Vibration / Self-Excitation	Backward Self-excited Vibration That Occurred on Low Torque Driven Testing Machine	Rotating Machinery

Object Machine

Vertical type rotor testing machine (reference 2, Fig.1), total length 1.34m, shaft diameter $2r$ = 12mm, disk mass about 1kg, annular guard radial gap c = 0.5mm, annular guard friction coefficient μ = 0.85, variable speed motor (250W), natural frequency 20Hz, damping ratio 0.012 (all of these under non-contact condition)

Observed Phenomena

A moderate unbalance (amount of eccentricity ε = 60μm) was added to the disk, and after keeping in contact with the annular guard, the rotating speed was maintained at 21Hz, with the result given in Fig.2. The phenomena that occurred are summarized as follows.

(1) 0.0 ~ 0.6sec: forward unbalance vibrations (amplitude increasing, but not yet in contact)

(2) 0.6 ~ 1.45sec: forward unbalance vibrations, whirling along the entire gap circle, while sliding in contact with the annular guard

(3) 1.45 ~ 1.9sec: vibrations in a radial fashion, while the rotor collides with the annular guard. The rotational speed $\dot{\phi}$ remains slightly less than 21Hz, but a whirling speed $\dot{\Psi}$ = –20Hz (minus sign means that whirling is in the backward direction) occurred.

(4) 1.9 ~ 2.4sec: the rotating speed $\dot{\phi}$ reduces from 21Hz to 8Hz by friction, while backward whirling is dominant.

(5) 2.5sec ~: the rotating speed $\dot{\phi}$ is kept at 8Hz, while whirling speed $\dot{\Psi}$ = –95Hz. Large backward vibrations accompanying deformation of the annular guard.

Cause Estimation

Phenomenon (2) represents a condition of contact while sliding on the annular guard surface in forward direction. As for phenomena (3) to (5), backward vibrations are generated, which are assumed to be self-excited vibrations due to friction.

Analysis and Data Processing

Analyzing the phenomenon (3) proved that self-excited vibrations of a backward natural frequency (–20Hz) was superimposed on the unbalanced vibrations (forward), leading to radial vibrations. Self-excited vibrations with a backward natural frequency corresponds to a so-called friction whip. Fig.3 (1) shows a description on friction whip. In case of full annular rub (continuous sliding), friction whip is a dangerous phenomenon directly leading to damage, but in this case, only an intermittent collision that did not result in large vibrations. The phenomenon (5) corresponds to rotor rolling on the inner face of the annular guard (rolling contact), and a description on the generated frequencies is shown in Fig.3 (2). Since sum of the rotating angle and a whirling angle for the rotor is 2π, the relationship between whirling frequency f and rotational frequency f_r can be obtained. This can also be calculated from the sliding speed is zero at a contact point: $\Delta v = 2\pi\,(rf_r - cf) = 0$. In this case, $f = r/c \times f_r = 6/0.5 \times 8 = 96$Hz, which is close to a measured value of 95Hz. This corresponds to a condition of a rotor rolling contact with no slipping on the surface of the annular guard. Crandall and Childs[4] call this condition as friction whirl. Relationship between whirl and whip is illustrated in Fig.4.

Countermeasures and Results

When the mass eccentricity was increased to 70, 80, and 130μm to increase unbalance, the above condition (2) remained the same afterwards (Fig.5). This phenomenon is closely related to a radial direction force F_n, As a matter of fact, a relative relation with a frictional force μF_n determines a condition for a generation of backward vibration.

Lesson

In order to prevent this phenomena, it is important first not to cause contact, and even if contact occurs, to hold a condition (2) to maintain low friction.

References

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(2) ED. Bernard, “Whirling of a vertical rotor contacting with annular guard during passage through critical speed”, Doctoral dissertation, Nagaoka University of Tech. (1999)

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(4) D. Childs, A. Bhattacharya, “Prediction of dry-friction whirl and whip between a rotor and a stator”, Trans ASME, J. Vib. Acoust, Vol.129, (2007) pp. 355-362.

Keywords

Friction whirl, friction whip, dry friction whip, rolling contact vibration, backward

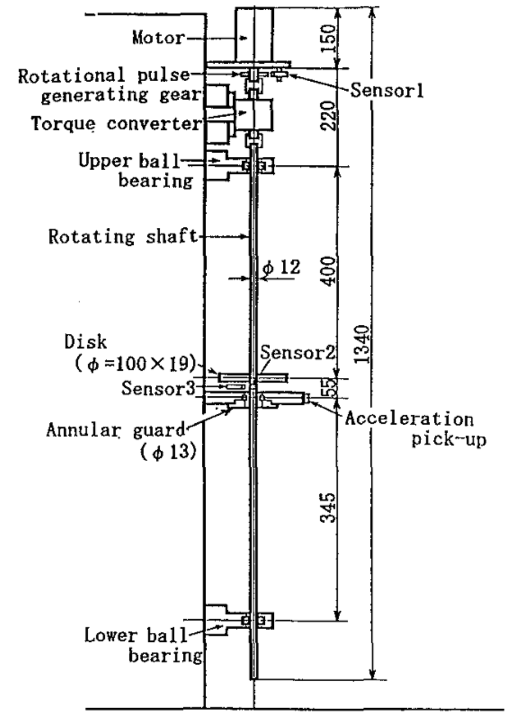


Fig.1 Experimental equipment (reference 1, 2)
Rotor in contact with annular guard (center rest)

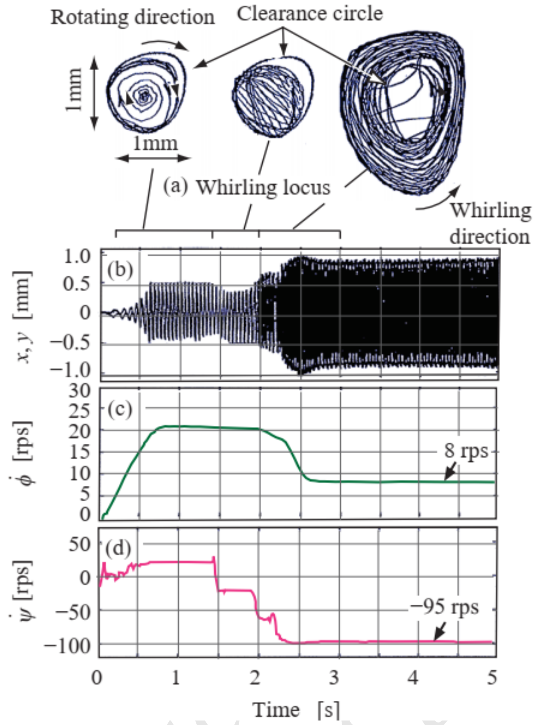
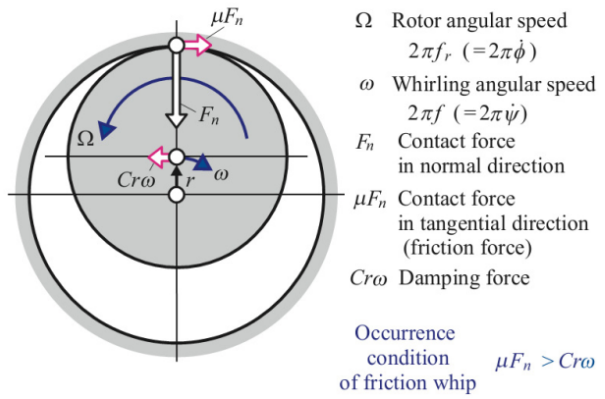
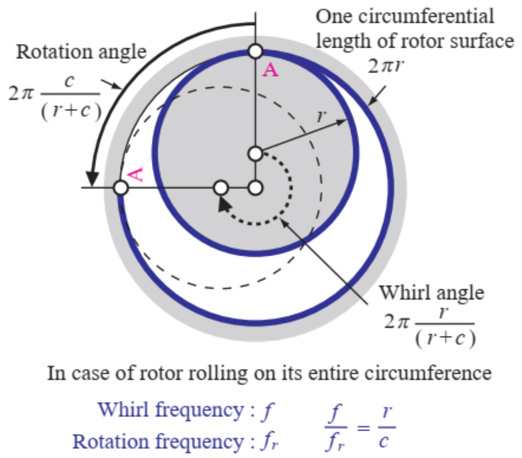


Fig.2 Vibration observed after passing a critical speed (reference 2), Vibrations sensors 2, 3: x, y, Rotating speed: $\dot{\phi}$ and whirling speed: $\dot{\Psi}$



(1) Mechanism of dry friction whip



(2) Rolling contact whirl without slip (dry friction whirl)

Fig.3 Friction whip and whirl (source: reference literature 3)

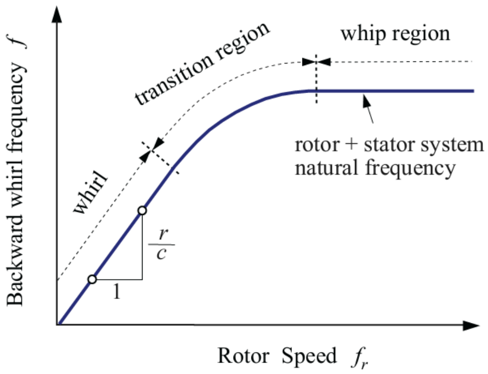


Fig.4 From friction whirl to whip (reference 4), Present case is from whip to whirl

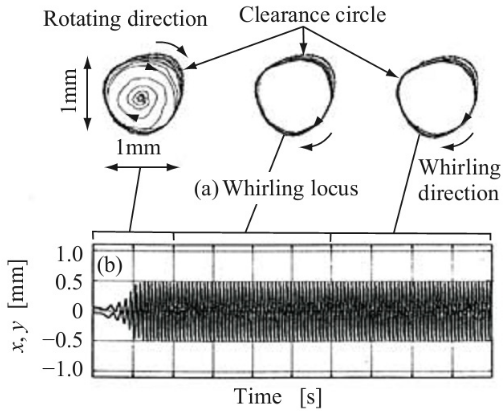


Fig.5 Vibration for amount of mass eccentricity ε = 130μm,, No backward vibration occurred (reference 2)