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CRACKED ROTOR DEMONSTRATION

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Rotating elements in turbomachinery are exposed to a number of concurrent forcing functions. These forces may result in large displacements and vibrations of the rotor. If the forces are periodic and very high, the rotor will experience high induced stress levels with a large number of cycles. Any combination of high stress/low number of cycles or low stress/high number cycles may cause a fatigue failure within the rotor, initiated by a crack in the rotor at a site of the highest stress level. Typically, this occurs in areas such as coupling keyways or other shaft lateral locations experiencing stress concentrations.

The onset of a crack in the rotor system introduces an immediate asymmetry in the rotor geometry. This asymmetry modifies the stiffness properties of the rotor. The stiffness in the plane of the crack is much softer than the axis perpendicular to the crack. If the rotor operates in the horizontal plane, a unique forcing function occurs. The force of gravity acts perpendicular downward on the rotor. Each time the crack (soft axis) is exposed to this force of gravity, the rotor will deflect some additional amount. For a singular crack site on the rotor, the soft axis will be exposed to gravity forces twice for each revolution of the rotor. This introduces a vibration component which has a frequency value of twice (2X) rotor speed in the rotor response. It can be measured with the use of proximity transducers and quantified with the help of an oscilloscope observing shaft centerline motion and/or a spectrum analyzer.

If this malfunction is observed over some RPM range of operation, a secondary effect can manifest. Since the rotor is experiencing a strong 2X vibration component, when the rotor speed is exactly one half the frequency of a system resonance, that resonance will be excited. Amplitudes of the 2X component will increase, inducing further stresses and ultimately crack propagation. Repeated operation in these areas will cause the rotor to ultimately fracture. This transient behavior can best be observed with oscilloscope, spectrum cascade, and 2X POLAR PLOTS. For the rotor operation speed exceeding 1/2 first balance resonance, each start-up and shutdown, the machine will cuase a transient high vibration level.

OBJECTIVE

The purpose of this demonstration is to observe the behavior of a rotor with a single crack. This will be presented in oscilloscope orbits, 2X POLAR PLOTS, and spectrum cascade diagrams. Crack detection must be observed in all three formats and monitored over a period of time or start-ups. The change in the 2X behavior pattern provides an early warning that a crack potentially exists and that it is likely propagating toward total rotor fracture.

ROTOR SYSTEM

The demonstration rotor system (FIG. 1) contains the following:

A) Variable speed drive motor with speed controller
B) Flexible Coupling
C) Three bronze oilite bearings
D) Two mass disks located between bearings 1 & 2 and 2 & 3

The rotor system is operated over a speed range from 0 - 5000 RPM. This range permits excitation of two balance resonances and two resonances of the from the 2X vibration component. The rotor contains a radial crack of approximately 25% shaft penetration. The crack is located between bearings 2 & 3. Speed is controlled with a special speed control module which determines maximum speed and rate of acceleration. During the start-up, the oscilloscope and spectrum analyzer are the primary instruments used for visual observation. The oscilloscope presentation will indicate a large internal loop on the orbit when the 2X vibration excites the balance resonance. The spectrum display will show the 1X and 2X components over the entire operating range. The dynamic motion data will be processed through the HP computer with ADRE software for 2X POLAR plots and spectrum cascade diagrams (FIG.'s 2, 3, & 4).

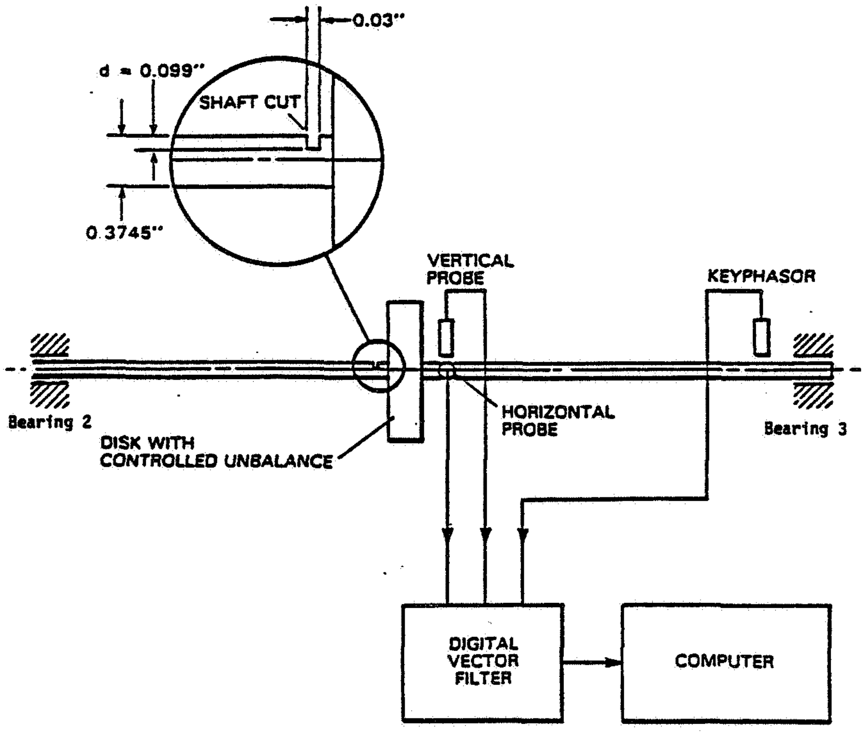

Figure 1.- Rotor system with "cracked" shaft simulated by saw cut.

INSTRUMENTATION

The system behavior is captured with proximity transducers located between bearing 1 & 2 and 2 & 3. The output of these transducers can be observed on the oscilloscope for shaft centerline motion studies. In addition, a DVF2 and spectrum analyzer are connected directly to an HP9836 computer operating on ADRE software. The DVF2 is configured with its internal tracking filter locked in to the 2X vibration component. This permits presentation of 2X POLAR PLOTS with the use of ADRE software. The spectrum analyzer and ADRE software permits presentation of spectrum cascade plots over the operating speed range. The 2X polar plots (FIG. 3) indicates the resonance response of the system due to the forcing function of 2X dynamic motion behavior. The spectrum cascade plot (FIG. 4) indicates the response of the 1X and 2X vibration over the entire operating speed range.

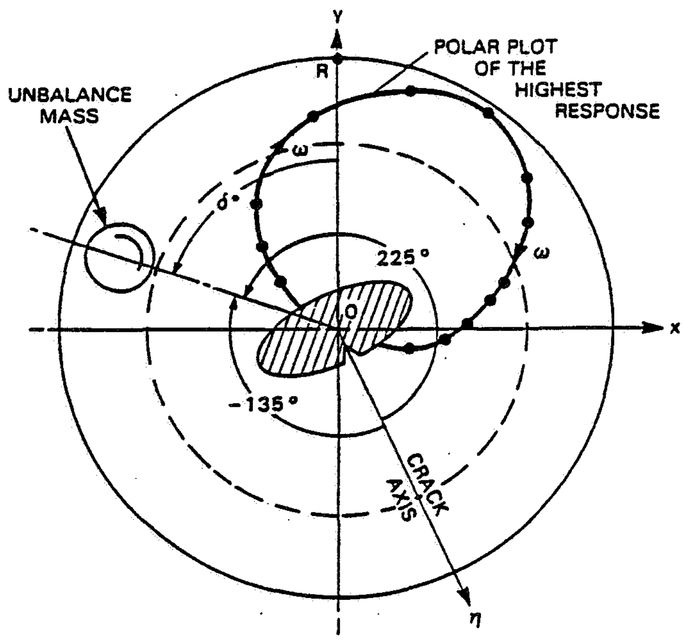

Figure 2.- 1X polar plot of cracked rotor response.

SUMMARY

Observing cracked rotor behavior in these three plot formats provides early warning of cracked rotor condition. Monitoring this behavior over a period of time provides insight toward rate of propagation of a crack and will prevent catastrophic rotor fracture. The 1X and 2X components must be monitored as vectors i.e. AMPLITUDE & PHASE have to be acquired at each rotative speed. Any change in behavior must be quantified as vectors. These vectors can be plotted within a POLAR diagram and a range of "normal" behavior established. Significant vectoral deviation from the acceptable range of values provides warning of cracked rotor activity.

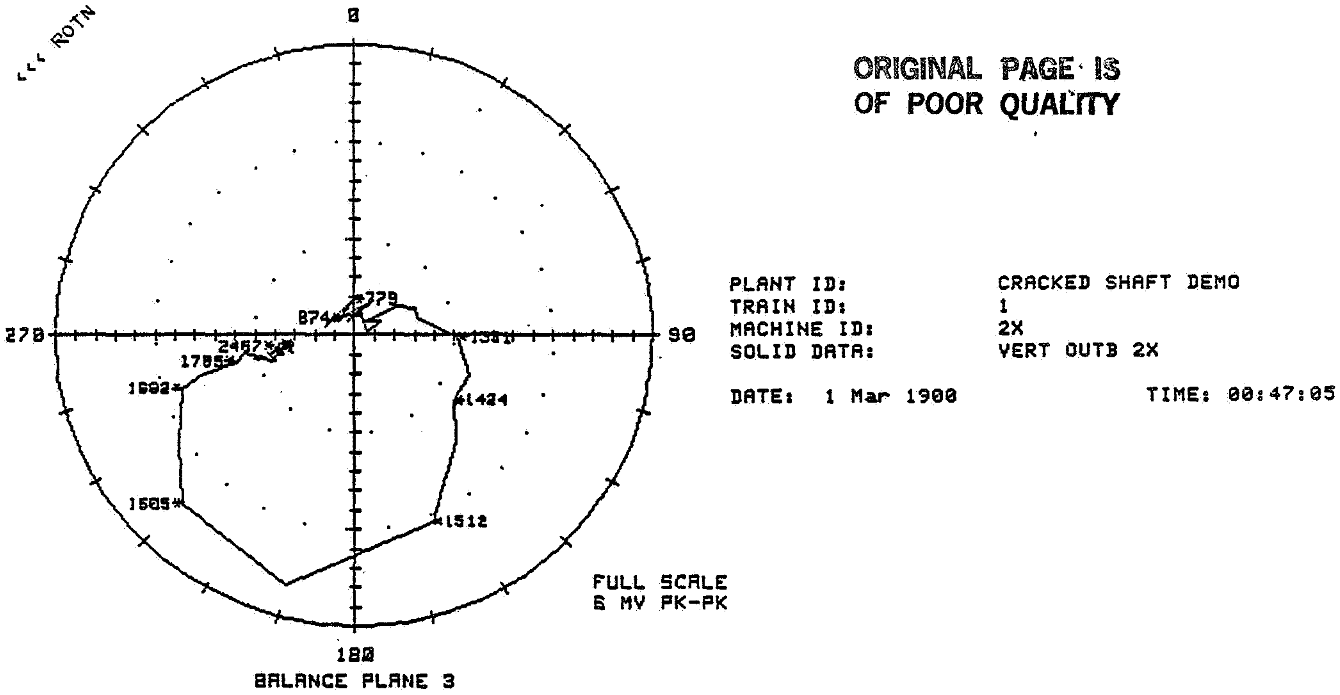

Figure 3.- 2X polar plot of cracked rotor response.

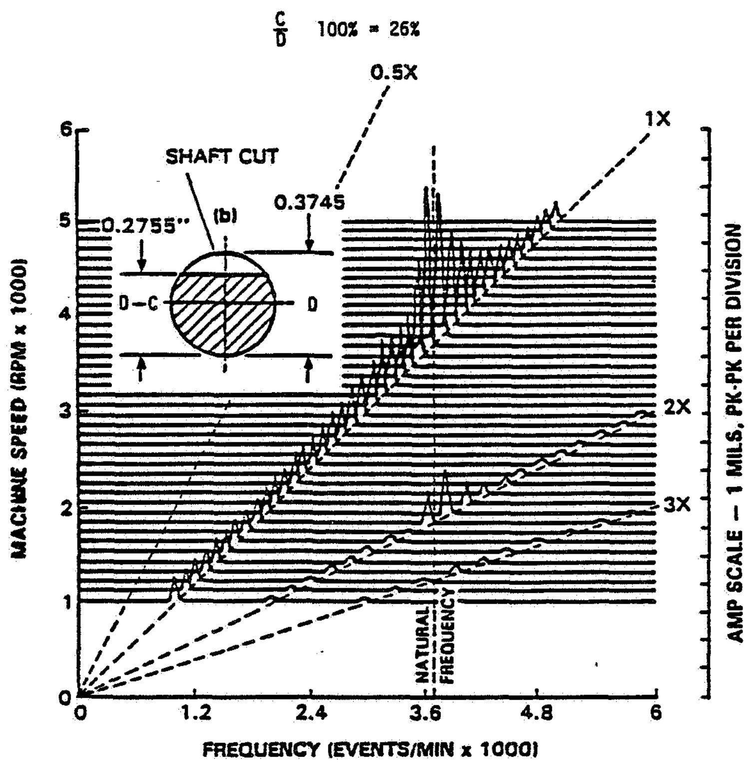

Figure 4.- Spectrum cascade diagram of cracked rotor response.