N86-30195

WHIRL/WHIP DEMONSTRATION

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Fluid flow in bearings and seals, set in motion by shaft rotation (Figure 1), generates dynamic forces which may result in a well-recognized instability known as whirl and whip. These are lateral, forward precessional, self-excited, subsynchronous vibrations in which the amplitude may vary from very small to nearly the limit of the bearing or seal clearances. Oil whirl in lubricated bearings, in particular, typically occurs at somewhat less than half rotative speed. As the rotative speed increases, the frequency relationship remains constant until the whirl frequency approaches the first balance resonance. Now the whirl is smoothly replaced by whip at a nearly constant frequency asymptotically approaching first balance resonance, independent of increasing rotative speed. Changes in bearing/seal radial loading can permit, prevent, or eliminate this instability.

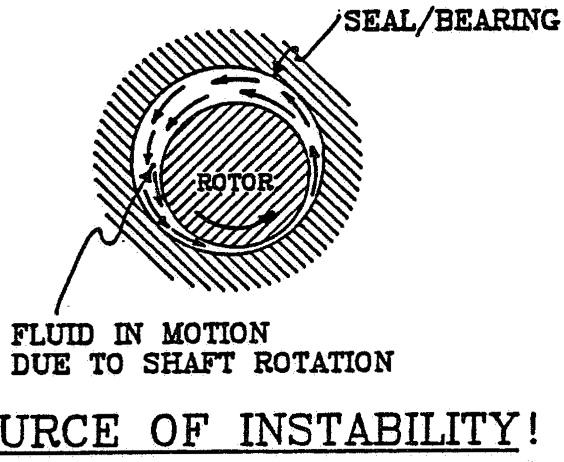

Figure 1. - Bearing/seal fluid-generated instability.

OBJECTIVE

The oil whirl/whip rig demonstrates the effects of fluid dynamic forces generated by the rotating shaft. At low rotative speeds, this produces changes of the journal static equilibrium position within the bearing. The demonstrator shows the relationship between any load direction and the average journal equilibrium position (attitude angle) (Figure 2). At higher rotative speeds, the instability threshold is observed as a function of unidirectional radial load, unbalance, and rotor configuration.

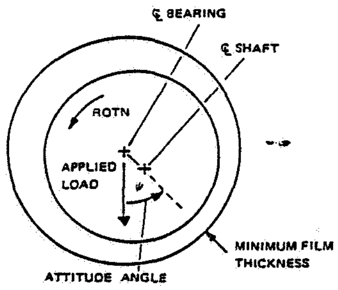

Figure 2. - Attitude angle between load direction and average journal equilibrium position.

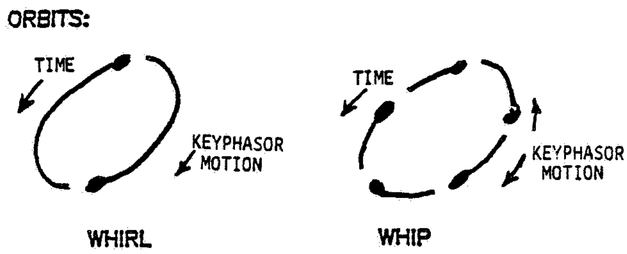

Figure 3. - Oscilloscope presentation of oil whirl and oil whip orbital motion (vibration precession) of journal, combined with once-per-turn reference (keyphasor) signal. Keyphasor marks may move forward or backward relative to time depending on ratio of vibration frequency to rotative speed.

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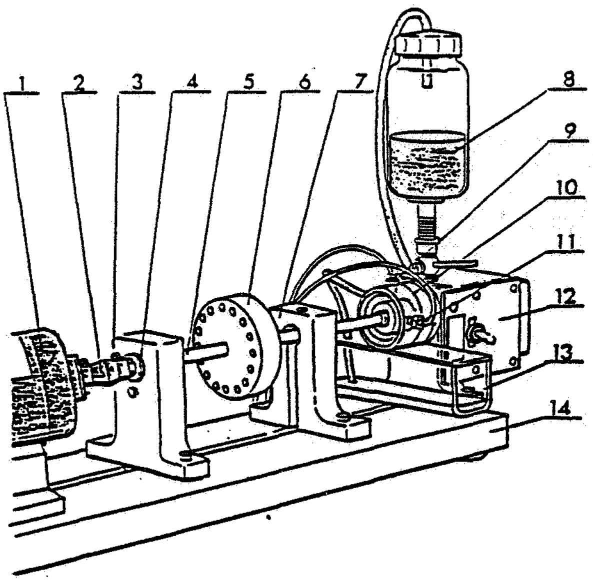
The fixed relationship between oil whirl frequency and rotative speed, as well as the transition to oil whip at a frequency slightly below the first balance resonance frequency, may be observed on the oscilloscope (Figure 3) and spectrum analyzer. Note the distinctive oscilloscope orbit pattern of the two Keyphasor marks slowly rotating counter to time direction (stroboscopic effect) during oil whirl and the multiple Keyphasor marks during oil whip (variable frequency ratios).

ROTOR RIG

The rotor rig consists of a single disk rotor supported in an Oilite (oil impregnated, sintered bronze) bearing at the inboard end and an oil lubricated Lucite journal bearing at the outboard end. The journal is 0.980" in diameter with 0.006" to 0.013" diametrical clearance. Oil is gravity fed through an axial groove (Figure 4).

The disk may be positioned anywhere along the shaft to modify the stiffness. Radial loading of the journal bearing may be controlled with horizontal and vertical springs or a nylon stick (Figure 5).

The rotor is driven by a variable speed (0-12,000 rpm) electric motor through a flexible coupling.



1. Variable speed electric motor
2. Flexible coupling
3. Bearing support
4. Oilite bearing
5. 12"x.375" shaft
6. 1 3/4 pound disk
7. Guard
8. Oil supply reservoir
9. Vertical proximity probe
10. Lucite bearing
11. Horizontal proximity probe
12. Oil pump
13. Oil drain reservoir
14. Base plate

Figure 4. - Rotor rig for demonstrating oil whirl/whip.

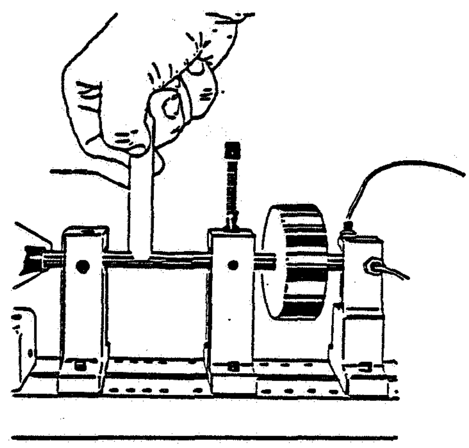


Figure 5. - Application of preload with nylon stick.

INSTRUMENTATION

X-Y proximity probes located at the journal bearing provide position and vibration information for the orbit and time base display on the oscilloscope. The Digital Vector Filter (DVF 2), an automatic or manually tuned bandpass filter, displays rotative speed, amplitude, and phase. An FFT spectrum analyzer generates a frequency domain display.

MEASUREMENT PARAMETERS

The parameters of interest are:

- Rotor equilibrium position and vibration measured at the journal.
- Average oil swirling ratio, λ.
- Oil whip frequency.
- Direction of vibration precession.
- Change in threshold of stability with changes in disk position and unbalance (two additional stability thresholds).
- Relative radial load changes (magnitude and direction) to stabilize or destabilize system.

RESULTS

Figures 6 through 15 illustrate the transition from whirl to whip and the effect of unbalance force on the whirl threshold. The vibration mode shape for whirl and whip and variations in stability threshold with rotor configuration are also shown.

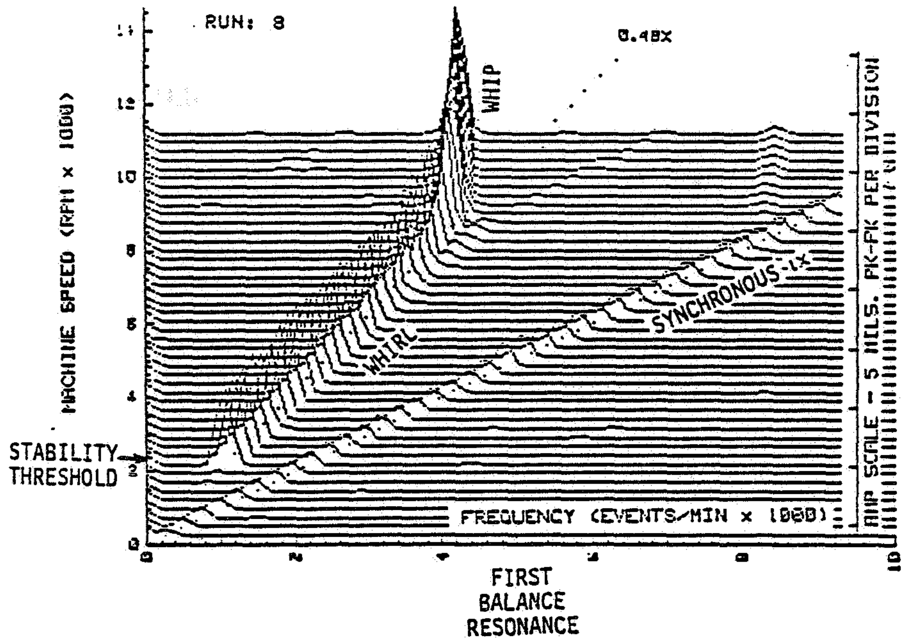


Figure 6. - Cascade spectrum of vertical vibration response during startup with well-balanced rotor.

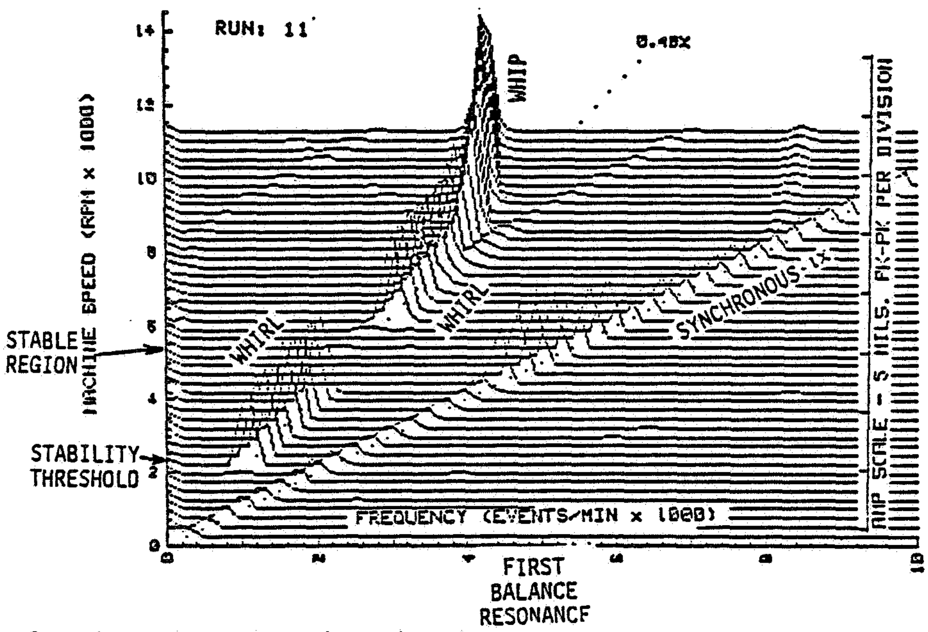


Figure 7. - Cascade spectrum of vertical vibration response during startup with moderately unbalanced rotor. Note stable region for synchronous vibrations associated with increased unbalance vibration.

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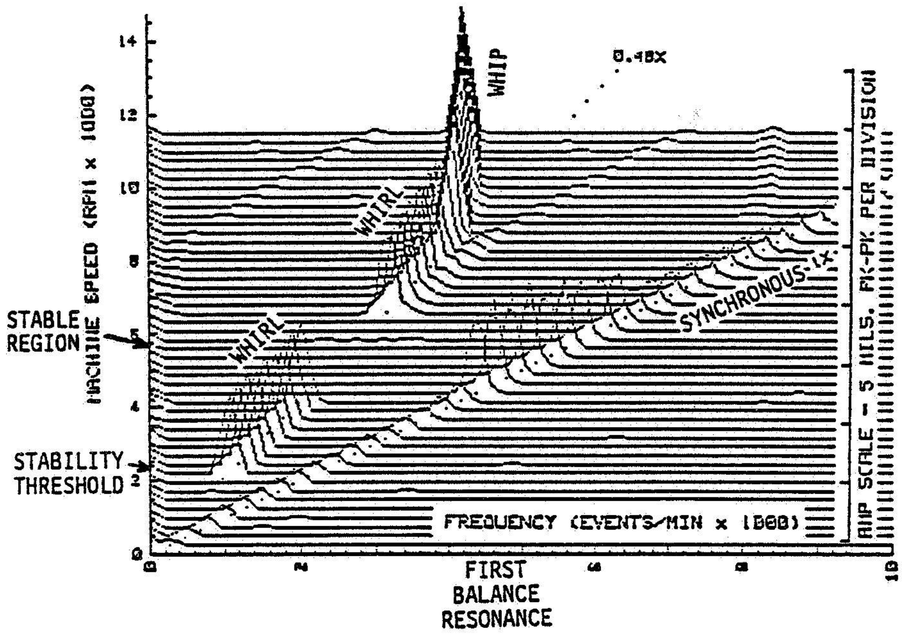
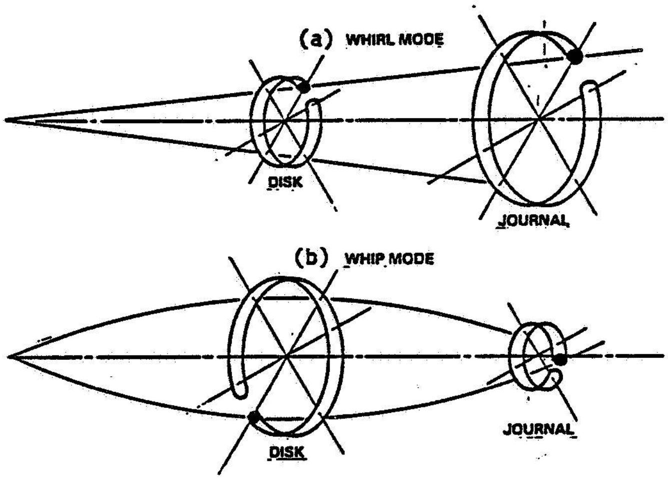


Figure 8. - Cascade spectrum of vertical vibration response during startup with more severely unbalanced rotor. Note expanded stable region of synchronous vibrations.



(a) Whirl mode - disk and journal motion in phase.
(b) Whip mode - journal motion 90° ahead of disk motion.

Figure 9. - Rotor modes revealed by perturbation testing.

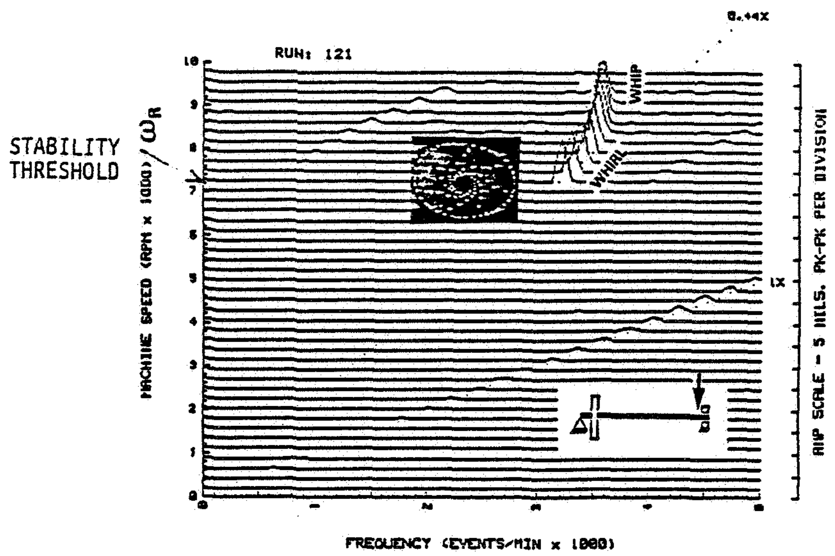


Figure 10. - Cascade spectrum of main rotor runup vertical vibration response and oil whirl inception measured at oil bearing position. Disk located next to motor.

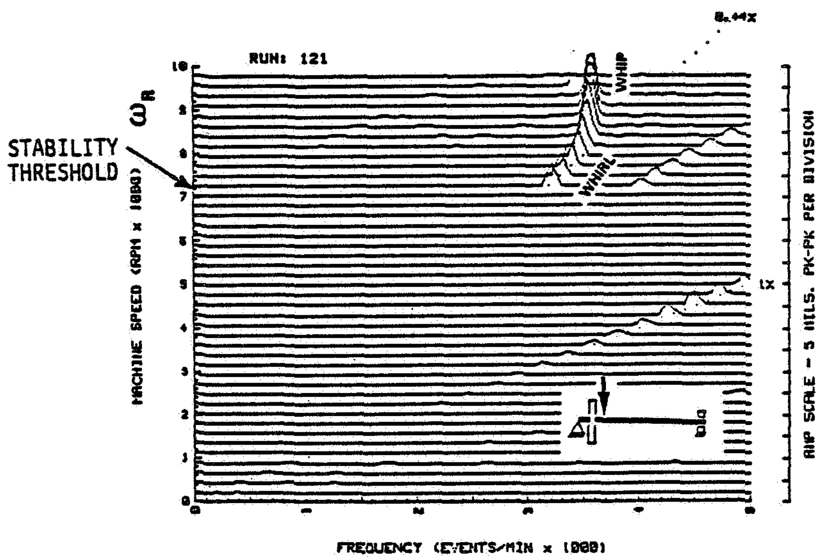


Figure 11. - Cascade spectrum of main rotor runup vertical vibration response measured at disk position. Disk located next to motor.

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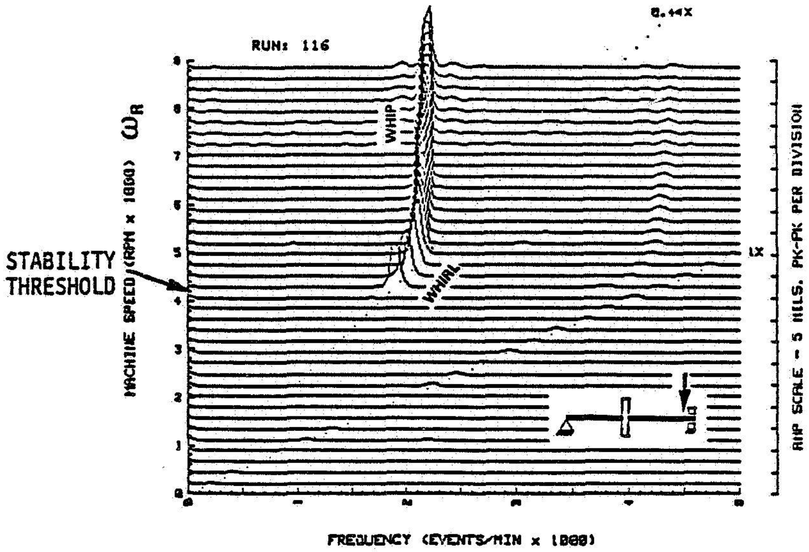

Figure 12. - Cascade spectrum of main rotor runup vertical vibration response measured at oil bearing position. Disk located at shaft midspan.

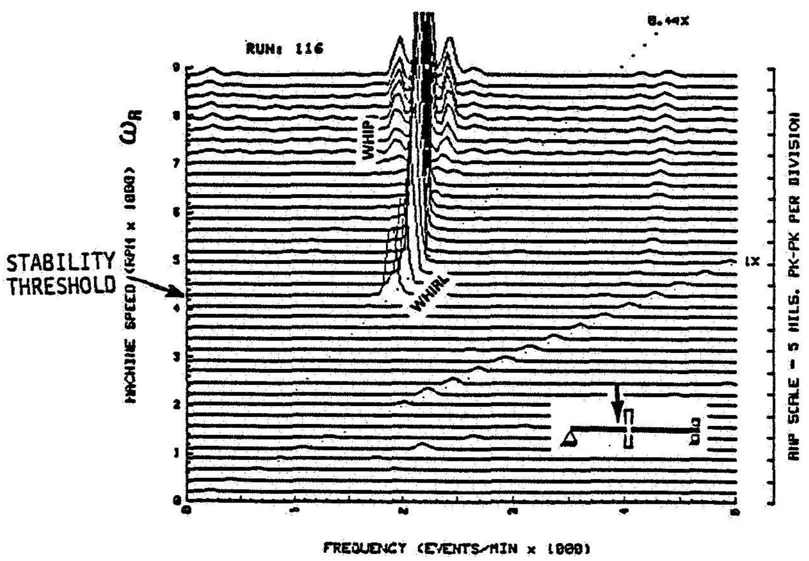

Figure 13. - Cascade spectrum of main rotor runup vertical vibration response measured at disk position. Disk located at shaft midspan.

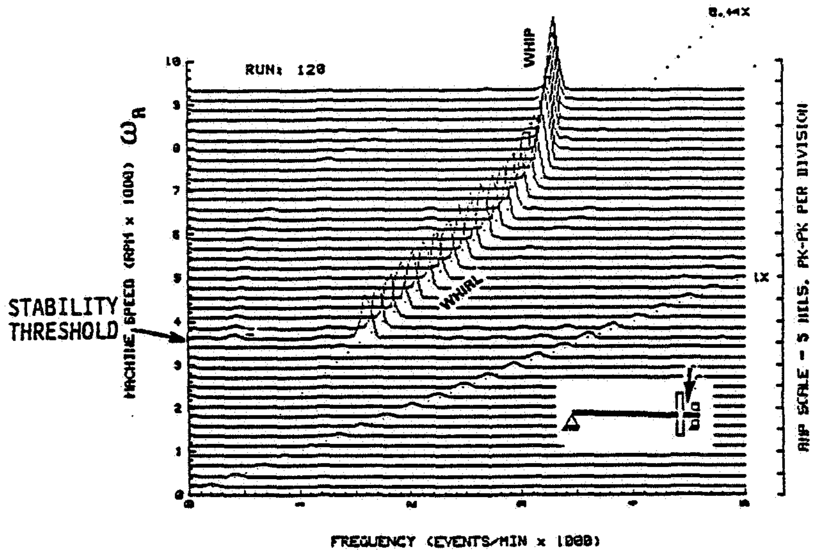

Figure 14. - Cascade spectrum of main rotor runup vertical vibration response measured at bearing position. Disk located next to oil bearing.

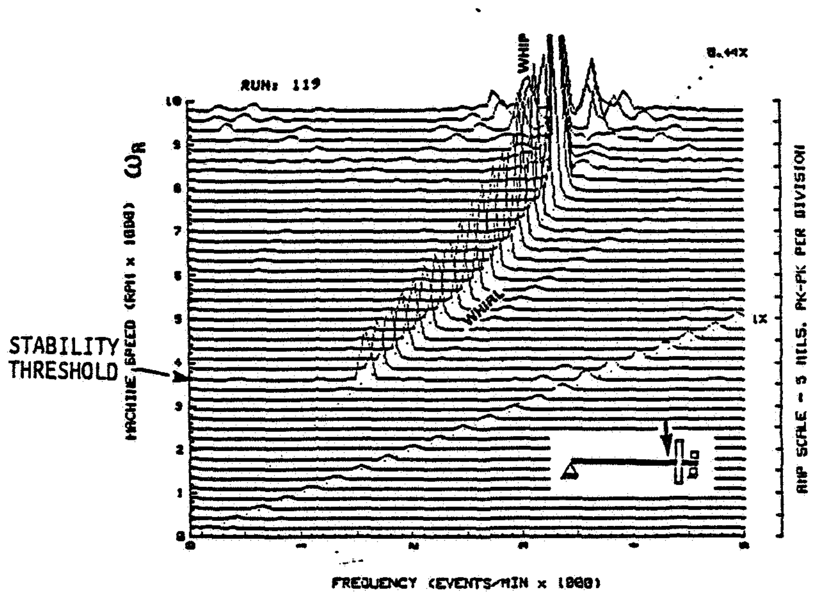

Figure 15. - Cascade spectrum of main rotor runup vertical vibration response measured at disk position. Disk located next to oil bearing. Compare stability threshold versus disk position of figures 10, 12, and 14.