Vibration	Sub-harmonic Vibration due to Nonlinearity of Bearing Support	Rotating Machinery
Nonlinear		

Object Machine

Turbocharger supported by rolling bearing for large diesel engine (refer to Fig.4, maximum rotating speed 14,000rpm)

Observed Phenomena

Vibration investigation was made about a turbocharger where a damage problem occurred on the rolling bearing. In addition to the vibration components of the rotational frequency, there were found various large amplitude vibrations with lower frequencies. The examination revealed that, in the FFT resolution range, they were exactly 1/2, 1/3 and 2/3 sub-harmonic vibrations (refer to Campbell diagram in Fig.1).

Cause Estimation

The bearing uses angular ball bearings as shown in Fig.2, where a multi-layered laminated leaf spring type damper, called a damper plate, was mounted on the outside of the bearing outer ring. Especially, the latter is said to have a damping effect, but at the same time, has a significant non-linearity, which was assumed to be a cause of sub-harmonic vibrations.

Analysis and Data Processing

Results of a static load-applied test as to the bearing revealed that the damper plate had backlashes in excess of 200μm in diameter, and had a typical nonlinear spring characteristics that the stiffness steeply increases by loading (Fig.3). Thus, in order to verify if such a nonlinear spring generates sub-harmonic vibrations in question, a steady state nonlinear response was calculated. The employed shaft system is in Fig.4 and a nonlinear bearing is modeled with a nonlinear spring having a backlash of radius r_1 while the interval between r_1 and r_2 was approximated by a 5th polynomial equation, and damping is abbreviated, And then the harmonic balance method [1] was used for analysis.

One example of the calculation results is given in Fig.5. As a result, it was found that the primary critical speed was around 3,500 cpm, and a good simulation was accomplished to indicate a tendency as to 1/2 sub-harmonic vibration around 7,500rpm, and 1/3 and 2/3 sub-harmonic vibrations to appear around 12,000rpm, and thus, the cause was attributable to the non-linearity of bearing and low damping.

Countermeasures and Results

In place of the damper plate, a squeeze film damper was used, where a centering spring (K = 3×10^7N/m) with less nonlinearity was employed. In order to predict the effect of the countermeasures, calculations were made using the damper characteristics of a 2π film model [2] in Equations (1): damping force to occur in the direction of eccentricity ε and in the direction of eccentric angle φ, where ε and μ are eccentricity and oil viscosity coefficient, and R, L, and c are damper radius, width and gap in the radial direction, respectively.

$$F_\varepsilon = -\frac{\pi\mu R L^3}{c^2}\frac{1+2\varepsilon^2}{(1-\varepsilon^2)^{5/2}}\dot{\varepsilon}\,, \qquad F_\varphi = -\frac{\pi\mu R L^3}{c^2}\frac{1}{(1-\varepsilon^2)^{3/2}}\varepsilon\dot{\varphi} \qquad (1)$$

The calculation results are shown in Fig.6, where the previous complex responses are simplified, with no sub-harmonic vibrations. The actual operation also has the same results, and thus the bearing damage problem has been settled.

Lesson

Sub-harmonic vibrations are liable to occur in the low damping condition. In case of this machine, the damping was originally deficient.

References

(1) M. Kobayashi et al. (two persons), "Nonlinear steady-state vibration analysis of rotor by substructure synthesis", Transaction of JSME, ser. C, Vol.57. No.533, in Japanese (1991), pp.1-8
(2) O. Matsushita et al. (four persons), "Vibrations of rotating machinery Volume 2. Advanced Rotordynamics", Springer Japan KK, (2019), p.255

Keywords

Sub-harmonic vibration, higher harmonic vibration, oil damper, turbocharger

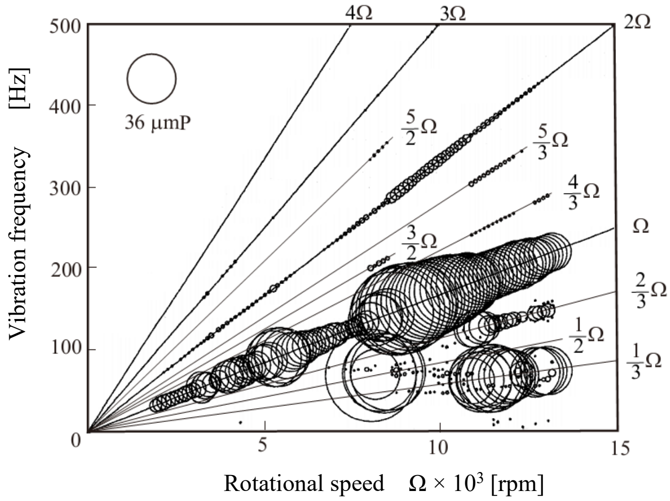

Fig.1 Measured Campbell diagram

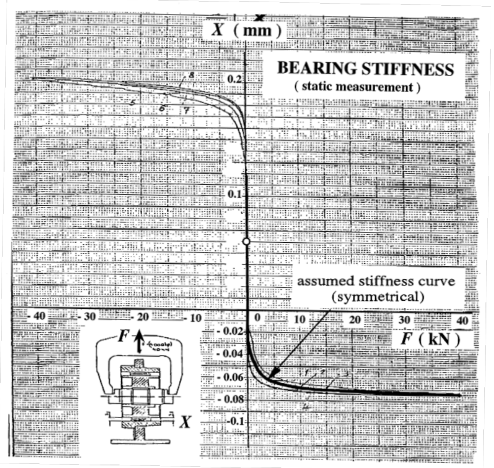

Fig.3 Nonlinear spring characteristics of bearing part

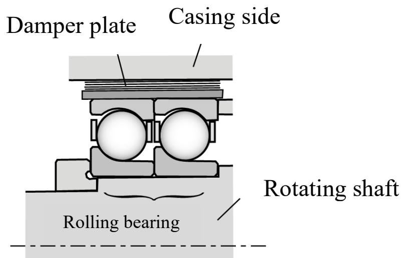

Fig.2 Details of bearing

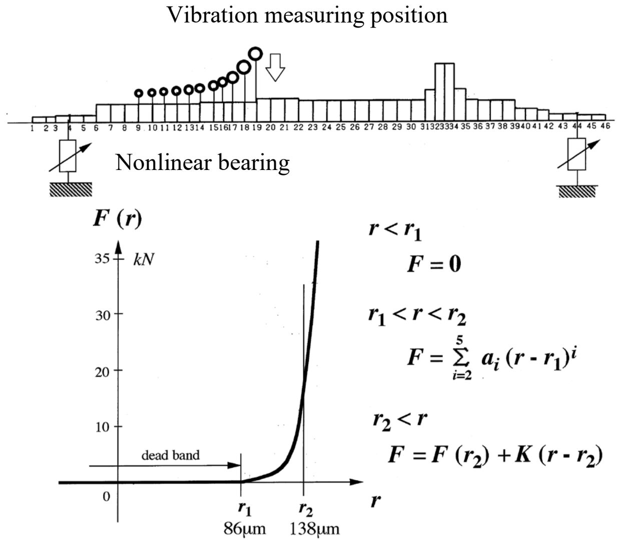

Fig.4 Shaft system model and
nonlinear shaft system model of supercharger

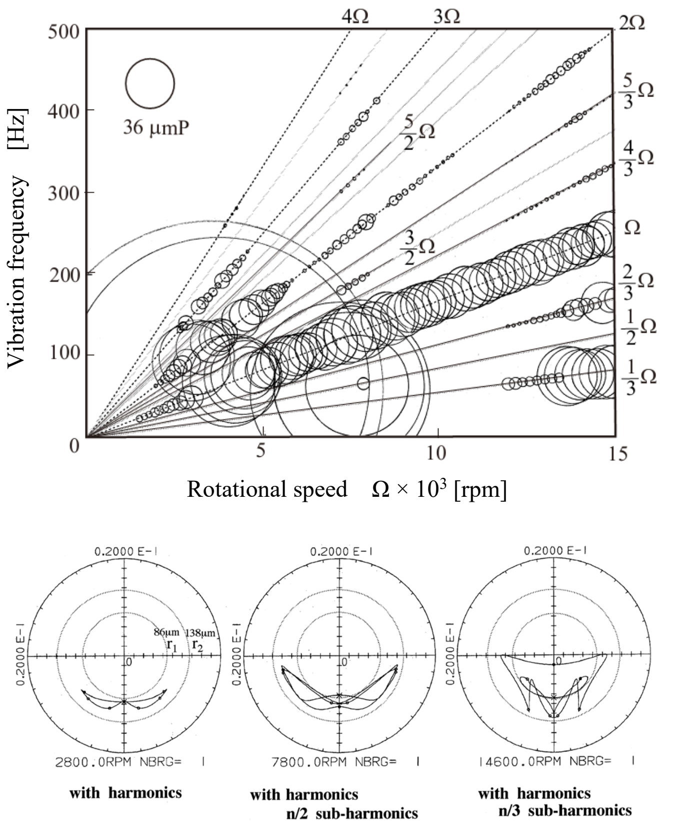

Fig.5 Calculation results
(Campbell diagram and shaft loci at the bearing)

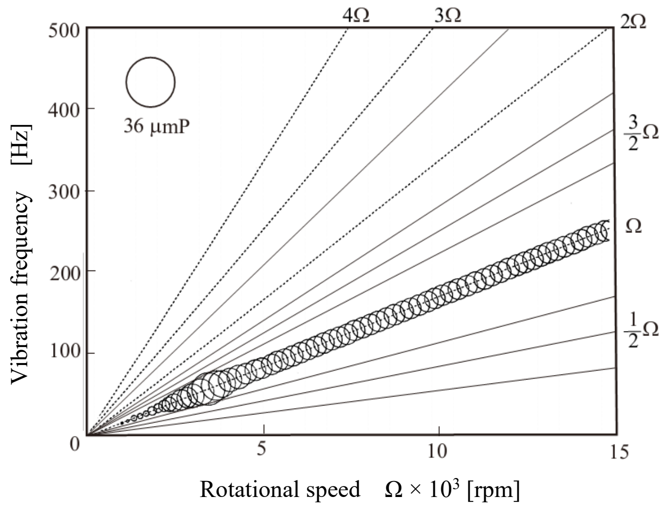

Fig.6 Change to squeeze film damper