Case History	Control of Blade-Shaft Coupled Vibration by Active Magnetic Bearing	Rotating machinery
Control		

Object Machine

A blade-shaft coupled rotor shown in Fig.1 was used. Eight blades, blade natural frequency 21.5 Hz, shaft natural frequency 12 Hz, and stagger angle 45 deg. The experiment was conducted in a vacuum.

Observed Phenomena

As indicated in Fig.2, unstable shaft vibrations occurred at around the rotational speed of 1,500 rpm during rotation tests, followed by such a large vibration as to cause contact with the stator of the active magnetic bearing. Fig.3 shows the results of FFT of the blades and the shaft before occurrence of vibration, while Fig.4 represents the measurement results obtained immediately after occurrence of vibration. The vibrations of the shaft occurred at 9.5 Hz, while those of the blades at 35 Hz, respectively.

Cause Presumed

The vibrations in question were considered to be self-excited vibrations of the shaft because they developed on the curves of the natural frequency of backward whirl. Thus, in consideration of the possibility for insufficient blade damping and blade-shaft coupled resonance, several experiments were conducted.

Analysis and Data Processing

・**Air damping effect (Fig.5):** Assuming that blade damping was insufficient in a vacuum, vacuum leak was tried after occurrence of self-excited vibrations to provide air damping, but the vibrations did not cease as in Fig.5 bottom.
・**Vibration suppression by cross feedback (Fig.6):** An experiment was made by incorporating the cross feedback described in "v-BASE No.247" [(1)]. Introducing the backward cross feedback adjusted to the frequency of the self-excited vibration enabled to settle the vibration, thus succeeding in attaining the rotational speed up to 2,400 rpm. However, a complete solution was not achieved because manual synchronization of the frequency (frequency of self-excited vibration) setting was required in accordance with increase in the rotational speed.
・**Review of active magnetic bearing controller (Fig.7):** In order to review the characteristics of the active magnetic bearing controller, the open loop characteristics were measured, which revealed a phase delay in the low frequency region.

Countermeasures and Results

・**Re-adjustment of controller**
The controller was re-adjusted by decreasing the cutoff frequency of the integrator (1st order low pass filter). Fig.7 shows the result of another measurement of the open loop characteristics, indicating a phase lead to 7.5 Hz. The rotation test succeeded in reaching 2,400 rpm (Fig.8).

Lesson Learned

In designing an active magnetic bearing controller, special attention should be paid to decrease in the backward natural frequency. This was experienced before [(2)], but was not taken advantage of.

References

(1) "Stabilization Using Active Magnetic Bearings against Unstable Vibration of a Liquid Containing Rotor", v-BASE Data Book 247
(2) Fujiwara, H.; Ito, M.; and Matsushita, O. "Rotational test of a Flexible Rotor Supported by Active Magnetic Bearing", Iscorma-2 (2006)

Keyword

Active magnetic bearing, phase lead, controller, backward natural frequency

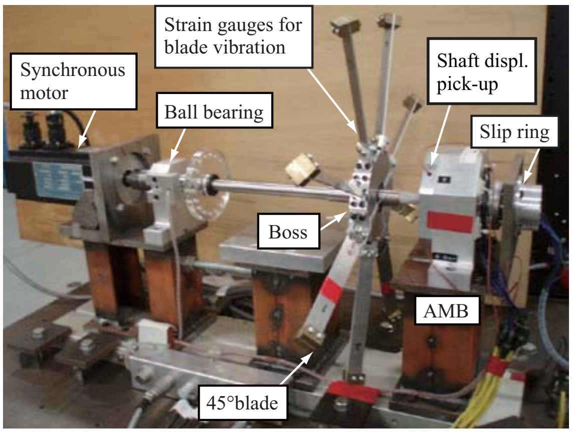

Fig.1: Experimental apparatus

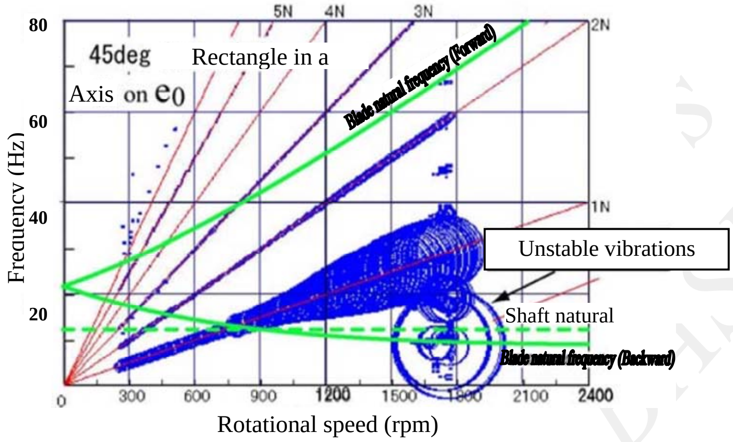

Fig.2: Campbell diagram (rotor vibration)

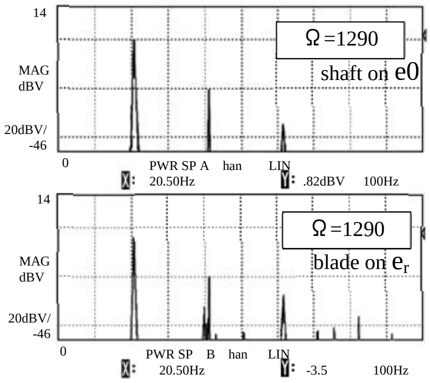

Fig.3: Vibrations of blade and shaft (1,290 rps)

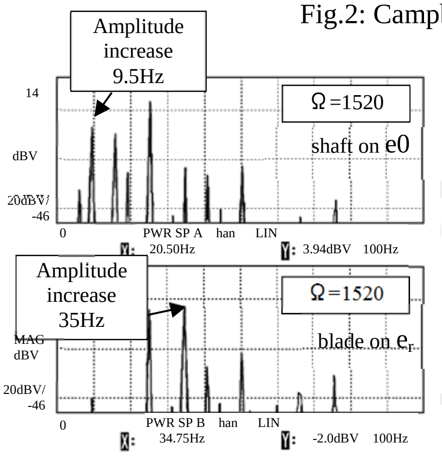

Fig.4: Vibrations of blade and shaft (1,520 rps)

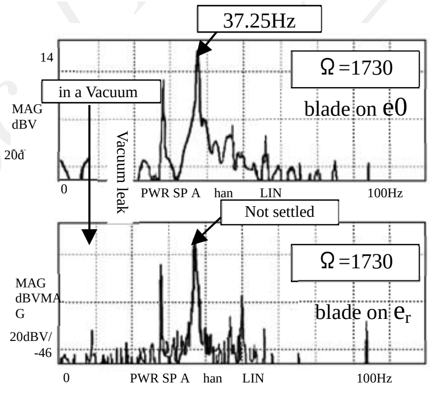

Fig.5: Blade vibration (vacuum leak)

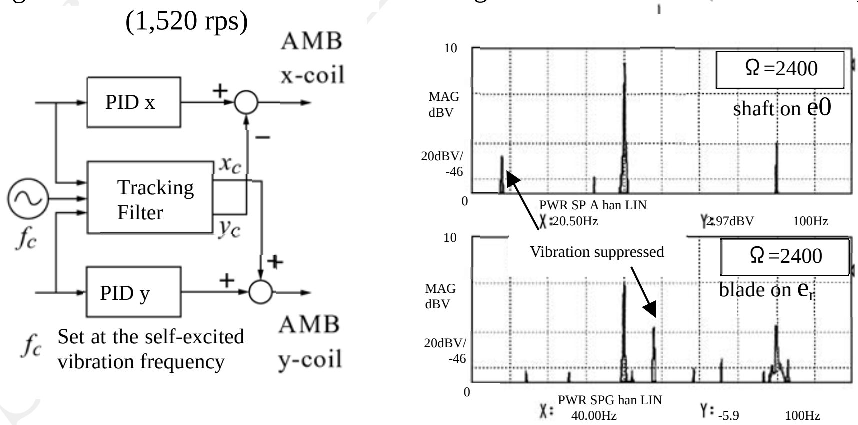

Fig.6: Cross feedback fc (for backward)

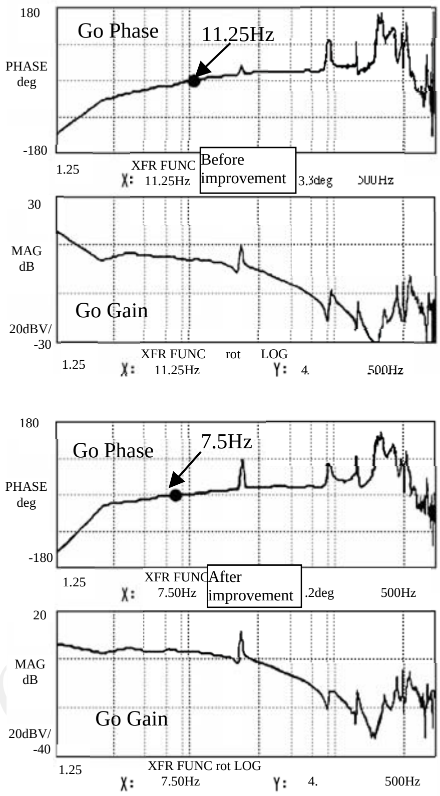

Fig.7: Open loop characteristics of the controller before & after improvement

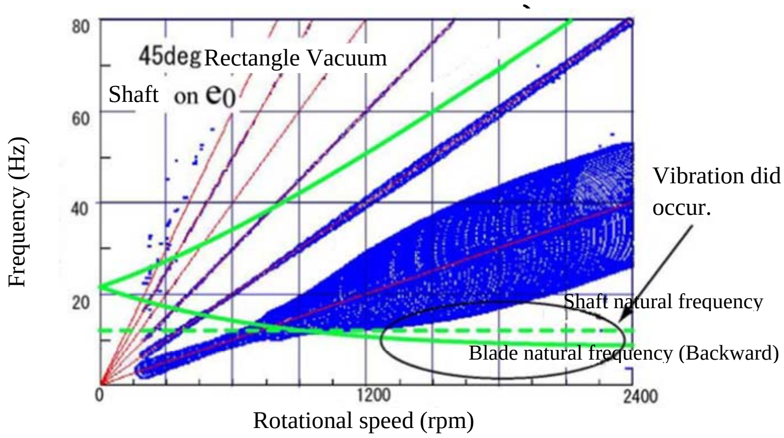

Fig.8: Campbell diagram after improvement of controller