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# Effect of dimensional tolerances on the performance of hybrid bearing

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**ABSTRACT** – In extreme operating condition of a fluid film bearing (FFB), metal to metal contact occurs and resulting in failure of the bearings. Under such extreme conditions wear of the FFB are highly sensitive to the tolerance of the bearings. A theoretical study on the tolerance sensitivity of a sugar mill bearing has been performed. To provide solution to reduce the sensitivity of the FFB, a hybrid (FFB + rotating magnetization direction Magnetic Bearing (RMDMB)) is proposed. The tolerance sensitivity towards load carrying capacity of FFB, RMDMB and Hybrid bearing is evaluated for the sugar mill bearing and results are presented.

## 1. INTRODUCTION

Fluid film bearings [1] are known for negligible friction and almost zero wear. However performance of FFB decreases drastically under "low speed and high load [1]" conditions and an efficient bearing designed for such conditions is really a challenging task. In the present work, one of the severe operating conditions has been studied. One such practical example where very low speed and high load prevails is top half bearing of sugar mills (Somerfeld number 0.0011-0.0026 [4]) and these bearings are prone to high wear due to metal to metal contact.

In FFB, high viscous oils along with additives can be used under extreme operating conditions to reduce the wear [4] but the effectiveness of this approach reduces with tolerances of the bearing. Ogrodnik *et al* [5]5] studied the effect of tolerances on the bearing stability particularly for low eccentricity bearings and concluded that the journal bearing is insensitive to the manufacturing tolerances when the system eccentricity ratio runs at more than 0.4, but in severe operating condition it is expected that the eccentricity ratio will be >0.95 which is other extreme of eccentricity studied by [5]. This condition emphasis for the study of the effect of tolerance on the performance of extreme operating condition is necessary. Hence in the present work sensitivity of tolerance on the FFB bearing operating under low speed and high load conditions is carried out.

To reduce the sensitivity of tolerance in FFB, a hybrid (FFB+RMDMB) bearing is proposed. In hybrid bearing it is expected that the static load is carried by the RMDMB [6-7] and dynamic load by FFB. RMDMBs are operated with larger clearance (~mm) compared to fluid film bearing (~µm), therefore it is expected that the RMDMBs will be insensitive to dimensional tolerance of sugar mill bearing. It is expected that hybrid bearing likely to provide a desirable performance. Considering the dimension of a sugar mill bearing the load carrying capacity of the FFB, RMDMB and Hybrid bearing is estimated and results are presented.

## 2. METHODOLOGY

Reynolds's equation in cylindrical coordinate (equation (1)) is used to estimate the hydrodynamic pressure of FFB and Finite Difference Method (FDM) is used to solve this equation (1).

$$\frac{\partial}{\partial\theta}\left(\bar{h}^3\frac{\partial\bar{p}}{\partial\theta}\right)+\frac{\partial}{\partial\bar{z}}\left(\bar{h}^3\frac{\partial\bar{p}}{\partial\bar{z}}\right)=\frac{\partial\bar{h}}{\partial\theta} \tag{1}$$

In the above equations 'θ' is coordinate in circumferential direction in radians, R is radius of journal in m. $\bar{h}$ , $\bar{z}$ , $\bar{p}$ is the non-dimensional film thickness, axial distance and pressure of the bearing. By central difference method equation (1) can be written as

$$\bar{p}_{i,j}=\frac{\left(\frac{R_3}{L}\right)^2\left(\frac{\bar{p}_{i,j+1}+\bar{p}_{i,j-1}}{\Delta\bar{z}^2}\right)+\left(\left(-\frac{3}{2}\frac{\varepsilon\sin\theta}{h\Delta\theta}\right)+\frac{1}{\Delta\theta^2}\right)\bar{p}_{i+1,j}+\left(\left(\frac{3}{2}\frac{\varepsilon\sin\theta}{h\Delta\theta}\right)+\frac{1}{\Delta\theta^2}\right)\bar{p}_{i-1,j}+\left(\frac{R_3}{L\Delta\bar{z}}\right)^2}{2\left(\frac{1}{\Delta\theta^2}+\left(\frac{R_3}{L\Delta\bar{z}}\right)^2\right)}$$

$$F_r=\int_0^{2\pi}\int_o^{H}p\cos\theta\,dz\,R_3d\theta$$

$$F_\theta=\int_0^{2\pi}\int_o^{H}p\sin\theta\,dz\,R_3d\theta \tag{2}$$

$$F_h=\sqrt{{F_r}^2+{F_\theta}^2} \tag{3}$$

$$\phi=\tan^{-1}\left(\frac{F_\theta}{F_r}\right) \tag{4}$$

Where, $F_h$ is the hydrodynamic force.

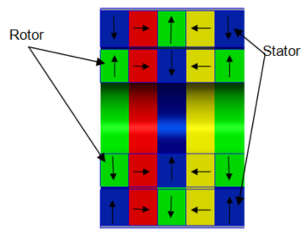


Figure 1 RMD Arrangement.

Hybrid bearing is the combination of FFB and RMDMB. RMDMB consists of radial, axial and perpendicular polarized bearings (shown in figure 1). For developing theoretical formulation for RMDMB, the load carried by the by axially, radially and perpendicular polarized rotor and stator magnets are to be formulated. Yonnet [8] proved that for an identical bearing, the load carrying capacity between two radial polarized magnets remains same as load capacity between two axial polarized magnets; hence a separate formulation for radial polarized magnets is not required.

The total load carrying capacity of RMDMB ($F_{r,RMD}$) is given by:

$$F_{r,HAL} = \sum \left( \sum_{j=1}^{k+m} F_{r,z,j} + \sum_{j=1}^{n} F_{r,p,j} \right) \quad (5)$$

Where $F_{r,z}$ and $F_{r,p}$ is the radial load carried by axial and perpendicular polarized bearings, 'n' is number of axial polarized bearings and 'm' is number of perpendicular polarized bearings. The radial force between the two rings axial polarized bearing and radial polarized bearing is estimated using equation given by Hirani and Samanta [9] and Lijesh and Hirani [6] respectively.

To estimate the load carrying capacity of hybrid bearing, the following procedure is followed:

(a) Hydrodynamic force and attitude angle is estimated using equations (3) and (4).
(b) RMDMB force for the estimated attitude angle is calculated using equation (5)
(c) The vector sum of the hydrodynamic force and magnetic force for the attitude angle is calculate
(d) An iterative loop of step 1 to 3 is carried out, for finding the eccentricity ratio for which the sum of hydrodynamic and magnetic force is equal to the total applied load.

## 3. RESULTS AND DISCUSSION

The theoretical calculation for different bearing is calculated for the eccentricity ratio (ε) corresponding to film thickness (λ)=3 and is given by $\varepsilon=1-\lambda\sqrt{((\sigma_1)^2+(\sigma_2)^2)}/(C)$. The roughness of the journal ($\sigma_1$) and bearing ($\sigma_2$) are 1μm and 3μm respectively. The estimated value of eccentricity ration is 0.9873. The dimension of the sugar mill bearing considered for analysis is: Diameter of bearing: $550^{+0.11}$mm, length 700mm, clearance 250μm and journal diameter is $549.5^{-0.11}$mm. The applied load on the bearing 1.8MN and rotational speed of the journal is 5 RPM.

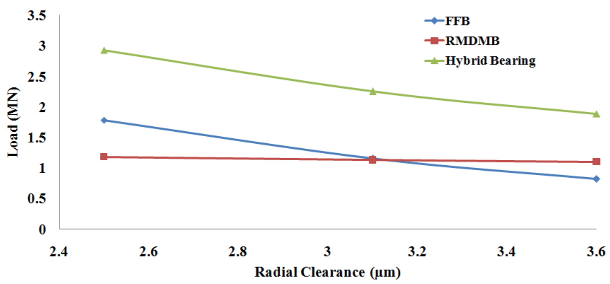


Figure 2 Load carrying capacity by different bearings.

The variation of load carrying capacity of different bearings is plotted in figure 2. From this figure following conclusions can be made:

(a) The load carrying capacity of FFB decrease by 50% by considering the tolerance and load becomes less than applied load (1.8MN) resulting in metal to metal contact. So this implies that the hydrodynamic bearing is too sensitive to the tolerance effect and which will lead to failure of bearing.
(b) The load carrying capacity of the RMDMB is reduced by 6.6% due to variation of tolerance, but the load by the RMDMB is less than the applied load of 1.8MN, hence a standalone RMDMB will also result in failure.
(c) For hybrid bearing, the estimated bearing load for all the dimensional tolerances is more than the applied load, hence the bearing operates in hydrodynamic regime resulting in no wear.

## 4. CONCLUSIONS

Detailed theoretical study on the effect of manufacturing tolerances FFB, RMDMB and Hybird bearing was carried out. Following conclusion can be derived:

(a) Load carrying capacity of RMDMB reduced by 6.6% to the variation of tolerances.
(b) Load carrying capacity of FFB reduced by 50% of the performance by considering the tolerance.
(c) Both bearing was unable to provide desired load carrying capacity at all tolerance condition.
(d) Hybrid bearing delivered desired load carrying capacity considering all range of tolerances.

## 5. REFERENCES

[1] T. V. V. L. N., Rao, H. Hirani, K. Athre, and S. Biswas, "An Analytical Approach to Evaluate Dynamic Coefficients and Non-linear Transient Analysis of a Hydrodynamic Journal Bearing," *STLE Tribology Transactions*, vol. 23, no.1, pp. 109-115, 2000.

[2] S.M. Muzakkir, H. Hirani, G.D. Thakre, and M.R. Tyagi, "Tribological failure analysis of journal bearings used in sugar mills," *Engineering Failure Analysis*, vol. 18, pp. 2093–2103, 2011.

[3] H. Hirani, and M. Verma, "Tribological study of elastomeric bearings of marine shaft system," *Tribology International*, vol. 42, no. 2, pp. 378-390, 2009.

[4] S.M. Muzakkir, K.P. Lijesh, H. Hirani, and G.D. Thakre, "Effect of cylindricity on the tribological performance of the heavily loaded slow speed journal bearing", *Journal of Engineering Tribology*, vol. 229, no. 2, pp. 178–195, 2014.

[5] P.J. Ogrodnik, W. Xu, M.J. Goodwin, and G.A. Bancroft, "The effects of dimensional manufacturing tolerances on stability of a symmetric hydrodynamic journal bearing rotor system – an experimental investigation," *ProcIMechE J Engineering Tribology*, Vol. 225, pp. 1152-1158, 2011.

[6] K.P. Lijesh and Harish Hirani, "Magnetic Bearing Using RMD Configuration," *ASME, Journal of Tribology*, 2015, Accepted.

[7] K.P. Lijesh and Harish Hirani, "Mathematical modeling and Development of RMD Configuration magnetic Bearing," *Tribology in Industry*, 2015, Accepted.

[8] J.P. Yonnet, "Passive magnetic bearings with permanent magnets," Magnetics,*IEEE Transactions on*, **14**(5), pp. 803,805, 1978.

[9] H. Hirani, and P. Samanta, "Hybrid (hydrodynamic + permanent magnetic) journal bearings," *Proc. Inst. Mech. Eng. Part J J. Eng. Tribol.*, vol. 221, no.8, pp. 881–891, 2007.