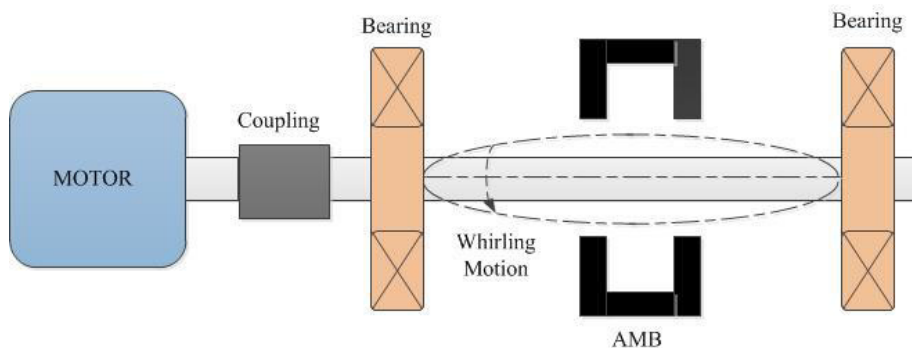


Fig. 2. A schematic representation of a rotor – AMB system coupled with motor.

In order to counteract an unbalance force, which is rotating in nature, it is required to generate a rotating magnetic force which is synchronous with the unbalance force. A sinusoidal excitation of a particular frequency would generate a force of twice the excitation frequency with only positive amplitude, as represented in Eq. 1 (where $\mu_0 = 4\pi \times 10^{-7} N/A^2$, I_x and I_y are the amplitudes of excitation in x and y directions with f as the excitation frequency, F_x and F_y are the magnetic forces in x and y directions) and shown in Fig. 4.

$$F_x = \frac{\mu_0 n_p^2 A}{2S_0^2} I_x^2 \cos^2(2\pi ft)$$

$$F_y = \frac{\mu_0 n_p^2 A}{2S_0^2} I_y^2 \sin^2(2\pi ft)$$
(1)

This positive amplitude is required to be converted in to negative amplitude to generate a sinusoidal force and this has been achieved by adopting a proper switching sequence of the excitation as shown in Table 2 and represented in Fig.3. Representation of the switching sequence can also be observed in Fig. 4. It has been assumed that the unbalance present in the rotor is coinciding with the +ve x - axis at $t = 0$ sec. Further if the used motor is a 4-pole induction machine and it is operated at normal supply frequency of 50 Hz, the rotor would revolve at 25 Hz and hence unbalanced force would also revolve with the same speed as that of the rotor. So it is required to generate a force which is revolving at 25 Hz to counteract the unbalance of the system.

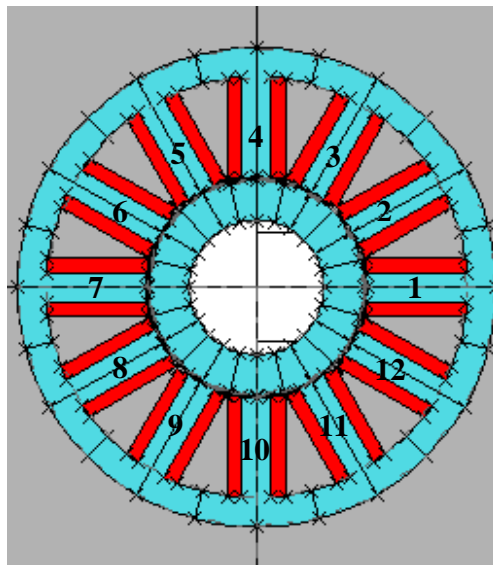


Fig. 3. Two dimensional view of a 12 pole AMB with respective tooth numbers.

Fig. 3 represents the 2D view of AMB with the respective tooth numbers. To generate a revolving force it is required to generate a force of nature $A\sin(2\pi ft)$ along x -direction and $A\cos(2\pi ft)$ along y -direction or vice versa. When an AC excitation is provided in coils of tooth no. 1 and 4, generated force would have square component of sine and cosine. An AC current of 25 Hz has been supplied and generated force as shown in Eq. 1 has been plotted in Fig. 4 (Upper portion termed as without switching). Let's concentrate on without switching condition. Fig. 4 has been divided into four groups. It can be observed that if the direction of the force along x -axis can be reversed in group II and group III, a sinusoidal force can be obtained having the same frequency as that of the excitation frequency (here it is 25 Hz). Similarly if the direction of the force along y -axis can be reversed in group III and group IV, a sinusoidal force can be obtained having the same frequency as of the excitation frequency (here it is 25 Hz). This change in the direction of the force can be achieved by changing the excitation tooth with time as shown in Table 2.

Table 2. Switching pattern of the coil.

Rotor Position	0°-90°	90°-180°	180°-270°	270°-360°
Excitation Coil pair	1-4	4-7	7-10	10-1

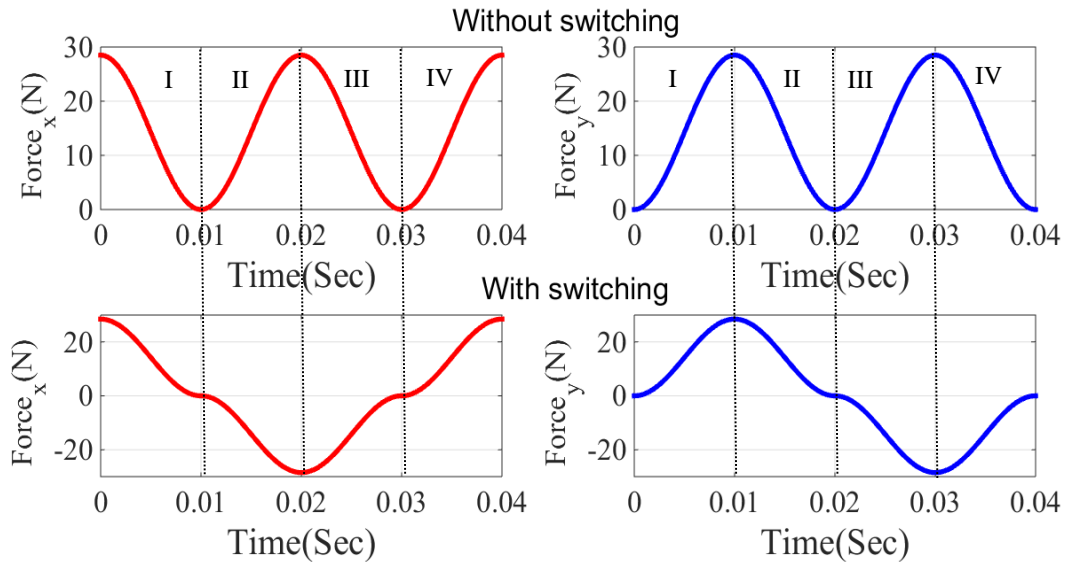


Fig. 4. Force generation with and without switching.

4. Verification Using FE Analysis

A 12-pole AMB has been designed in Opera FEA software for the verification and application of the proposed switching scheme. Fig. 5 represents the flux path orientation according to the switching scheme when a sinusoidal excitation of 3 A, 25 Hz is given to the stator teeth. The stator tooth coinciding with the positive x - direction is considered as tooth no. 1 and subsequently the other teeth are numbered in the counterclockwise direction.

Vector diffusion equation has been solved using opera with the magnetic vector potential as the unknown variable.

$$\nabla \times \left(\frac{1}{\mu} \nabla \times A \right) = J_s \quad (2)$$

Where A is the magnetic vector potential, μ is the permeability of the air gap and J_s is the applied current density in the coil. With the obtained magnetic vector potential, it calculates x and y component of the magnetic field. Further using this obtained field, Maxwell force acting on the rotor has been calculated. The developed model has been discretized using triangular elements. It has 8546 elements and 17188 nodes.

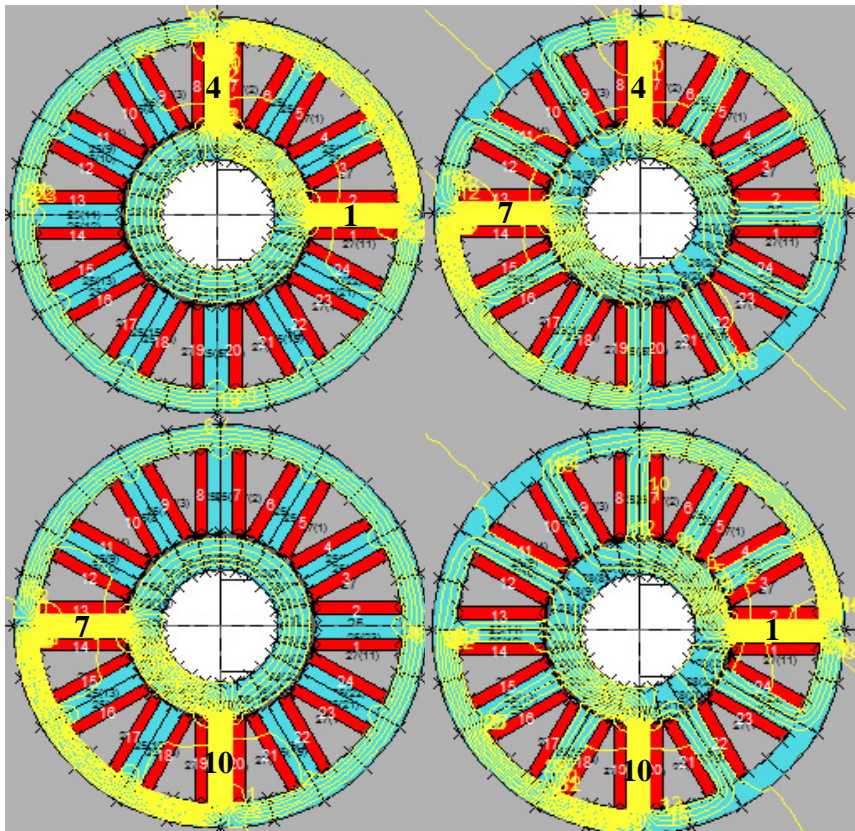


Fig. 5. Flux path in different excitation orientation.

A comparison between the analytical and the FEM force calculations taking switching into account for an AC excitation of 3A has been presented in Fig.6 and they have been found to be within acceptable limits.

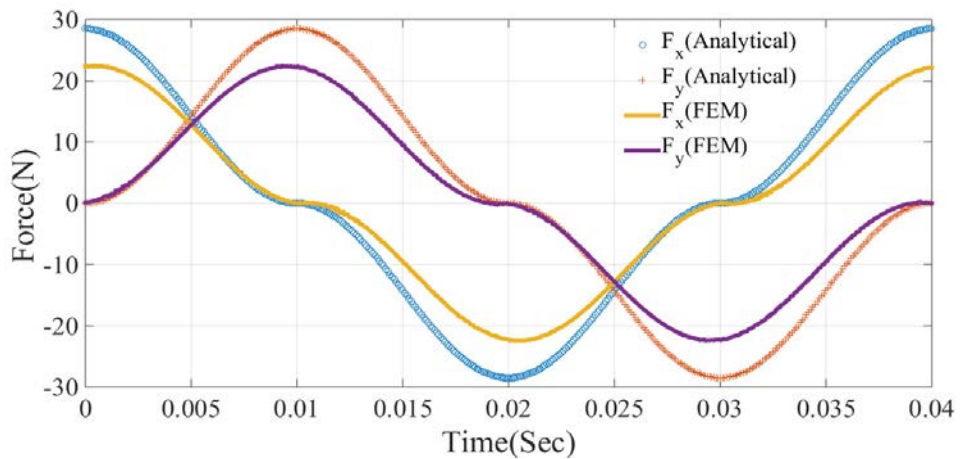


Fig. 6. Comparison of components of rotating force generated by AMB in x and y direction.

5. Conclusion

A 12-pole AMB has been designed and an excitation scheme has been proposed to control the rotor vibration using the AMB. The present work, only demonstrates an idea for the generation of the revolving force. However it is required to estimate the orientation of the unbalance force online for the implementation of the proposed scheme. It has been observed that a revolving force of the same frequency as that of the excitation frequency can be produced by proper switching of the excitation. A complete model for the detection and control of the rotor vibration would be communicated later.

References

- [1] G. Schweitzer, E. Maslen, *Magnetic Bearings - Theory, Design and Application to Rotating Machinery*, Springer – Verlag, Berlin. 2009.
- [2] E. Maslen, *Magnetic Bearings*, University of Virginia. June, 2000.
- [3] M. Kasarda, H. Mendoza, R. Kirk, A. Wicks, Reduction of subsynchronous vibrations in a single-disk rotor using an active magnetic damper, *Mechanics Research Communications*, 31 (2004) 689–695.
- [4] J. Nikolajsen, R. Holmes, V. Gondhaleker, Investigation of an electromagnetic damper for vibration control of a transmission shaft, *Applied Mechanics Group, Proceedings of the Institution of Mechanical Engineers*, 193 (1979) 331–336.
- [5] M. Kasarda, P. Allaire, R. Humphris, L. Barrett, A magnetic damper for first-mode vibration reduction in multi-mass flexible rotors, *ASME Journal of Engineering for Gas Turbines and Power*, 112 (4) (1990) 463–469.
- [6] W. K. S. Khoo, S. D. Garvey, K. Kalita, The Specific Load Capacity of Radial-Flux Radial Magnetic Bearings, *IEEE Transactions on Magnetics*, 43 (7) (2007) 3293–3300.
- [7] C. Lusty, K. Sahinkaya, P. Keogh, A Novel Twin-Shaft Rotor with Active Magnetic Couplings for Vibration Control, *Proceedings of 14th ISMB*, 2014.