Case History	Whirling of Vertical Pump Intermediate Shaft due to Internal Friction	Rotating machinery (pump & water turbine)
Self-excited Vibration		

Object Machine

Vertical pump
(A motor and a pump are connected by a plate type flexible coupling and a slender hollow shaft.)

Observed Phenomena

Increasing the rotational speed beyond a critical speed caused vibrations at a point where the sum of damping becomes zero.
The measured vibrations have the following characteristics.

1) Increasing the speed beyond a critical speed causes vibrations.
2) Its frequency is equal to the first natural frequency of the intermediate shaft, which increases exponentially over time.
3) The vibrations are liable to develop if they are large when passing the critical speed.

Cause Presumed

Since friction (internal decrease) on the rotating shaft has a negative damping action after passing the critical speed, self-exited vibration may occur if external damping is extremely small.
The pump was traditionally of a rigid design, but here, in order to improve the problems of bearing life due to misalignment and of maintenance, the design was changed to be a flexible type, and the critical speed fell below the normal rotational speed. However, as a result, it was estimated that a self-exited vibration occurred because of internal friction inside the flexible coupling and of insufficient external damping due to the use of roller bearings.

Analysis and Data Processing

Theoretical analysis has proven that the limiting speed of instability due to internal friction can be expressed by the equation (1) and oblique lines in Fig.1.

$$\omega_L = \left(1 + \frac{\zeta_o}{\zeta_i}\right)\omega_m \qquad (1)$$

where
ω_L represents safety limit angular velocity; ω_m represents critical angular velocity; ζ_i represents internal damping ratio; and ζ_o represents external damping ratio.

As shown in Fig.1, the safety limit of the equation (1) is a point where the sum of internal damping and external damping is zero.

Countermeasures and Results

There are two possible countermeasures; one is to raise the critical speed, and the other is to increase the external damping while maintaining the low critical speed. As a result of examining both of these, the latter was chosen as the countermeasure, in which the bearings were changed to those having a rubber cushion support to enhance external damping, thus completely solving the problem. Fig.2 shows the difference between the intermediate shaft system before and after taking the countermeasures, while Fig.3 illustrates the resulting characteristics before and after taking the countermeasures. (However, a calculation of shaft system vibrations shall be required at the time of adopting this method.). Ball bearings are soft-supported by rubber in this case, which is a rare successful example.

Lesson Learned

In fact, this type of phenomenon rarely happens, but attention should be paid when loose fittings are used where internal friction is likely to develop, or when radial thrust is large.

References

H. Kanki et al. SOLUTION FOR VERTICAL PUMP VIBRATION PROBLEMS — Field Experiences and Engineering Technology —. *Proceedings of the KSME/JEME Vibration Conference* '87, 1987: 34~35

Keyword

Whirl induced by internal friction

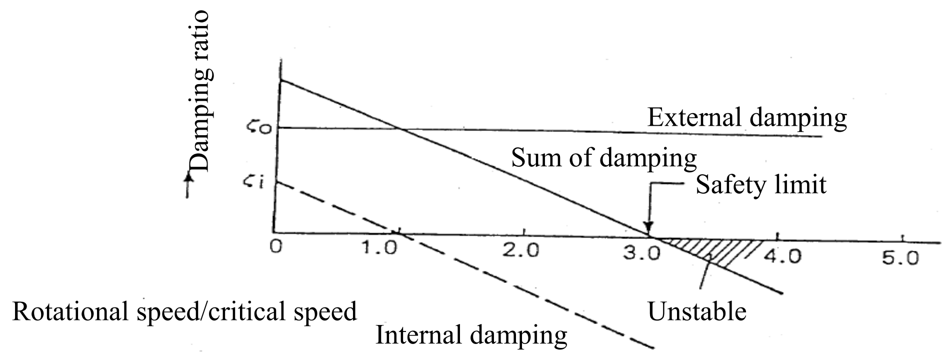
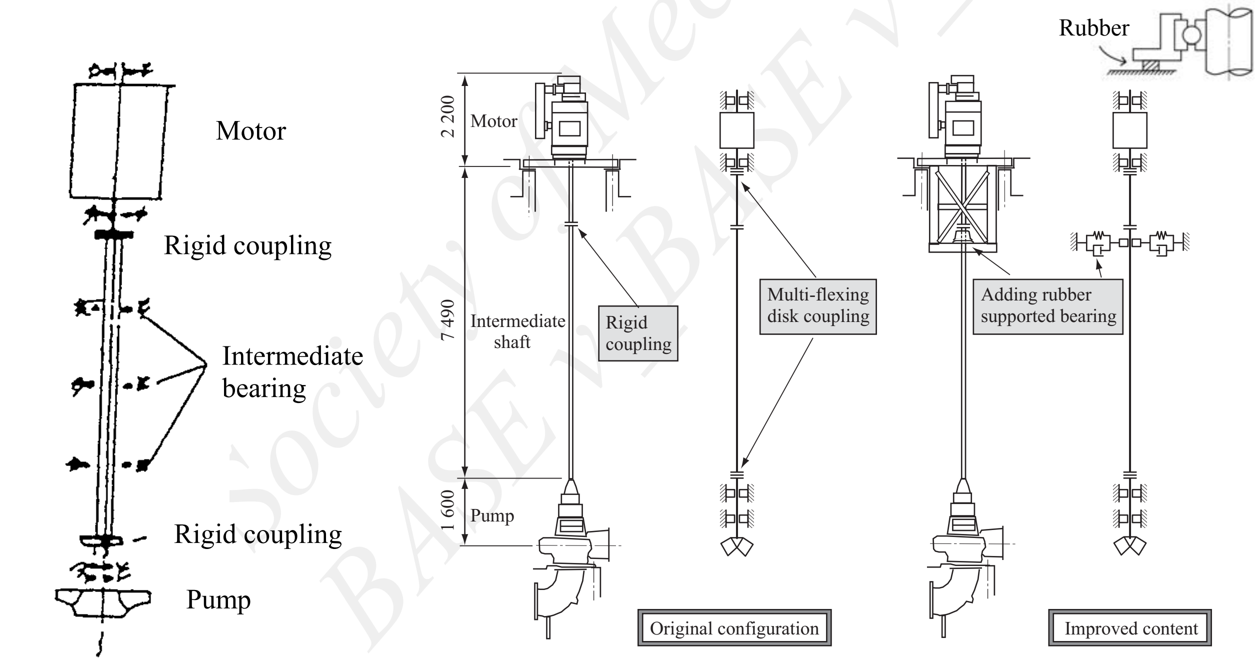


Fig.1: Unstable vibration mechanism due to internal friction



(a) Rigid shaft design (previous design)

(b) Elastic shaft with rigid support design (shaft system where unstable vibration occurred)

(c) Elastic shaft with damping support design (shaft system after taking countermeasures)

Fig.2: Variations of intermediate shaft system

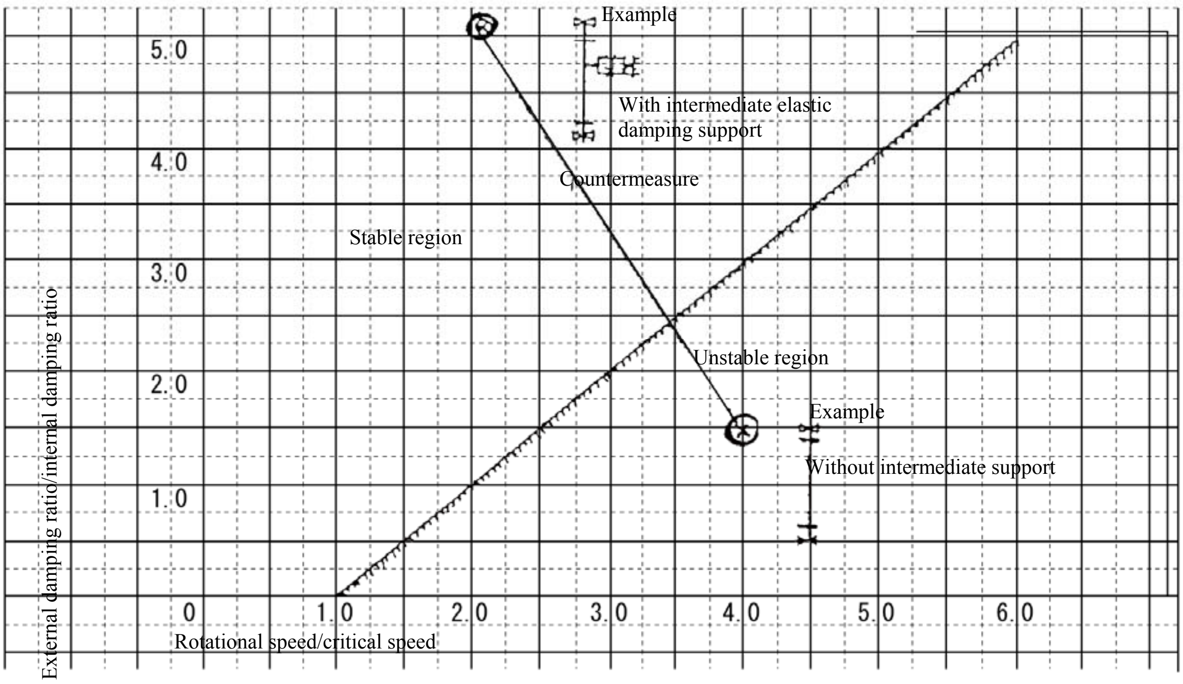


Fig.3: Result of stability evaluation