Case History	Tie Bolt Resonance in Assembled Rotor	Rotating machinery (turbine & generator)
Forced Vibration		

Object Machine

Small gas turbine testing machine that is fastened using a tie bolt (tension bolt) as well as curvic couplings and a shrink fit for each stage (Fig.1)

Observed Phenomena

It became impossible to raise the rotational speed because of larger vibrations of the rotation frequency. Fig.2 shows this state using a Nyquist diagram (modal circle plot).

The vibration condition was not changed for the increase and decrease in rotational speed including several stops, and repeatability was observed. Since it was clear that unbalance was the cause, field balancing was conducted, where the influence coefficient method with one correction plane was applied.

○ Correction plane: rear side of 2nd stage turbine disk

○ Vibration to be balanced: a vibration increment vector from point A to B in Fig.2

However, this balancing revealed no effect at all, resulting in no reduction of vibrations.

Cause Presumed

Table 1 shows the amount of correction weights at each balancing step and the measured influence coefficients, while Fig.3 displays the vector of the influence coefficients. It is observed from these data that the influence coefficient varies at each measurement. Although under condition of a constant unbalance, vibrations showed repeatability during increasing and decreasing the rotational speed, the reproducibility of the influence coefficient (increment rate in vibration for increased unbalance) often tended to disappear due to deformations caused by centrifugal force especially in case of an assembly type rotor. Initially, this was considered to be the cause, and a countermeasure was taken to improve the reproducibility of influence coefficient by increasing the tie bolt tension for stiffening the fastenings.

Besides, Fig.4 shows the process of balancing correction (vibration changes from A to B in Fig.2). It appears that vibrations indicate no tendency of decrease and moreover, they seem to go back and forth between two vibration values. It was thus presumed that because of a slip in the fastening (where looseness essentially exists), unbalances at both ends of looseness caused vibrations in two modes.

Analysis and Data Processing

The upper limit of rotational speed certainly increased by enhancing the tie bolt tension, but the phenomenon remained unchanged (no reproducibility of influence coefficient). However, the study of tie bolt strength that was additionally made for the tension increase revealed that the natural frequency of the tie bolt itself was in the vicinity of the rotational speed in question.

As a consequence, vibration control of the tie bolt has been included in our study. The phenomenon shown in Fig.4 suggests that the direction of tie bolt deflections (that deforms nearly statically) varies according to unbalance of the outer shaft, and that the deflection remains below the gap. Thus, it seems reasonable to consider that two modes of unbalance appear.

Countermeasures and Results

A bush (loose fit cylindrical spacer) was inserted in a gap between the impeller and the tie bolt (in Fig.1), so as to restrict the tie-bolt movement in the radial direction. As a result, the increase in vibration between A and B in Fig.2 disappeared, allowing the rotor to rotate up to the rated speed without any problems. It has thus become clear that resonance of the tie bolt was the cause of phenomenon in question.

Lesson Learned

Although it took a long time to implement countermeasures, these were the fundamental problem. The natural frequency of the tie bolt was first inquired about and judged to be "adequately high, and thus no problem". What is important is to affirm the key items by myself. It has also been found that balancing has no meaning in some cases.

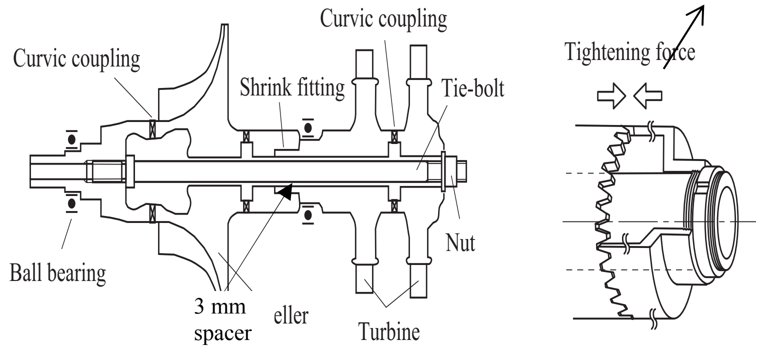
References

Nothing in particular

★ Rotors should have minimum loose portions. Looseness of the tie bolt may cause unstable vibrations due to internal friction, to which attention shall be paid.

Keyword
Assembly type rotor, tie bolt, resonance, balancing

★ Tension enhancement allowed to maintain repeatability in rotational speed increase and decrease, but with no reproducibility of influence coefficient.



★ Insertion of a loose spacer in this position will sometimes cause unstable vibrations due to internal friction, thus requiring attention to be paid.

Fig.1 Gas turbine shaft model

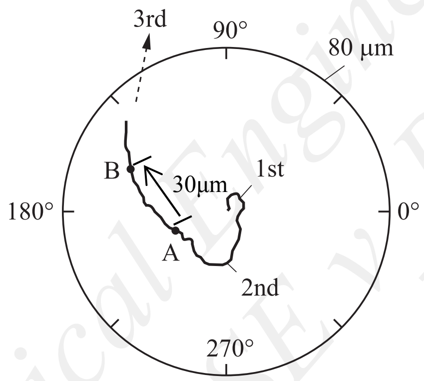


Fig.2 Nyquist plot of shaft vibration

Table 1 Measured influence coefficients

Table 7·2 Trial weights and measured influence coefficients

No	Added weight [g]	Influence coefficient [µm/g]
(1)	0.3 ∠ 120°	7.6 ∠ −272°
(2)	0.5 ∠ 120°	9.2 ∠ −104°
(3)	1.5 ∠ 48°	38.0 ∠ −124°
(4)	0.5 ∠ 196°	8.0 ∠ −107°
(5)	1.5 ∠ 214°	42.0 ∠ −118°

Note : influence coefficient
= vibration change between A-B/added weight

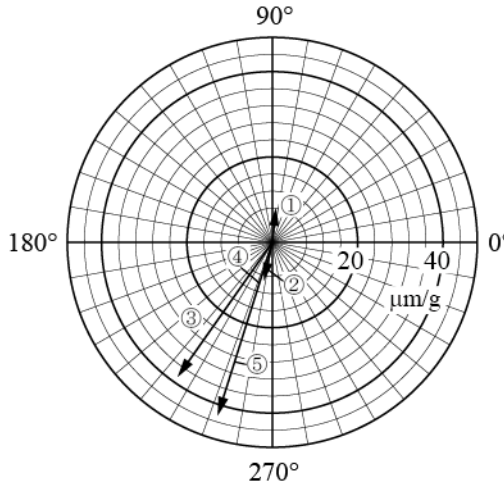


Fig.3 Variation in influence coefficients

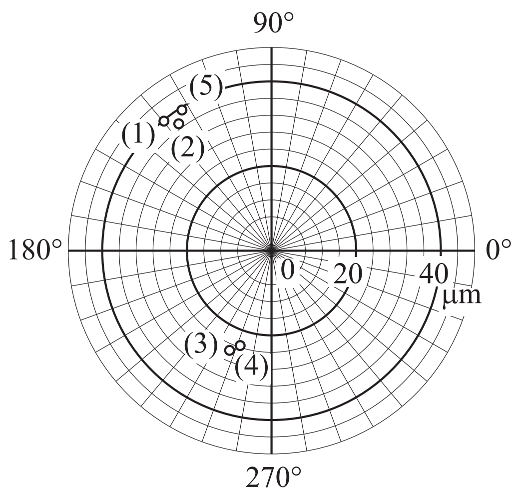


Fig.4 Process of each balance correction (vibration between A and B)