BWR INSTRUMENT TUBE VIBRATIONS

Quite recently the problem of flow-excited vibration of instrument tubes causing fuel channel box wear has led to power de-rates and shutdowns in a class of boiling water reactors (BWRs) (Ref. 1). It is the purpose here to point out how analysis of neutron noise from detectors in these tubes provides a means of assisting in this problem by use of a disciplined approach—both while the problem exists and during subsequent monitoring after a fix.

The root-mean-square (rms) motion amplitude can be determined from the measured normalized cross-power spectral density (NCPSD), which is the CPSD from signals divided by their means, after subtracting out nonmotional background neutron noise. For the usual mechanical resonance, such as at ~3 Hz for the instrument tubes, the width Δf 3 dB down from the peak is used in the one-dimensional s-direction relation rather similar to that used for core barrel motion measurement in pressurized water reactors (PWRs) (Ref. 2):

$$\overline{\text{rms motional amplitude}} = \frac{A}{\sqrt{2}} = \frac{(\pi\,\text{NCPSD}\,\Delta f/2)^{1/2}}{\overline{d\ln\phi(s)/ds}} \quad , \quad (1)$$

where the average bars designate geometric means for the positions of the two vertically spaced in-phase detectors. Calibration, consisting of determining the fractional flux gradient denominator, can be by a variety of methods previously described[2] for PWRs, with neutron transport calculation of $\phi(s)$ being one of the most straightforward.

It is known that motion in a curved flux leads to harmonics, and indeed this is the case for vibrating BWR detectors. It is suggested here that one utilize information present in the "tonal quality" of the noise, specifically its first harmonic to fundamental amplitude ratio. At the detector location s_0, the Taylor series can be used in the product of curved local ϕ and linear global Φ flux functions,

$$\phi(s) = [\phi_0 + \phi_0'(s - s_0) + \phi_0''(s - s_0)^2/2]$$
$$\times [1 + (s - s_0)d\ln\Phi/ds] \quad . \quad (2)$$

Substitution of sinusoidal detector motion, $s - s_0 = A \sin 2\pi ft$, into Eq. (2) leads to the resulting harmonic ration in detector current

$$\frac{\text{the amplitude of } 2f}{\text{the amplitude of } f}$$

$$= \frac{A\phi''}{4\phi'} [1 + \text{terms of order } (d\ln\Phi/ds)/(d\ln\phi/ds)]$$

$$\cong \frac{A}{4 \times \text{detector distance from water gap center}} \quad . \quad (3)$$

The last approximation makes use of the local ϕ' being zero at the nearby center of a water gap and ignores the global gradient correction.

As one application, if A is unknown, a single value can be determined to satisfy Eqs. (1) and (3) simultaneously when having a measured noise spectrum and harmonic ratio but no knowledge of precise detector location in a rapidly changing $d\ln\phi/ds$ region near a water gap center. More generally, Eqs. (2) and (3) can be used to assist in understanding and utilizing data from any type of flux gradient motion where curvature is important.

A detector current bias from its mean i_0 also results from deriving Eq. (3),

$$\frac{\delta i}{i_0} = \text{fractional bias} = \frac{A^2\phi_0''}{4\phi_0'}$$

$$\times [1 + \text{term of order } (d\ln\Phi/ds)/(d\ln\phi/ds)] \quad . \quad (4)$$

With the amplitude having a time dependence $A(t)$, the physical significance here is a time varying offset in the dc chamber current.

A straightforward extension of the above to describe two-dimensional lateral motion leads to the results:

1. Using components of the flux gradient and assumptions about properties of the motion, bounds can be set on the rms by Eq. (1). However, since no upper bound can be set on the motion in the direction perpendicular to the flux gradient vector without assumptions being made, variety in experimental conditions that change the vector could be exploited.

2. When anisotrophy is present in the instrument tube's fundamental frequencies in the two transverse directions, the sums and differences of these frequencies also appear in the neutron noise because of the two-dimensional curvature, $\partial^2\phi/\partial x\partial y$.

Finally, a suggested experimental method for a better observation of the tube's bending modes is based on reversing the customary roles of height z and time t in cross-correlation and cross-spectra analyses. Instead of correlating time recordings, $\phi(t)$, at two heights, one correlates spatial (from all detectors in a tube) "snapshots," $\phi(z)$, at two times.

J. A. Thie

Consultant
P.O. Box 517
Barrington, Illinois 60010

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