Case History / Resonance	Vibration of Ball Pass Frequency Occurred in Multi-Disk Spindle System	Information equipment

Object Machine

Large-scale hard disk assembly (HDA, Fig. 1)

Observed Phenomena

At the rated rotational speed of 60 rps=3,600 rpm, abnormal vibration (the predominant frequency is 380 Hz and amplitude about 0.8 μm) appeared in the position signal that represents relative gap between the rotating disk and the stationary magnetic head, as shown in Fig.2. This excessive vibration induced error signal by the defectiveness of head positioning function.

Cause Presumed

From evaluating the fact that vibration was observed even when the head was not accessed, and that the vibration frequency coincided with some relations to the ball pass frequencies of ball bearings. The vibration is predicted by being caused in the spindle system.

Analysis and Data Processing

In order to clarify the rotational vibration characteristic of the spindle, the harmonic wave excitation force was applied to the HDA device using a shaking apparatus shown in Fig.3. In addition, variable speed operation was performed to measure radial vibrations of the shaft and hub using a non-contact displacement pick-up. The shaft FRA (frequency response analysis) curves are shown in Fig. 4 and the hub FRA curves are seen in Fig.5 (upper two curves). The base FRA (acceleration) and the excitation force are also included in Fig.5. The position signal response is shown in Fig.6. Figure 7 indicates the vibration mode of the shaft and the hub.

As summarized in Fig.8, all of frequencies of resonance peaks of FRA curves are plotted for each rotational speed at which the excitation was done. From these data mentioned above, we clarified that the 380 Hz vibration is of a shaft tilting mode including the base structural deformation and resonated with an excitation frequency + 6.42 Ω caused by inner ring swell of ball bearing (refer to Table 1).

Meanwhile, a detailed modeling and the corresponding vibration calculation were conducted using the 3D FEM for the disk spindle system and using 1D-FEM (beam element only) for analyzing the natural frequency and shaft resonant modes. Figure 9 shows the analysis model and calculation results. According to these calculation results, it is known that the 4th mode corresponds to the resonant frequency of 380 Hz, which is in good agreement with experimental results.

Countermeasures and Results

Based on the above discussion, countermeasures were taken to enhance the bending stiffness of the bearing housing standing the base. Prior to manufacture of the parts for the countermeasures, the calculated eigenvalues of the rotor system were checked and examination was made to avoid the resonance of 380 Hz at the rated speed 60 rps. Moreover, accuracy of single ball bearing unit to be assembled was improved, thus restraining abnormal vibration.

Lesson Learned

In the case of super-precision machine like HDA, little deformation of ball bearings generates an inherent excitation force. It is thus important to design the avoidance of the resonance due to ball pass frequencies in relation to the rotor system and the base system.

References

Matsushita, et al. "Ball Pass Frequency Analysis of Magnetic Disk Spindle System", *Transactions of the JSME* (Edition C), Vol 52, Series 474 (1986: 439-447)

Keyword

Rotating machinery, vibration of rotating body, rotating circular plate, ball bearing, vibration mode, vibration analysis, vibration measurement, ball pass frequencies, resonance vibration

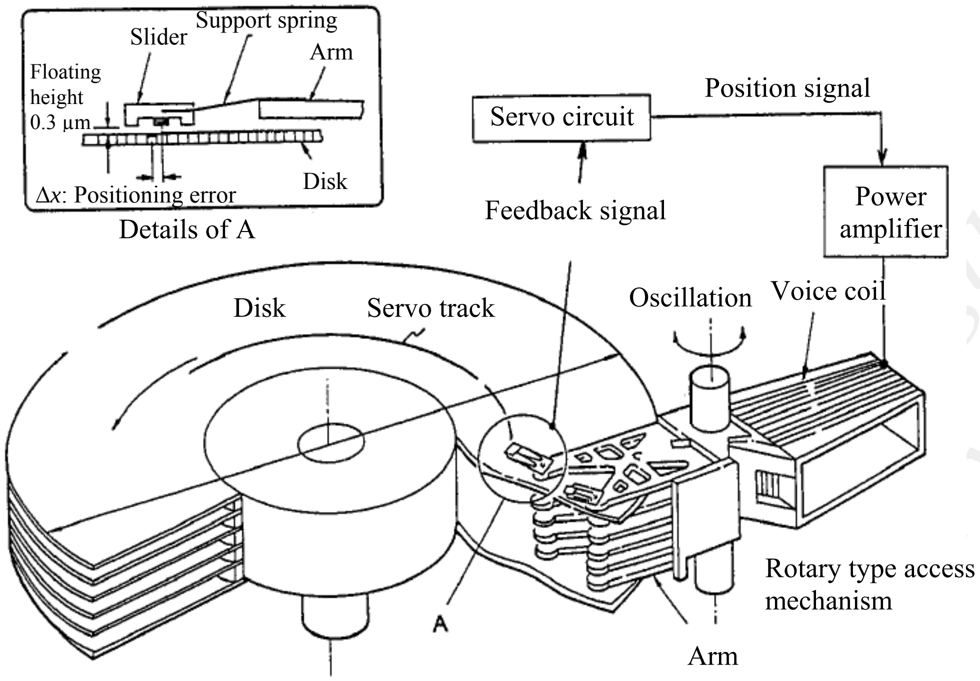


Fig.1: Conceptual drawing of position signal

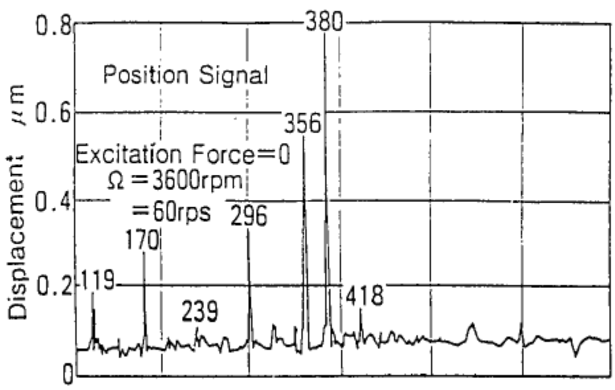


Fig.2: Amplitude of position signal

Equipment specification

Disk outer diameter × plate thickness × number of sheets:	14 inch × 1.9 × 13 (φ 357)
Memory capacity/spindle:	600 MB
Rated rotational speed:	3,600 rpm
Head access type:	rotary (× 2)
Equipment weight/spindle:	about 60 kg
Support bearing:	single row deep groove ball bearing (6207, 6206)

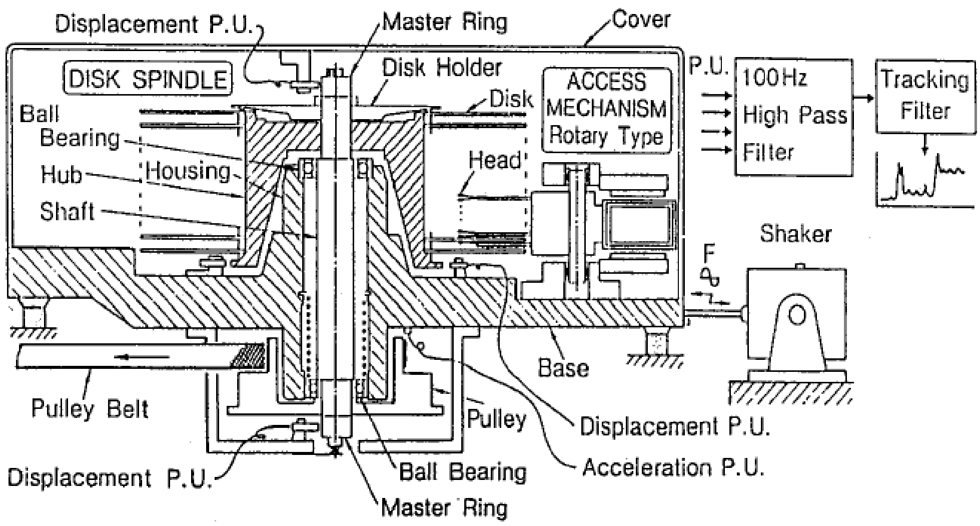


Fig.3: Experimental excitation apparatus

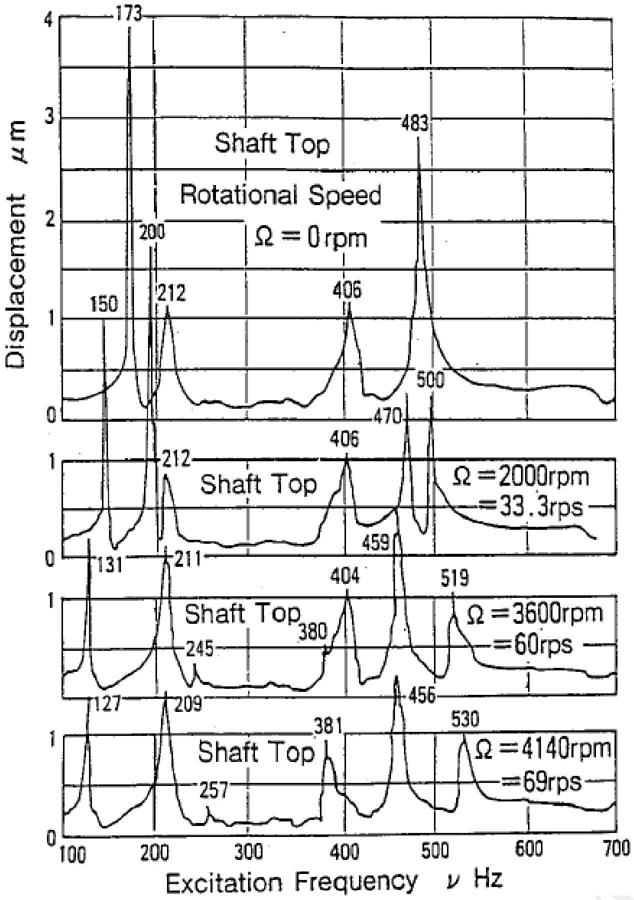


Fig.4: Response curves for sinusoidal excitation
(main axis top)

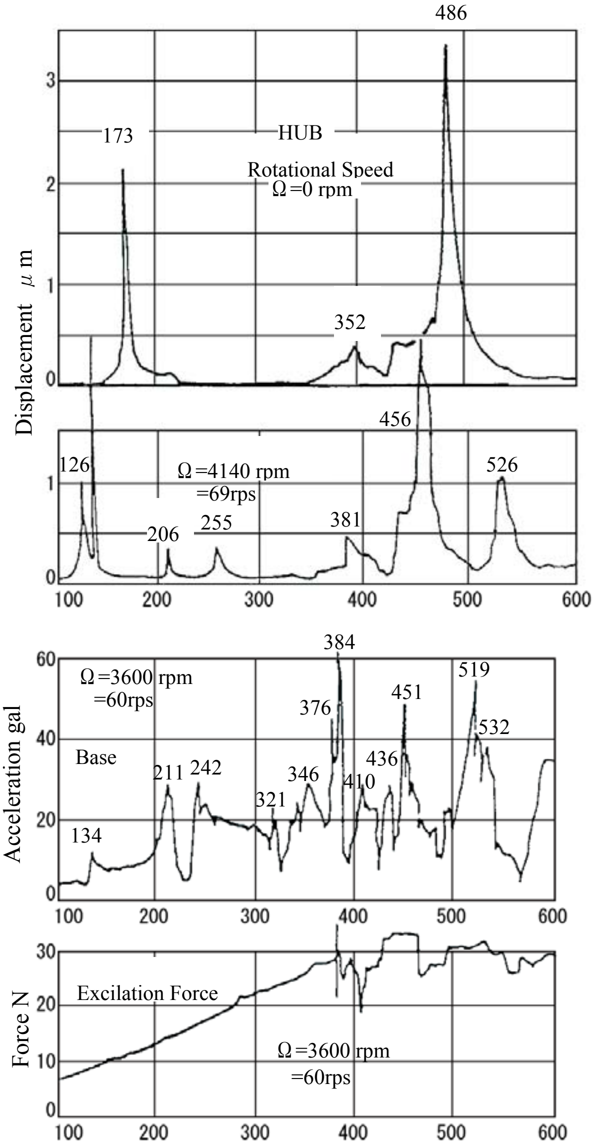


Fig.5: Response curves for sinusoidal excitation

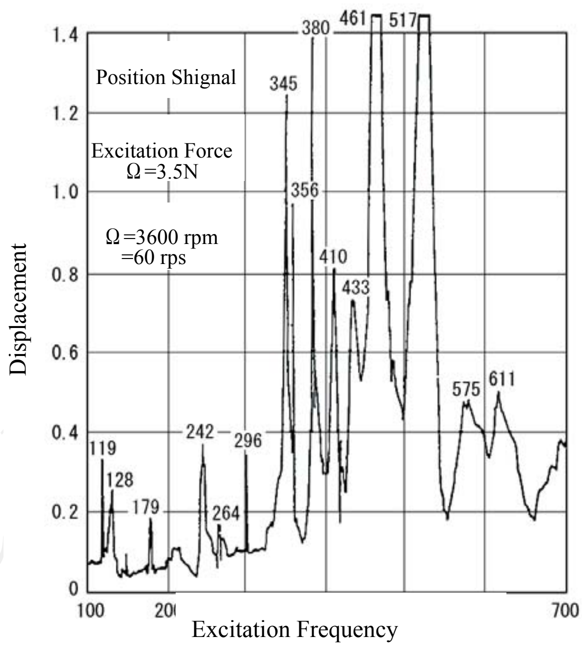


Fig.6: Response curves for sinusoidal excitation
(position signal)

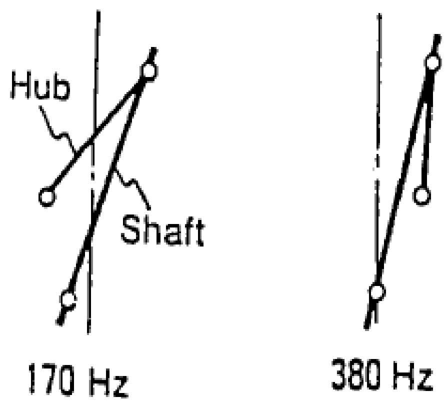


Fig.7: Results of experiment (vibration mode)

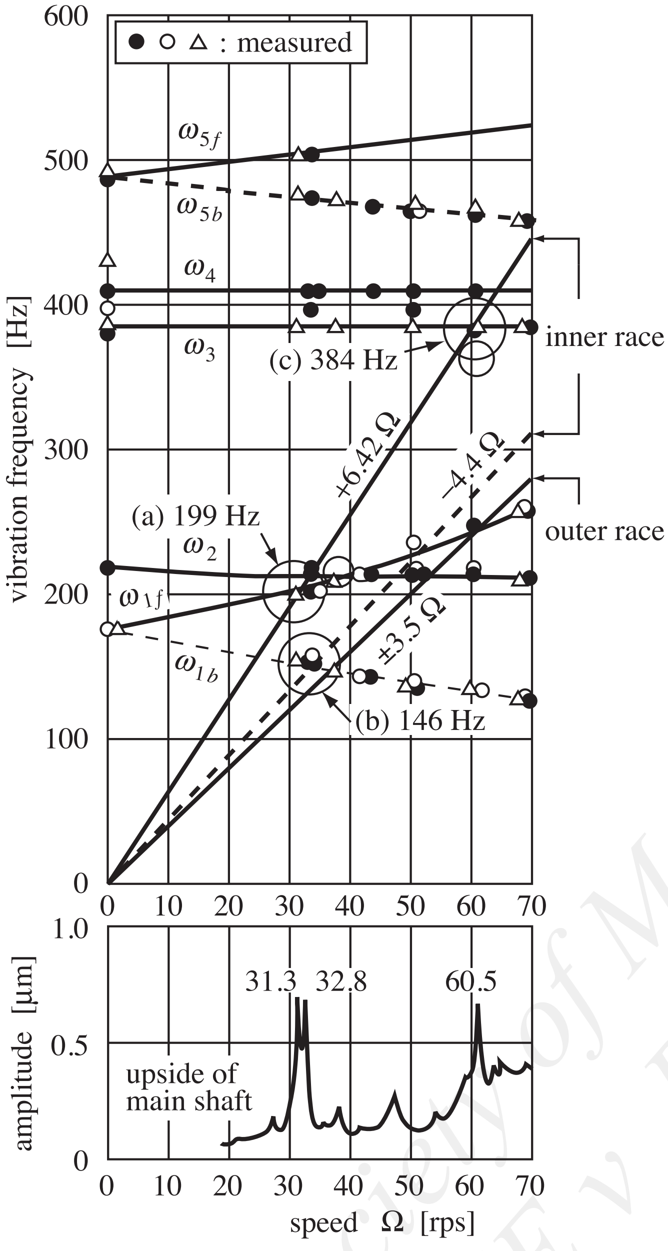


Fig.8: Results of experiment (resonance map)

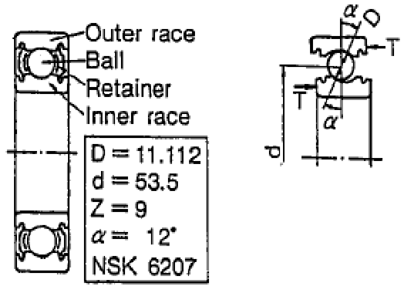
Table 1: Excitation frequency at the time of ball pass

Deformation		Excitation Ferquency	
Bearing Race	Number	Forward	Backward
INNER	1	$(Z+1-Z\beta)\Omega$	$-(Z-1-Z\beta)\Omega$
	m	$(mZ+1-mZ\beta)\Omega$	$-(mZ-1-mZ\beta)\Omega$
OUTER	1	$+Z\beta\Omega$	$-Z\beta\Omega$
	m	$-mZ\beta\Omega$	$-mZ\beta\Omega$

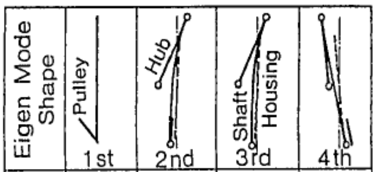
Ω : inner race rotational speed

Ωr : rotating retainer frequency relative to the stationary outer race

$$\Omega r = \frac{\Omega}{2}\left(1 - \frac{D}{d}\cos\alpha\right) \equiv \beta\Omega$$



$K_{\theta,hs} = 5.9\times10^8$ N.mm/rad	
$K_{ps} = 5.9\times10^3$ N./mm	
$K_{\theta,dh} = 4.2\times10^6$ N.mm/rad	
$K_{\theta,b} = 2.0\times10^9$ N.mm/rad	



Eigen Mode Shape	1st	2nd	3rd	4th
EXP.	—	160Hz	216Hz	368Hz
CAL.	72Hz	170Hz	212Hz	378Hz

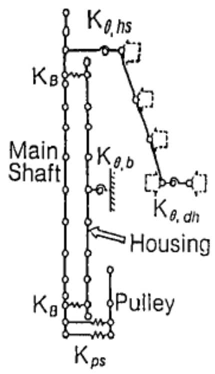


Fig.9: Analysis model and calculation results (at standstill)