Case History	Resonance of Compressor Pinion Gear	Rotating machinery (displacement type)
Resonance		

Object Machine

Centrifugal type compressor

Observed Phenomena

A centrifugal type compressor shown in Fig.1 constitutes a gear-coupled shaft system supported by plain bearings, where the gear shaft is on the drive side, and the pinion shaft is on the anti-drive side. During operation at the rated speed (pinion: 14,293 rpm), a phenomenon occurred that the pinion shaft vibration increased for increasing the load (rating: 2,700 kW), and the vibration amplitude reached its peak value at a certain load. The dominant frequency was six times of the rotation speed of the gear shaft, i.e., 6x The gear ratio was 308/32 = 9.625.

Cause Presumed

Figure 2 shows the vibration amplitude of the pinion shaft, measured by an eddy-current type non-contact displacement pick-up, with varying the load taken as a parameter. Because of the peak phenomenon in Fig.2 and the change of spring–damping characteristics of the oil film plain bearings of gear transmission, associated with load i.e., the gear transmission force (F_G), we guess that the natural frequency of the pinion shaft-bearing system is varied so that the resonance condition results in a certain load. As shown in the right of Fig.1, the relationship between the load and the gear transmission force and load angle (θ) was such that F_G became small and θ = 0° for light load, whereas F_G became large and θ = 160° for heavy load.
Therefore, it was estimated that the natural frequency of the pinion shaft-bearing system came close to the excitation frequency (6th order of the rotation speed of the gear shaft), thus causing a resonance problem.

Analysis and Data Processing

In Fig. 3, we see the results of frequency analysis of the rotor vibration waveforms at the peak point in Fig.2. It is observed from this figure that the six times component (6 N_G) of the rotation speed of the gear shaft is predominant, which is significant for the entire range of measured load as noted in Fig.2. It is thus understood that the resonance phenomenon is also a peak phenomenon due to the excitation of this 6 N_G component.
Meanwhile, the bearing dynamic properties were obtained using an analysis software for the oil film bearing dynamics corresponding with the load as a parameter. Using these properties, an eigenvalue analysis was conducted by means of a rotor eigenvalue analyzing software. Changes in each eigenvalue thus obtained are indicated in Fig.4. The 6 N_G that was assumed to be an excitation frequency and the 3rd and 4th modes intersect at the load position in Fig.2. It was thus found that the 3rd and 4th modes were excited to cause forced vibration by the compelling force having a frequency six times the rotation speed of the gear shaft.
Measurement of pitch circle errors of the gear, with considering transmission errors during engagement with the gear as the excitation force, produced such waveforms as shown in Fig.5. In Fig.6, the results of an FFT analysis for the gear error waveform were shown, and we confirmed the presence of the excitation force having a frequency equal to six times the rotation speed of the gear shaft. Figure 5 also includes for comparison the synthesized waveforms consisting of 1 N_G, 2 N_G and 6 N_G, which have virtual amplitudes and phase differences.

Countermeasures and Results

The gears were grinded again to reduce the excitation force, together with modification of the bearing shape to eliminate the resonant eigenvalues from the operation range. In consequence, the peak phenomenon disappeared as shown in Fig.7.

Lesson Learned

In a gear shaft system, transmission errors occur depending on gear accuracy, so that it is necessary to take into account higher harmonic components of the gear shaft as an excitation frequency. For a gear shaft system using plain bearing supports, an analysis should be conducted for dynamic properties of oil film bearing in consideration of the magnitude and the phase θ of the gear transmission force.

References	Nothing in particular
Keyword	Resonance, gear, plain bearing, gear transmission error

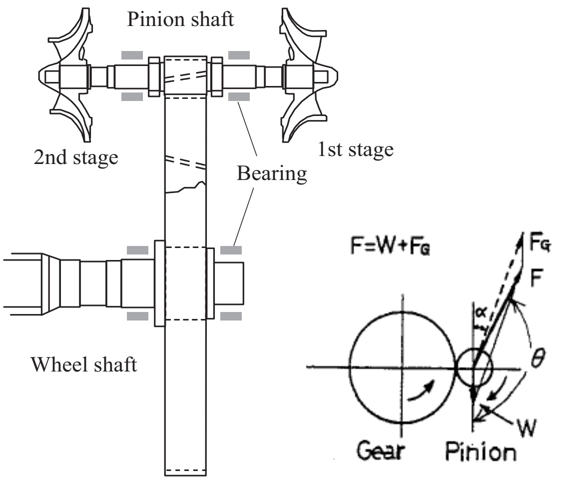

Fig.1: Centrifugal type compressor

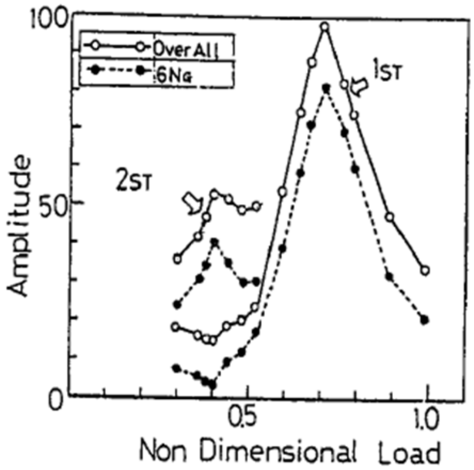

Fig.2: Pinion shaft vibration response

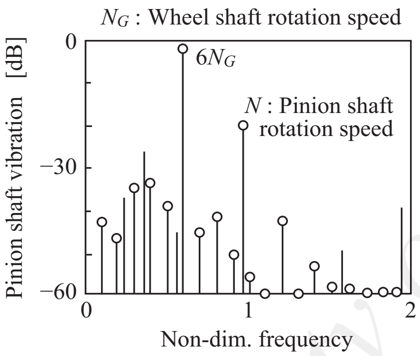

Fig.3: Frequency spectrum

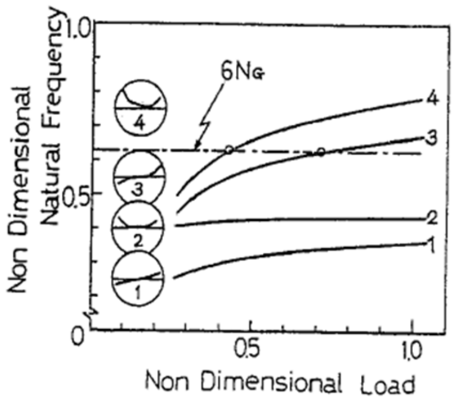

Fig.4: Eigenvalue of pinion shaft

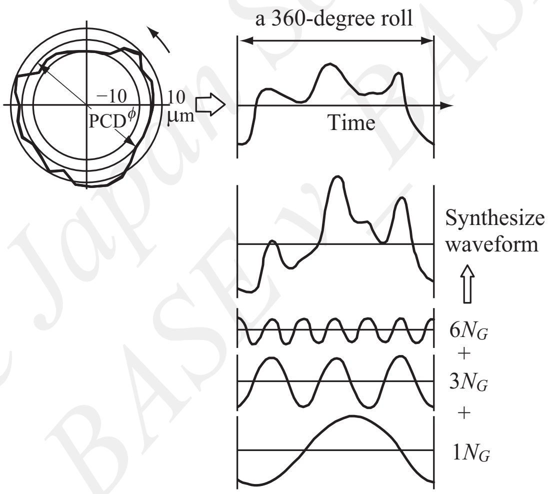

Fig.5: Shape of gear pitch circle

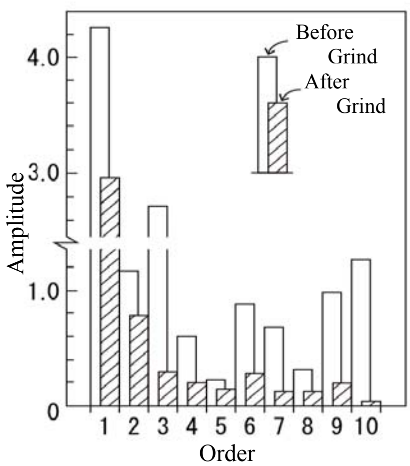

Fig.6: Error component of gear pitch circle

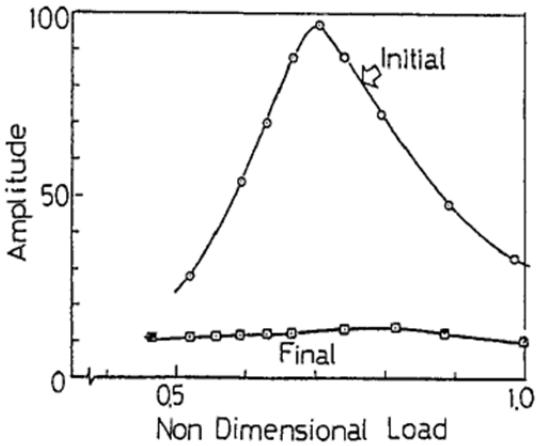

Fig.7: Vibration response (before & after taking countermeasures)