Development of micromagnetic bearing motors with suppressed magnetic coupling effect for small form factor optical drives

Chien-Chang Wang, Y. D. Yao, and Shyh-Jier Wang

Citation: Journal of Applied Physics **99**, 08R302 (2006); doi: 10.1063/1.2150387
View online: http://dx.doi.org/10.1063/1.2150387
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/99/8?ver=pdfcov
Published by the AIP Publishing

Development of micromagnetic bearing motors with suppressed magnetic coupling effect for small form factor optical drives

Chien-Chang Wang[a)]
Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 300, Taiwan

Y. D. Yao
Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 300, Taiwan and Institute of Physics, Academia Sinica, Taipei 115, Taiwan

Shyh-Jier Wang
Opto-Electronics and Systems Laboratories, ITRI, Hsinchu 310, Taiwan

(Presented on 3 November 2005; published online 18 April 2006)

The aim of this paper was to design a micromagnetic bearing (MMB) motor for small form factor optical drives. A MMB motor was developed with inner and outer magnetic-ring stack structure of high permeability. These rings were arranged on the shaft above the permanent magnet of the rotor and the stator. The magnetic force between the MMB, the permanent magnet, and the stator induced the magnetic coupling effect that generated the demon friction torque loss. However, the loss was controlled well under 1.93×10^{-4} N m by the proposed approach, so that the good stable system was achieved. After suppressing the loss caused by the magnetic coupling effect, the shaft can be rotated without any frictional contacts in radial direction, the running current was around 0.18 A, and the maximum speed was around 1850 rpm. It shows that the MMB demonstrates the lower friction torque loss in comparison with the conventional microball bearing (MBB). Moreover, the radial vibration of our device is 21% lower than the conventional MBB type. To verify the performance of the provided system, both the computer simulation and the experiment were performed. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2150387]

I. INTRODUCTION

To achieve low cost, simplicity, and high density in the trend of the optical data storage drives, the most important issue is to obtain the high-performance key elements of the drives. To develop these new micro-optical drives, recently, few papers have focused on the key components of small form factor optical (SFFO) drives, such as optical actuators. They have tried to improve the performances of miniature optical devices by applying the magnetic circuit designs.[1] The advantage of these designs is that they produce magnetic force without any contact between two objective components, and this may successfully lead to micromotors with low friction loss, long life span, and high speed.

Several researchers have been focused on the magnetic bearing design[2–4] to decrease the torque loss of a motor, but no work has been done on the miniature magnetic bearing development. The magnetic bearing may be a good approach in challenging tribology, the elimination of friction loss, which dominated the mechanical friction torque loss in the spindles. However, the additional magnetic bearing to be constructed in a micromotor will induce the magnetic coupling effect between the stator and the rotor that may increase the cogging torque[5] of the motor.

The main purpose of this paper is to design a simple and compact micromagnetic bearing (MMB) motor with a well-controlled dragging torque that achieves low friction loss for use in a miniature optical drive.

[a)]Electronic mail: jamesccw@itri.org.tw

II. CONFIGURATION OF THE MMB SYSTEM

The developed MMB motor was constructed by replacing the two microball bearings (MBBs) of a conventional brushless dc (BLDC) three-phase MBB motor with an unbalance of 0.002 g cm. The original motor had the rated speed of 1850 rpm and the current of 0.18 A. The slot number and pole number were 12 and 9, respectively. The configuration of the MMB is shown in Fig. 1. The micromotor consisted of a rotor and a stator. The shaft that had a pivot point contacted with the thrust plate was located in the center of the motor. The MQ (NdFeB) ring was fixed at the lower end of the shaft, and a radial air gap of 0.2 mm was assigned between the stator and the rotor. The outer diameter, inner diameter, and height of this ring were 9.4, 7, and 1.5 mm, respectively. The yoke with an outer diameter of 9.8 mm and a height of

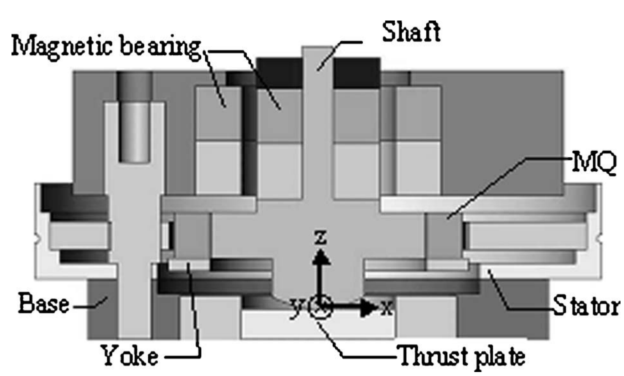

FIG. 1. The micromagnetic bearing motor.

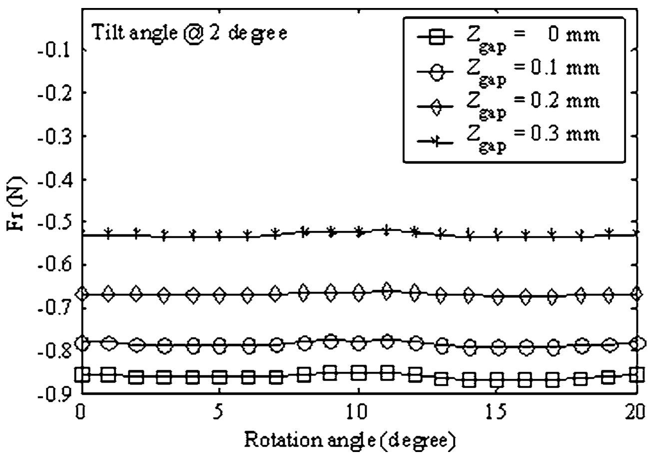

FIG. 2. Restoring radial force varies with the rotation angle.

0.4 mm was attached below this ring. The proposed MMB system was composed of inner and outer annular permanent magnetic rings that were made of NdFeB N45. The outer, inner diameter, and height of the inner ring were 4, 1, and 3.6 mm, respectively; those of the outer ring were 8, 4, and 3.6 mm, respectively. Each of these two rings contained the two same submagnetic rings that were provided with antiparallel magnetization directions along the axial axis.

Second, to obtain the dynamic stable state, the developed bearing must generate enough radial restoring force which was two times the radial loading at the rated speed, and this was referred to our laboratory data base. Because the radial runout (RRO) of this prototype was assigned to 10 μm (peak), the restoring force must be greater than 7.506 $\times 10^{-4}$ N. For this corresponding RRO constraint the tilt angle was 0.0785° and the desired RRO could be maintained according to the finite element analysis (FEA) estimation of magnetic radial forces which were −0.029 56 and −0.022 15 N when the Z_{gap} were 0.1 and 0.3 mm, respectively. To verify that the dynamic stable state could be maintained under the magnetic coupling effect, the restoring radial force changed due to the rotation angle and Z_{gap} was calculated, as shown in Fig. 2. It is manifest that the restoring force is high enough to resist the radial loading force when the Z_{gap} are operated between 0.1 and 0.3 mm. This guarantees that the target RRO could be satisfied and the system could be stable in the dynamic state.

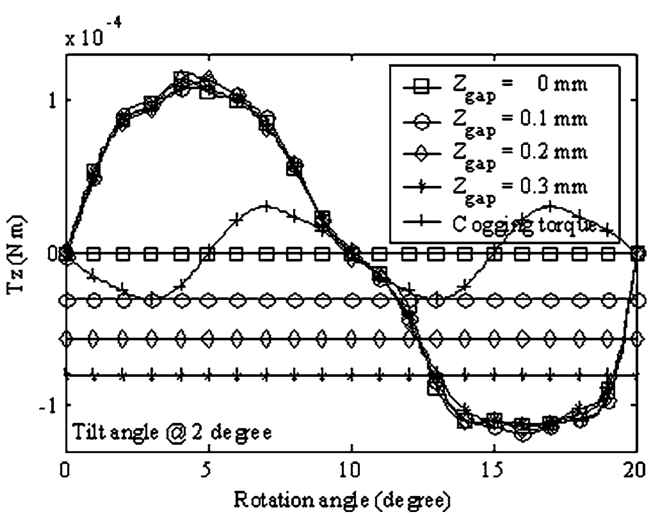

FIG. 3. Friction loss as a function of the rotation angle.

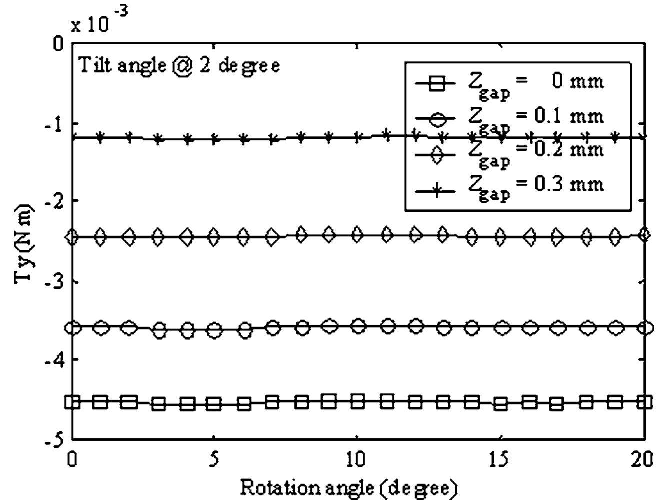

FIG. 4. Restoring torque varies with the rotation angle and Z_{gap}.

Third, for achieving the well-controlled axial force, four constraints should be specified as follows: $P < 10^6$ kg/m^2, $V < 7$ m/s, $P \times V < 10^5$ kg/(m s), and the target friction loss $< 2.926 \times 10^{-4}$ N m. The first three and the last items were constrained due to the specification of the thrust plate and because the desired friction loss must be lower than the MBB-type motor, respectively. According to these considerations, the corresponding final axial force criterion that must be smaller than 5.081 N was decided. The calculation shows that the axial force varies with the rotation angle steadily for each chosen Z_{gap} (0.1, 0.2, and 0.3 mm), and each maximum value of these axial forces is smaller than 5.081 N when the Z_{gap} ranges from 0.1 to 0.3 mm and the maximum goes from 1.339 to 3.599 N.

It was earlier mentioned that it is manifest that the restoring torque and radial force are not highly related to the variation of the rotation angle, but the friction loss is. According to the estimation of the friction loss shown in Fig. 3, in which the original cogging torque was represented by crosses, after the magnetic bearing system was assembled into the motor, it was increased and deformed to the dragging-torque curves when Z_{gap}=0−0.3 mm. However, the absolute peak values of these profiles were well controlled when the friction loss was smaller than 1.93×10^{-4} N m. Those horizontal lines indicated the friction loss contributed by the magnetic axial force.

III. DESIGN AND ANALYSIS

For identifying the proposed system, the magnetic forces were calculated by applying the Maxwell stress method, according to the governing equation of magnetic field, that is, Maxwell's equation. To perform these calculations, the FEA software MAGNET 6.18 was used. The three-dimensional (3D) half model of the design motor shown in Fig. 1 was provided with the number of tetrahedra, 252 987.

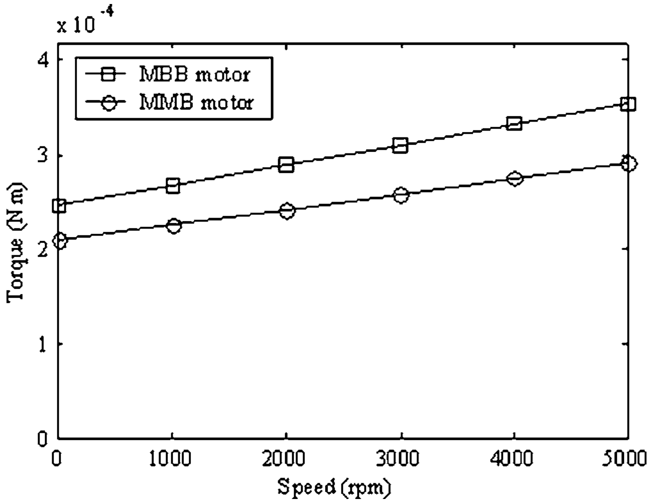

FIG. 5. The comparison of friction losses of the MBB and MMB motors.

To design a stable micromagnetic bearing system, there were three main subjects that must be considered. These subjects were as follows: (1) static stable state, (2) dynamic stable state, and (3) well-controlled axial force. First, to achieve the static stable state, the system must induce enough restoring torque when it suffered an additional tilt torque. Suppose that the shaft was tilted at an angle theta, relative to the pivot point, in the clockwise direction along the positive Y axis refer to the coordinate system in Fig. 1. Since it was a critical condition when the theta was 2°, the principal parameters that were sensitive to the stable state of the proposed system were estimated when the theta was chosen to be of this value. To analyze the distribution profile of the restoring torque Ty, the fluctuation of the Ty due to the axial gap Z_{gap} and the rotation angle were calculated, as shown in Fig. 4. The Z_{gap} was positive when the outer-diameter was higher than the inner-diameter magnetic ring of the MMB in positive axial direction. Figure 4 revealed that the stable region of the micromagnetic bearing system appeared when the Z_{gap} ranged from 0.1 to 0.3 mm.

It was assumed that the thrust plate contacted with the shaft in 1/4 times the shaft diameter. The kinetic friction coefficient of the thrust plate was 0.06. The total friction loss caused by the MMB was equivalent to the friction loss contributed by the magnetic axial force added by the dragging torque, then the total friction torque loss (peak) generated by the MMB were 1.16×10^{-4}, -1.49×10^{-4}, -1.73×10^{-4}, and 1.93×10^{-4} N m when the Z_{gap} were 0, 0.1, 0.2, and 0.3 mm, respectively. This leads to the conclusion that the designed motor has a lower friction loss compared to the MBB type.

IV. EXPERIMENT

Base on the analytical simulation that the stable state of the MMB motor appears when the Z_{gap}=0.1, 0.2, and 0.3 mm. During this region, the the experimental data of the MMB motor shows that the motor speed $\geqslant$1850 rpm and the running current $\leqslant$0.18 A, and these are consistent with the predicted values. As the Z_{gap}=0.2 mm, the total friction loss and radial vibration of the MMB motor were measured and represented in the following.

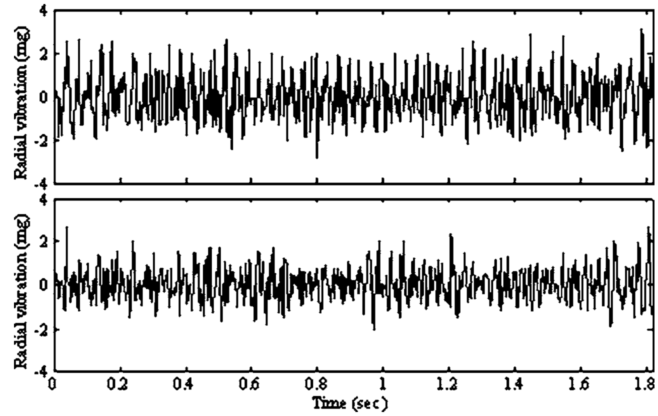

FIG. 6. Radial vibration history of the (a) MBB and (b) MMB motors.

To measure the friction loss of a micromotor, the motor was operated at various constant speeds. Then the friction loss was equivalent to the running current times the torque constant of the motor. The torque loss varies with the speed (shown in Fig. 5). It is apparent that the MMB motor had a lower friction loss compared to the ball bearing type. For observing the radial vibration of the micromotor, the motor was fixed to a free table, an accelerometer was attached to the motor in the radial direction, and a spectrum analyzer was employed to detect the output signal of the accelerometer. The time response signals were probed, as shown in Fig. 6, when the rotor was rotated at the speed of around 1850 rpm and at the running current of around 0.18 A. The radial vibration (peak-peak) of MBB and MMB motors were 5.954 and 4.668 mg, respectively.

V. CONCLUSION

A simple and compact MMB motor with suppressed magnetic coupling effect has been proposed. The shaft can be rotated without any frictional contacts in radial direction. The MMB motor presents a lower friction loss compared to the microball bearing type. Moreover, the radial vibration (peak-peak) is 21% lower than the conventional MBB type. This shows that the innovative magnetic bearing technology, with the consideration of the magnetic coupling effect applied to the passive MMB motor, improved the motor performance significantly.

[1]S. Q. Lee, K. H. Park, and M. C. Paek, Proceedings of the ISOM Conference, 2005 (unpublished), p. wp5.
[2]C. C. Wang, Y. D. Yao, P. C. Tung, R. B. Xiao, and Y. H. Chang, J. Appl. Phys. **97**, 502 (2005).
[3]V. Fernandez, J. Fandino, C. Sauvey, J. P. Yonnet, G. Reyne, and O. Cugat, IEEE Trans. Magn. **36**, 1919 (2000).
[4]J. Delamare, E. Rulliere, and J. P. Yonnet, IEEE Trans. Magn. **31**, 4190 (1995).
[5]Z. Q. Zhu and D. Howe, IEEE Trans. Magn. **28**, 1371 (1992).