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Shaft crack detection on centrifugal pumps by vibration analysis

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ABSTRACT: A prospective method for detecting fatigue cracks in rotating shafts by vibration analysis is proposed as an alternative to presently used methods, wich are ineffective. By normalizing the actual vibration levels with respect to one reference signature of the shaft system, the crack evolution may be revealed and a threshold alarm level can be established.

EXISTING ACCEPTANCE CRITERIA AND METHODS

The detection of fatigue cracks in rotating shafts by non-destructive inspection methods has been a classical problem in view of its irregular shape and position. This is particularly aggravated in the case of contaminated systems because of the occupational risks to the operators.

Incidence of cracks in shafts of primary circuits has been documented over the past decade, e.g. (Yoon 1987, Kowal 1989, EPRI NP6337 1989, Sunder 1989, Wach 1991). The effectiveness of existing vibration level acceptance criteria, e.g. (ISO 2372), or of methods to quantify the vibration levels, e.g. (Berry 1990), is being questioned for the specific case of fatigue cracks in view of their peculiar vibration signatures.

That is because depending upon the sensor position in the equipment under analysis, a crack growth may be associated to an actual reduction in one or more harmonic amplitude and not by an increase, as it would be intuitively expected (Serra 1995).

PROSPECTIVE METHOD FOR DETECTION

The frequency spectrum of one given shaft without any discontinuities may be affected by the specific configuration of the mechanical system into which it is inserted, e.g. as a function of mass and rigidity. Therefore, a prospective method needs to incorporate the initial frequency spectrum of that particular state on system being monitored. It should also be suitable for conversion into an adequate computer software package. Then, the indication of formation or evolution of a discontinuity or group of discontinuities would be derived from departures in the reference frequency spectrum.

If the series of harmonic amplitudes of the reference spectrum is designated by $A_{R,f}, A_{R,2f}, A_{R,3f} \ldots$ whereby indices f, 2f and 3f indicate the fundamental, second harmonic and third harmonic and

if the series of harmonic amplitudes for a given crack size is $A_{i,f}, A_{i,2f}, A_{i,3f} \ldots$ where i designates a given crack size or discontinuity, then

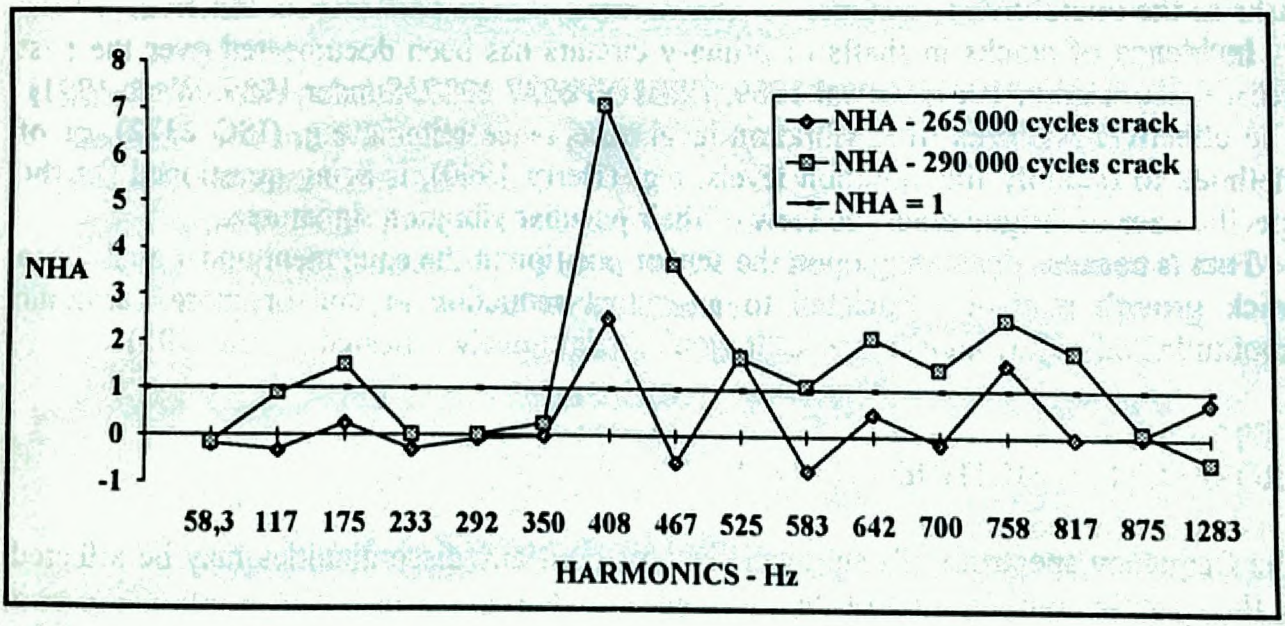
the series of Normalised Harmonic Amplitudes (NHA) would be

$$\frac{A_{i,f}}{A_{R,f}} - 1, \frac{A_{i,2f}}{A_{R,2f}} - 1, \frac{A_{i,3f}}{A_{R,3f}} - 1, \ldots$$

SIGNAL ANALYSIS

Figure 1 shows the NHA plots for three stages of evolution of a fatigue crack in a shaft, i.e. no crack, one crack corresponding to 265000 cycles which took up about 50% of the resisting area and another crack corresponding to 290000 cycles which took up to 80% of the resisting area. The values shown in the figure correspond to the tabulated NHA values for each harmonic up to the 22nd harmonic. It should be remembered that the NHA=0 value corresponds to the reference values of the shaft without any discontinuities.

FIGURE 1: Plots of NHA values for one shaft in which a fatigue crack was grown experimentally in torsion with 265000 cycles and then subsequently to a total 290000 cycles.



For all of the several accelerometer positions studied, including the least favourable ones, the presence of a discontinuity always implied in a change of at least one NHA for the first 13 harmonics with magnitude equal or greater than 1. This is the single most important systematic parameter that can be defined and is suggested as the criteria for use in the detection of possible cracks.

The change in NHA as a result of the presence of the crack or evolution in its size may not necessarily be positive, as shown in the figure. In fact, an actual decrease (i.e. a negative NHA) may be the indication of the crack presence. This behaviour cannot be fully explained in the present in simple terms.

It becomes evident that methods based on global levels of the very few first harmonics are inadequate for the detection of such cracks. Equally, the use of global levels or sums within specific bands may also not be adequate at all because an actual reduction in vibration level would normally be considered to be beneficial and not be indicative of such a detrimental discontinuity.

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