Case History	Modal Balancing Technique using Actual Eigen Mode of the Flexible Rotor supported by Active Magnetic Bearings	Rotating machinery
Forced Vibration		

Object Machine

Flexible rotor supported by active magnetic bearings (AMBs)

Observed Phenomena

In order to perform balancing of the flexible rotor supported by AMBs using the modal balancing method as shown in Fig.1, the mass ratio of correction weights was calculated under the eigen mode of free-free boundary condition of rotor illustrated at the bottom of Fig.1. Then, balancing of N_{C3} was performed at 80 Hz having a large unbalance vibration as given in Fig.2. When the correction weights were mounted with the mass ratio as shown in Fig.3, a substantial influence was also detected on the low order modes N_{C1} and N_{C2}.

Cause Presumed

The eigen mode, which was used for calculation on an assumption that the stiffness of AMBs would be very small compared to the rotor stiffness, was approximately equal to the eigen mode of free-free boundary condition. In case of a flexible rotor, the bending eigen mode is considered to be greatly different from that of the eigen mode of free-free boundary condition.

Analysis and Data Processing

Fig. 4 is a modal model diagram representing the balance correction of N_{C3}. Correction weights that do not have an effect on N_{C1} and N_{C2} are required. The equation of motion is given below:

$$M\ddot{X} + C\dot{X} + KX = U\Omega^2 e^{i\Omega t} + W_c\Omega^2 e^{i\Omega t}$$

The mass ratio of N_{C3} can be obtained by the following equation. Each mass ratio of N_{C4} and N_{C5} can be also obtained in the same manner.

$$\varphi_1^t W_C = 0,\ \ \varphi_2^t W_C = 0,\ \ \varphi_3^t W_C = -\varphi_3^t U$$

Countermeasures and Results

The eigen mode with the stiffness of an AMB equal to 10^6 (N/m) is shown in Fig.5. Applying this eigen mode, the mass ratios "W_{C1}: W_{C2}: W_{C3}: W_{C4}: W_{C5}" of the correction weights to be mounted on five circular plates were modified as follows.

	(Free-Free boundary condition)		(AMB stiffness considered)
N_{C3}	-1:0:2:0:-1	→	-1:0:0.9:0:-1
N_{C4}	-0.63:1:0:-1:0.63	→	-0.8:1:0:-1:0.8
N_{C5}	0.42:-0.92:1:-0.92:0.42	→	0.52:-1:1:-1:0.52

The results obtained after repeating the balance corrections using these mass ratios are shown in a polar diagram of Fig. 6 that represents the conditions before and after N_{C5} balancing after passing N_{C3} and N_{C4}. At 280 rps, an increase in the vibration amplitude due to the 3rd bending mode unbalance was observed. Thus, the 3rd bending mode balancing was performed by calculating effective vectors for 280 rps. After determining the correction weights as in Fig.7 using the above mass ratios, rotation tests were conducted. As a result, the vibration amplitude at 280 rps was able to be reduced from A to C, thus succeeding in passing the 3rd bending mode critical speed N_{C5}. Fig.8 shows the result of the rotation tests in the form of resonance curves. As Fig.8 indicates, the 3rd bending mode balancing using the mass ratios of the correction weights derived from the eigen mode in consideration of AMB stiffness enabled the balance correction only of the 3rd bending mode (N_{C5}/φ_5), without affecting other modes (N_{Ci}/φ_4, i = 1~4) that had already been balanced. Moreover, the vibration amplitude values of the critical speeds (N_{C1}~N_{C5}) present within 300 rps were successfully controlled below 150 μm p-p (Zone A in the ISO standard).

Lesson Learned

Although AMBs are said to be soft supports, the AMB stiffness of flexible rotor having high order critical speeds cannot be ignored in some instances. It is also found that consideration of AMB stiffness allows a high precision balance correction.

References

(1) Ito, Fujiwara, Matsushita. "Rotational Test of Flexible Rotor supported by Active Magnetic Bearings (1st report: Passing the 2nd Bending Critical Speed)", *Transaction of the Japan Society of Mechanical Engineers*, Series C, Vol.70, No.693, pp.1236-1243

(2) Ito, Fujiwara, Matsushita. "Rotational Test of Flexible Rotor supported by Active Magnetic Bearings (Passing the 3rd Bending Critical Speed)", D&D 2006, CD-ROM 325

Keyword

Active magnetic bearing, modal balancing, influence coefficient

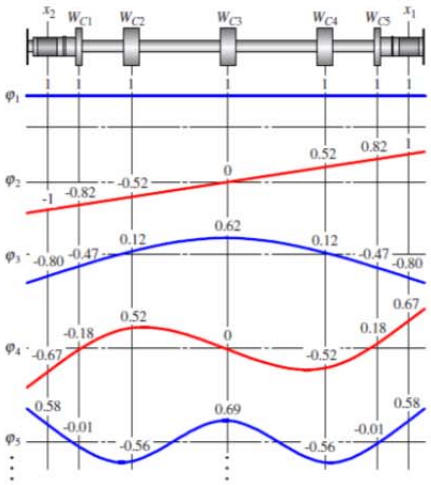

Fig.1: Eigen modes of free-free boundary condition

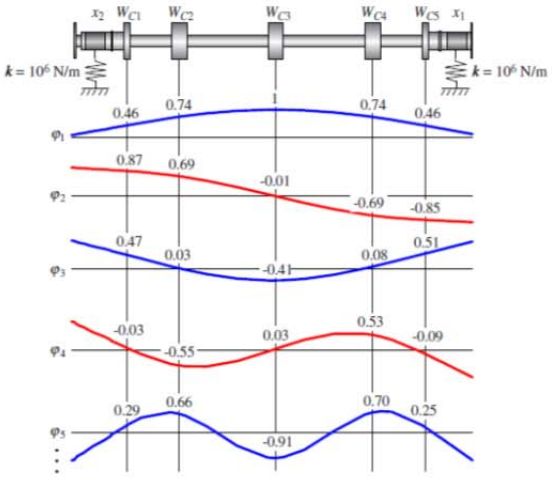

Fig.5: Actual eigen modes when AMB stiffness 10^6 N/m)

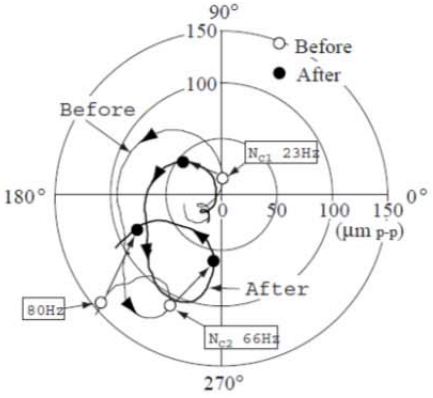

Fig.2: Polar plot (Passing the N_{C2})

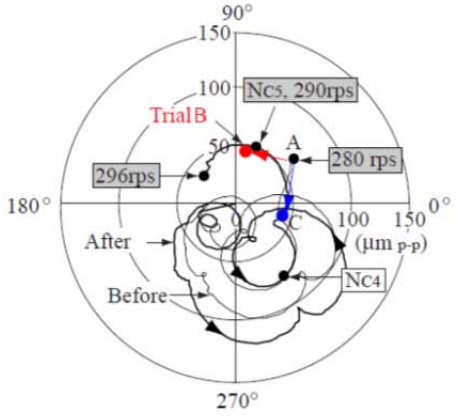

Fig.6: Polar plot (Passing the N_{C5})

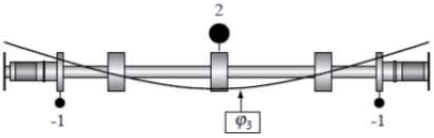

Fig.3: Mass ratio of correction weight (N_{C3})

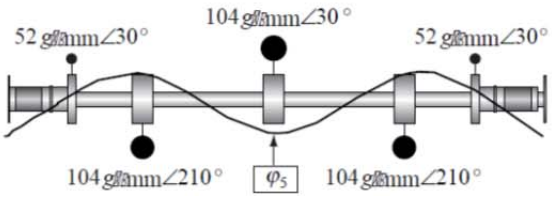

Fig.7: Mass ratio of correction weight (N_{C5})

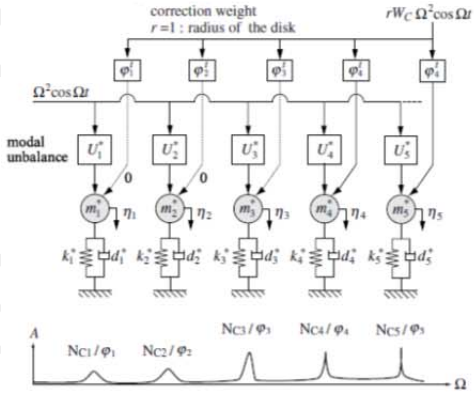

Fig.4: Modal model

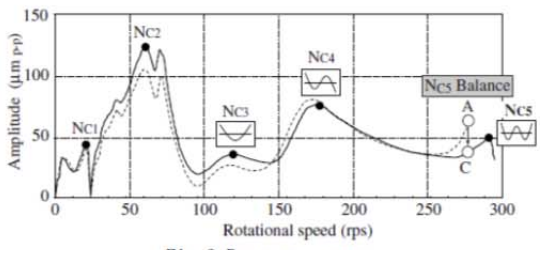

Fig.8: Response curve (Passing the N_{C5})