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A Comparative Experimental Study on Head-Disk Touch-Down Detectability Based on Off-Track Vibration

Sheng-Xiang Chen*, Shi-Yan Yin, Xiong-Fei Wei, Ai-Lian Peng

SAE Magnetics (H.K.) Ltd., DongGuan City, Guangdong Province 523087, China.

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Abstract

To further increase the hard-disk drive's areal density, the head-disk spacing needs to be reduced to sub 1 nm and it requires accurately detect the head-disk touch down (TD). The off-track-vibration-based TD detection methods are widely applied in current hard-disk drive (HDD) for head-disk TD detection. However, few studies perform on how to improve the off-track-vibration-based TD detection sensitivity. In this paper, a comparative experimental study was conducted between comparative two off-track-vibration-based TD detection methods: one is based on the low-frequency-forced vibration; the other is based on the off-track-structure vibration. Besides, the skew angle, touch down area (TDA), and the head-stack assembly (HSA) rotation inertia effects on TD detectability were discussed. Bigger skew angle and bigger TDA are helpful for good TD sensitivity for these two methods. To the method based on low frequency forced vibration, the smaller HSA rotation inertia design is also helpful.

Keywords: touch down detection, low frequency forced vibration, off-track structure vibration, skew angle, touch down area, rotation inertia

1. Introduction

In order to achieve a constant increase in the areal recording density of the hard-disk drive (HDD), the head-disk spacing needs to be continuously decreased. One way to reduce the spacing is utilizing the thermal flying-height control (TFC) technique that can adjust the slider pole-tip protrusion amount by applying variable electric power to the heating element (heater) embedded near the read/write element scussedtiability track al study [1-2]. To utilize the TFC technique (as shown in Fig. 1) to achieve an accurate head-disk spacing (up to sub-1-nm) [3], a very sensitive head-disk touch down detection method is needed to detect in what amount of TFC power that the head and disk will contact. Once the heating power for head-disk contact is detected, the accurate head-disk spacing can be achieved by setting a back-off power. The relationship between the head-disk spacing and TFC power can be described by Eq. (1) and Eq. (2).

$$\text{Back-off power} = \text{Head-disk spacing} / \text{TFC protrusion efficiency} \tag{1}$$

$$\text{Target TFC power} = \text{Head-disk touch down power} - \text{Back-off power} \tag{2}$$

The off-track-vibration-based touch-down (TD) detection method is standard for the HDD to detect the head-disk contact. When the head-disk contact occurs, the contact force will induce an off-track component that results in an off-track vibration of magnetic head. The HDD can measure this off-track vibration by the position error signal (PES), and whereby head-disk contact can be detected.

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* Corresponding author. E-mail address: shx.chen@hotmail.com

Tel.: +86 769 22810033; Fax: +86 769 22811524

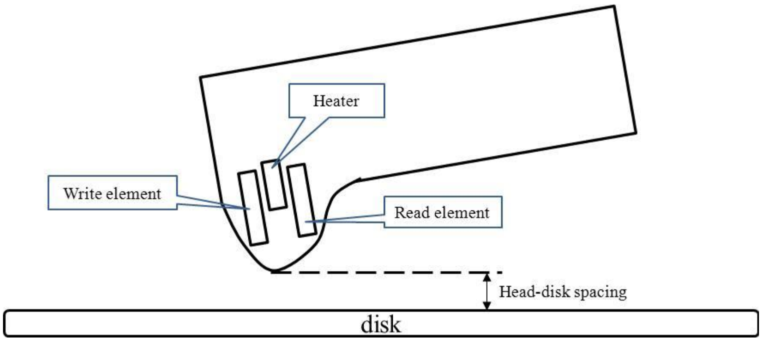

Fig. 1 Thermal flying-height control (TFC) technique

Currently, few studies perform on how to improve the TD detection sensitivity for the off-track-vibration-based TD detection method [4]. In this paper, two off-track-vibration based TD detection methods were discussed. One is based on the low-frequency-forced vibration; the other is based on the off-track-structure vibration. The experiment was conducted on the drive-based tester (DBT) and the lateral Laser Doppler Vibrometer (LDV) was applied to measure the off-track vibration caused by the head-disk contact. Three factors - the skew angle (as shown in Fig. 2) is angle between the HSA length direction and the tangent of the disk rotation direction, touch down area (TDA) and the HSA rotation inertia were discussed in this paper. The experimental results show that bigger skew angle and bigger TDA are helpful for both of the two methods. The HSA rotation inertia only has effect on the method that based on low-frequency-forced vibration but has no clear effect on the method that based on the off-track-structure vibration due to the fact of the off-track-structure vibration mainly relies on the HSA off-track structure mode.

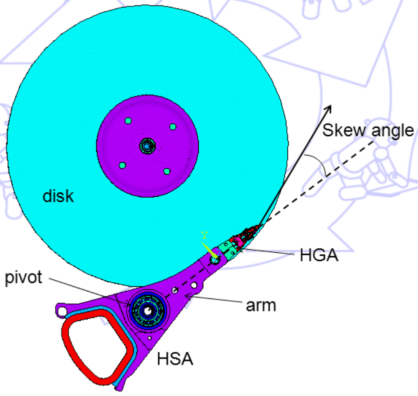

Fig. 2 Skew angle

2. Experimental Setup

In this paper, the experiment was conducted on a 2.5 inch DBT tester (as shown in Fig. 3). A spinbox was used to drive the spindle with 5400 RPM rotating speed. To investigate the head-disk touch down detectability based on the off-track vibration, two LDVs were utilized to measure the vertical vibration and off-track vibration synchronously. The lateral LDV focused on the side of the slider near the read/write element. The vertical LDV focused on the leg of head-gimbal assembly (HGA) (as shown in Fig. 4). The vertical LDV TDP will be detected when the vertical LDV response reached a threshold of 6*sigma of the baseline. This vertical LDV TDP was used as a reference of the head-disk first TD, indicating the beginning of head-disk contact together [5-6]. A TFC control module was used to supply the TFC power to the heating element of the slider. For the low frequency forced vibration detectability study, a 100Hz square wave TFC power (as shown in Fig. 5) was applied to the heating element. For the off-track-structure vibration detectability study, a step-like TFC power was applied to heating element. Each power step lasts 100ms (as shown in the Fig. 6).

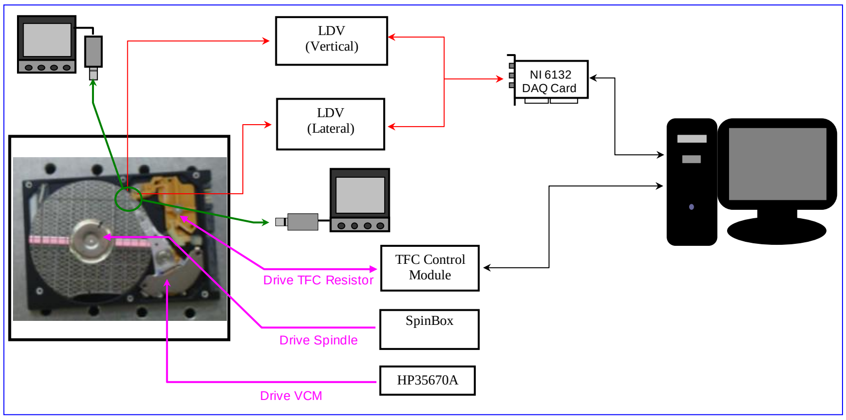

Fig. 3 Experimental setup

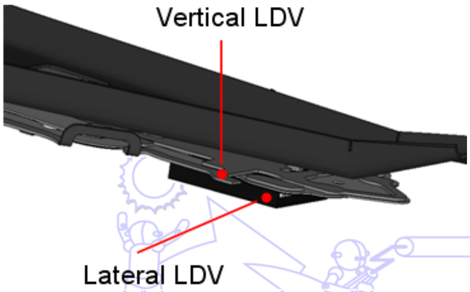

Fig. 4 LDV laser spot

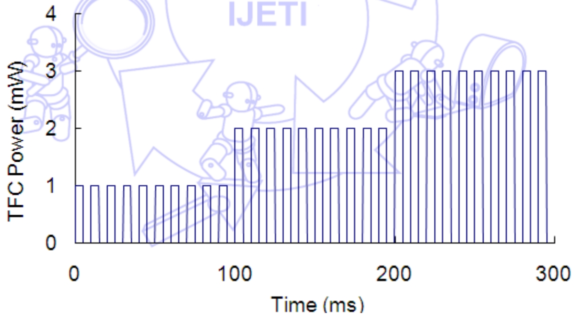

Fig. 5 100Hz square wave TFC power

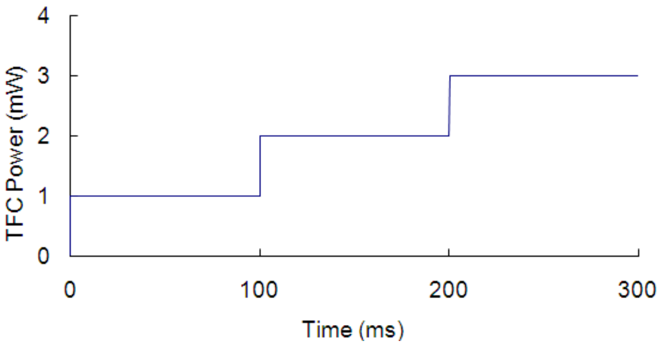

Fig. 6 Step-like TFC power

3. Experiment Result and Discussion

3.1. *Skew angle effect*

Fig. 7 and Fig. 8 are the results of low-frequency-forced vibration and off-track-structure vibration in different skew angle. The TFC power was offset according to the vertical LDV TDP. The 0 mW in the following figures (Figs. 7-8, Figs. 11-14) is the power of vertical LDV TDP, indicating the beginning of the head-disk contact. Both the low-frequency-forced vibration and off-track-structure vibration are more sensitive to the head-disk contact in bigger skew angle. This can be explained by the bigger off-track component force, as illustrated by Eq. (3).

$$\textit{Off-track component force} = \textit{Friction force} * \textit{Sin (skew angle)} \tag{3}$$

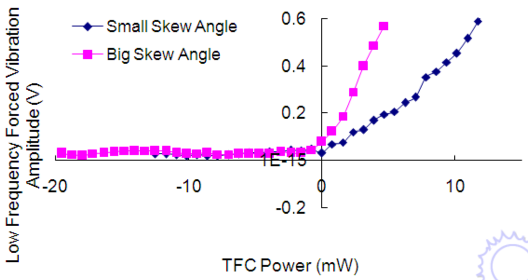

Fig. 7 Skew angle effect to forced vibration (measured by lateral LDV)

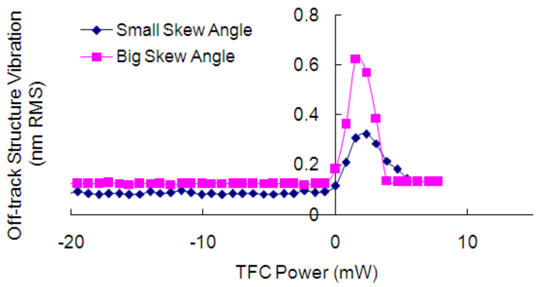

Fig. 8 Skew angle effect to off-track structure vibration (measured by lateral LDV)

3.2. *TDA effect*

To study the TDA effect, there are two the same with HSAs but with different TFC protrusion profiles, were used for comparative study. To verify the TDA difference of these two TFC protrusion profiles, these two HSAs were selected with the same TFC protrusion efficiency. And the vertical LDV was used to detect the LDV TDP (indicate the beginning of head-disk contact) of these two HSAs were overdriven 5 mW (applying a TFC power of LDV TDP + 5mW to ensure the head contact with disk) for about 5minutes. After the overdrive experiment, the contact area between the head and disk will be worn out. The worn out area can be checked with the Scanning Electric Microscope (SEM) because it will be lower than the other area. The following Fig. 9 and Fig. 10 are the SEM results for these two TFC protrusion profile designs after overdrive experiment. The light area is lower than the dark area in the SEM image so the light area is the touch down area (TDA) that was worn out. Comparing with the SEM image of Fig. 9 and Fig. 10, it is very clear that Fig. 9 design has a much bigger TDA than the Fig. 10 design.

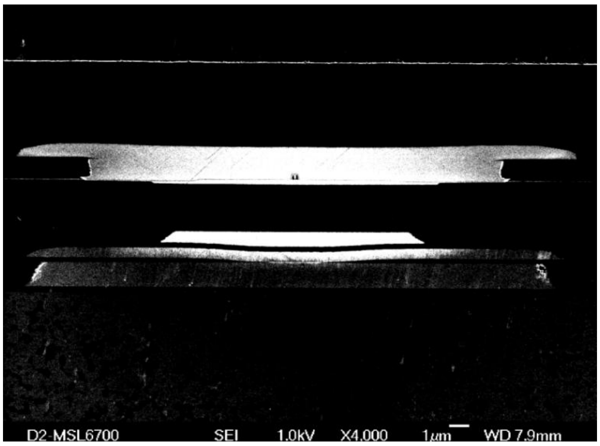

Fig. 9 SEM result for big TDA design

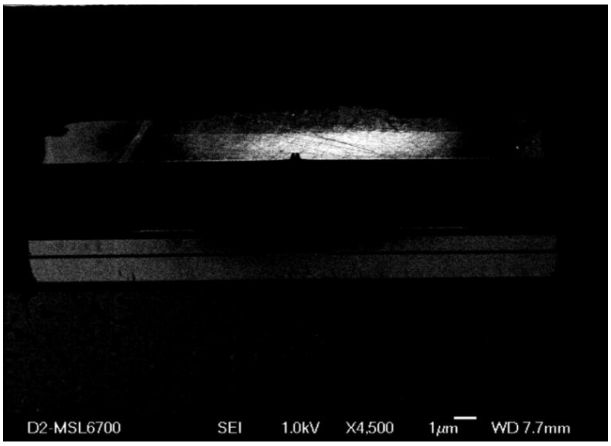

Fig. 10 SEM image for small TDA design

Fig. 11 and Fig. 12 are the results of low-frequency-forced vibration and off-track-structure vibration for these two TFC protrusion profiles with different TDA. Both the low-frequency-forced vibration and off-track-structure vibration are more sensitive to the head-disk contact in big TDA.

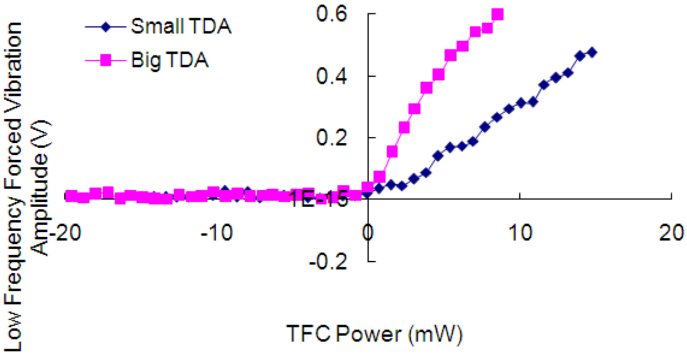

Fig. 11 TDA effect to forced vibration

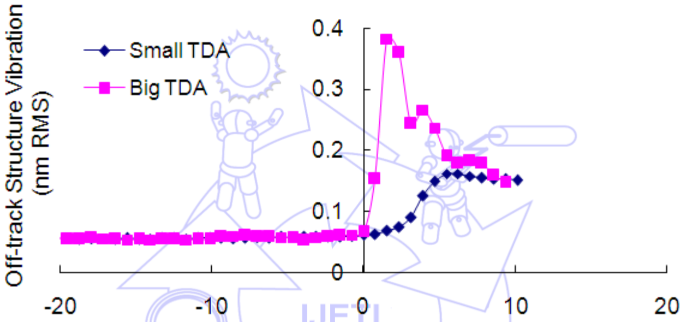

Fig. 12 TDA effect to structure vibration

Base on the Adhesion and Contact Models [7], the total adhesion force ***Fs*** between the head and disk can describe as the Eq. (4),

$$F_S=\eta A_n\left(\begin{array}{l}\displaystyle\int_{-\infty}^{d-t}\frac{8}{3}\pi R\delta\gamma\left[\left(\frac{\varepsilon}{d-u-t+\varepsilon}\right)^2-0.25\left(\frac{\varepsilon}{d-u-t+\varepsilon}\right)^8\right]\phi(u)du\\ \displaystyle+2\pi R\delta\gamma\int_{d-t}^{d}\phi(u)du\\ \displaystyle+\int_{d}^{\infty}\int_{r_t}^{\infty}\frac{8\delta\gamma}{3\varepsilon}\left[\left(\frac{\varepsilon}{z-t+\varepsilon}\right)^3-\left(\frac{\varepsilon}{z-t+\varepsilon}\right)^9\right]\cdot 2\pi r dr\phi(u)du\end{array}\right) \tag{4}$$

where η is the areal density of asperities, An is the nominal contact area, R is the radius of curvature of asperity summits, $\delta\gamma$ is the adhesion energy per unit area for the head–disk interface, ε is the equilibrium intermolecular spacing, d is the separation of the mean plane of asperity heights, u is the asperity height, t is the thickness of the lubricant layer, $\phi(u)$ is the probability density function of asperity heights [7].

Base on the Eq. (4), the contact force has a linear relationship to the TDA. The design with bigger TDA will have a bigger contact force and better TD detection sensitivity.

3.3. *HSA rotation inertia effect*

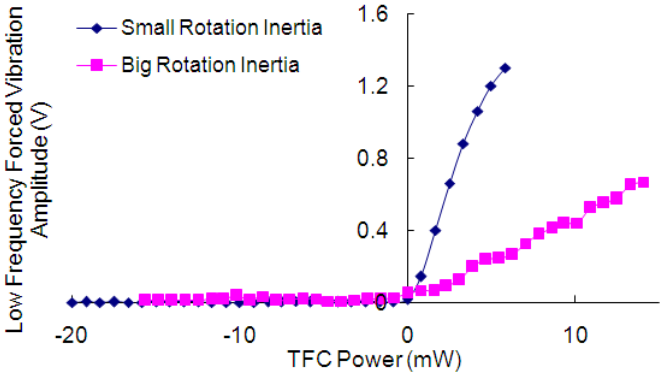

Fig. 13 Rotation inertia effect to forced vibration

To study the rotation inertia effect on the off-track-vibration touch-down detectability, two HSAs with different rotation inertia were used for comparative experimental study. These two HSAs were sharing the same HGA design and with different arms. One HSA is for one-disk HDD with two arms, the other HSA is for 3-disks HDD with 4 arms. The 4-arm HSA has much bigger rotation inertia than 2-arm HSA. Fig. 13 is the result of low-frequency-forced vibration for these two HSAs. The HSA with smaller rotation inertia has sharper lateral response after TD and better TD detectability than the HSA with bigger rotation inertia. Fig. 14 is off-track-structure vibration for these two HSAs with different rotation inertia. The off-track-structure vibration for these two HSAs is very close.

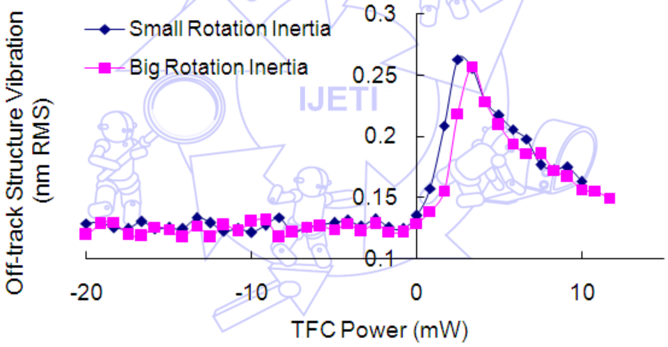

Fig. 14 Rotation inertia effect to structure vibration

Fig. 15 is the HSA lateral frequency-response function (FRF) which is very clean and has no any structure mode before 3 kHz. Therefore, for the 100Hz forced vibration, the HSA can be treated as rigid body and rotate along the center of the pivot and the amplitude of the 100Hz forced vibration does not rely on the HSA structure mode.

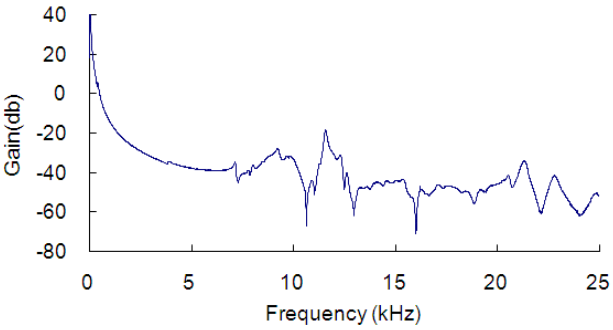

Fig. 15 HSA lateral FRF

Fig. 16 is the fast Fourier transform (FFT) for the lateral low frequency forced vibration when the head and disk contacted. As shown in Fig. 16, the FFT was clean and has no obvious peak before 25 kHz. After zoom the FFT result to 500 Hz, it was clear that the major peak is on 100Hz (as shown in Fig. 17). This agrees with frequency of the TFC power applied for low frequency forced vibration.

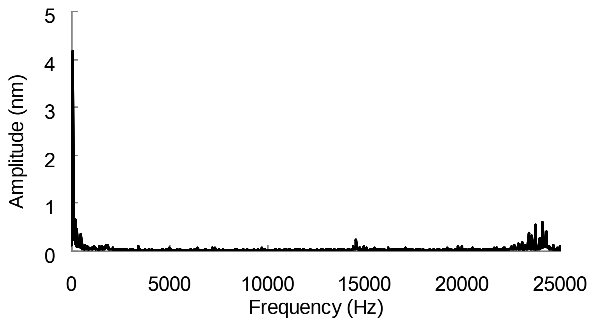

Fig. 16 Forced vibration FFT

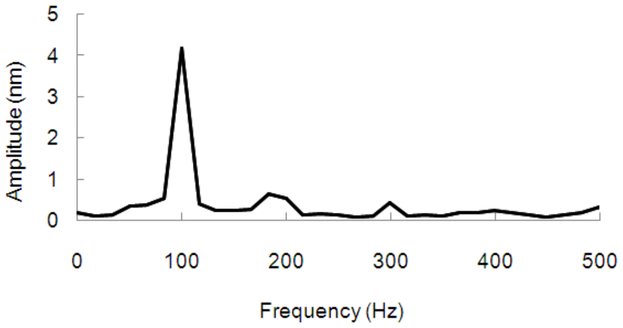

Fig. 17 Forced vibration FFT (zoomed to 500Hz)

According to the Eq. (5), with the same excitation force and torque ***M***, the smaller the rotation inertia ***I***, the bigger the angular acceleration ***β*** and off-track-vibration amplitude is. Therefore, the rotation inertia has a significant effect on the response of low-frequency-forced vibration. With the same contact force, the smaller rotational inertia, the sharper of the low-frequency-forced vibration, the better sensitivity for TD detection is.

$$M = I \cdot \beta \tag{5}$$

But for the off-track-structure vibration excited by the head-disk contact, the lateral response mainly relies on the HSA off-track structure mode [8] rather than the rotation of the HSA. So the HSA rotation inertia has very limited effect on the off-track-structure vibration.

Fig. 18 is the FFT for off-track-structure vibration. The FFT result is different to the FFT of forced vibration. It has a very clear dominant peak on about 12 kHz. This agrees with the dominant peak on the HSA FRF (as shown in Fig. 15).

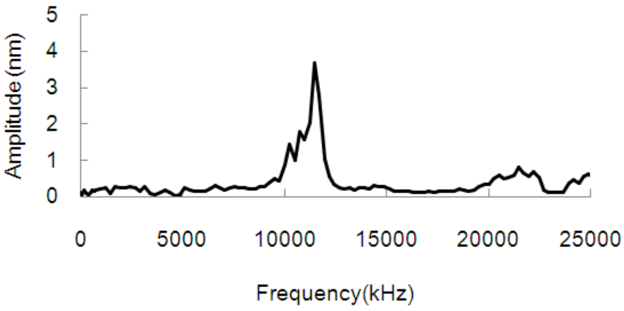

Fig. 18 Off-track-structure vibration FFT

4. Conclusion

In this paper, a systematic study performed on how to improve the off-track-vibration-based TD detection sensitivity and two popular off-track-vibration-based TD detection methods were discussed. Also, the effects of skew angle, TDA and rotation inertia to these two methods were studied. Base on the experimental result, both of the low-frequency-forced-vibration-based method and off-track-structure-vibration-based method are very sensitive to the skew angle and TDA. Bigger skew angle and

TDA is helpful for good TD detection sensitivity. The rotation inertia has a significant effect on the low-frequency-forced-vibration-based method only. For such a method, smaller rotation inertia has better TD sensitivity. These findings were very helpful for the HDD design optimization to achieve good off-track-vibration-based TD detection. Table 1 summarizes the TD detectability optimization for these two methods.

Table 1 TD detectability optimization summary

	Skew angle	TDA	Rotation inertia
Low frequency forced vibration	Bigger skew angle	Bigger TDA	Smaller rotation inertia
Off-track structure vibration	Bigger skew angle	Bigger TDA	No clear effect

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