Drag Torque Measurement of Hard Disk Drive Spindle Motors

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***Abstract*—The drag torque of a hard disk drive (HDD) is a key variable to its spindle motor. It should be accurately tested during R&D and mass productions of HDDs. This paper reviews its existing measurement methods currently used by HDD industry first. Then an effective method to measure the drag torque is introduced. Through the proposed method, the drag torque can be measured more precisely and easily.**

Index Terms— **Drag torque, hard disk drives, spindle motors and torque measurement.**

I. INTRODUCTION

The major load of a hard disk drive (HDD) spindle motor to overcome is the drag torque, which includes the bearing friction torque and the windage loss as well as the motor core loss [1]. Actually, the drag torque of the spindle motor and platters dominates the power consumption and thus the heat generation of an HDD. As the spin-speed of high-end HDDs tends to be higher and higher, the drag torque becomes more significant in determining the HDD form factor and designing the spindle motors.

Since all components of the drag torque, i.e., the bearing frictional torque, the windage loss and the motor core loss, are very difficult to be accurately calculated from the theoretical formulae, the experimental measurement of the drag torque is almost the only approach to know how much the drag torque of each HDD is [2]. In particular, due to the application of the fluid dynamic bearings (FDB), the drag torque of an HDD is not constant at a speed and varies with the bearing running history, the temperature and its oil viscosity.

Now, there are two conventional methods to measure the drag torque of an HDD. One method is to simply multiply the phase RMS current and the average torque constant. The other is to drive the tested HDD to a higher speed and then spin down the spindle motor freely [3]. During the freewheeling, the deceleration at the rated spin-speed is detected through a complex set of devices. Then the drag torque is defined as the product of the system inertia and the deceleration.

Normally, the average torque constant is defined provided that the motor is excited by an ideal constant phase current, i.e., rectangle waveform current, in BLDC mode. In actual operations, the exciting current waveforms may not be rectangle. Therefore, the first method is not accurate in many cases. The second method must know the inertia values of the spindle motor, platters, spacers and even screws or the fixture of platters. However, the inertia of the actual rotating system depends on the HDD assembly and its eccentricity as well as the spin-speed. To be accurate, it is better to measure the total rotating inertia firstly before the drag torque is measured. Usually, the method is time consuming and costly.

In this paper, another approach is suggested to measure the drag torque. According to the theory of electrical machines, the drag torque is equivalent to the quotient of the mechanical output power divided by the running speed. This mechanical output power can be obtained through subtracting the copper losses from the input power. In following sections, this method will be introduced in detail.

II. DRAG TORQUE MEASUREMENT BASED ON THE OUTPUT POWER OF SPINDLE MOTORS

In general, when an HDD spindle motor runs at a constant speed, the output power could be expressed as:

$$P_{out} = p_f + p_{Fe} + p_w = P_{in} - p_{Cu}\,, \tag{1}$$

where p_f, p_{Fe} and p_w are bearing frictional loss, the core loss of the stator and windage loss respectively, and P_{in} is the input power and p_{Cu} is the copper loss. For a three-phase spindle motor, the input power and copper loss can be expressed as follows:

$$P_{in} = \frac{1}{T_c}\int_0^{T_c}\left[u_{AN}(t)i_A(t) + u_{BN}(t)i_B(t) + u_{CN}(t)i_C(t)\right]dt \tag{2}$$

Manuscript received August 9, 2006.

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$$p_{Cu} = \frac{1}{T_c}\int_0^{T_c}\left[i_A^{\,2}(t)R_A + i_B^{\,2}(t)R_B + i_C^{\,2}(t)R_C\right]dt, \qquad (3)$$

where u_{AN}, u_{BN} and u_{CN} are the phase voltages, i_A, i_B and i_C are the phase currents, and R_A, R_B and R_C are the phase resistances. Although the spindle motor may run in BLDC mode, the phase currents actually are high frequency AC current and their frequency may be up to 750 Hz. The resistances in (3) should adopt the AC resistance corresponding to the fundamental frequency of the phase current.

Fig. 1 shows the current and voltage waveforms of a typical HDD spindle motor at 7,200 rpm. Through (1) to (3), the output power can be easily obtained. Then the drag torque can be calculated as:

$$T_{drag} = \frac{60}{2\pi n}P_{out} = \frac{60}{2\pi n}(P_{in} - p_{Cu}). \qquad (4)$$

In order to verify the accuracy of the proposed method, the transient electromagnetic torque is measured through the product of the real back EMF and the phase current, as shown in Fig. 3. Table I lists the drag torque values measured by different methods.

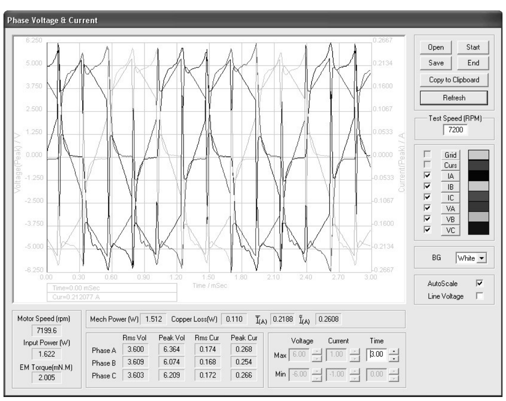

Fig. 1. Input power, copper loss and drag torque.

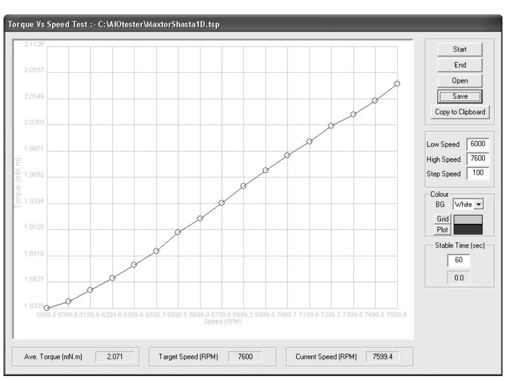

Fig. 2. Drag torque at different speeds.

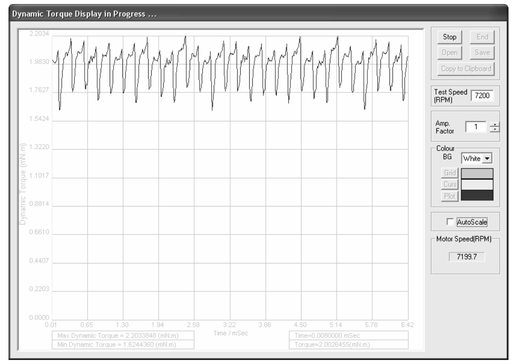

Fig. 3. Transient electromagnetic torque of a BLDC spindle motor at 7,200 rpm.

TABLE I
DRAG TORQUE VALUES MEASURED BY DIFFERENT METHODS

Methods	$K_t \times I_{ph}$	$J \times d$	P_{out}/ω	T_{em}
T_{drag} (mNm)	1.680	2.550	2.005	2.003

From Table I, it is found that the drag torque measured with the proposed method matches very well with the transient electromagnetic torque. But the drag torque value measured by the average torque constant method is too small because the phase current waveform is not rectangle. Also the drag torque based on the freewheeling method is too big. The error may be caused by the inaccurate inertia value or the transient status of motor bearing. It should be investigated further.

III. CONCLUSION

The experimental results have confirmed that the drag torque of an HDD spindle motor can be precisely and conveniently measured through detecting the phase voltages and currents and calculating the output power. To obtain the accurate drag torque, the high-speed and high-resolution A/D converters are needed for high-speed spindle motors, in particular sinusoidal PWM driving mode. The phase resistances should adopt the AC resistance at the frequency of the phase currents. To be more accurate, Fourier analysis of the phase currents and high order frequency phase resistances are recommended to measure the copper loss of the phase winding when the phase current is non-sinusoidal.

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