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MEASUREMENT OF CORE COOLANT FLOW VELOCITIES IN PWRs USING TEMPERATURE - NEUTRON NOISE CROSS CORRELATION*

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A linear relationship of phase angle versus frequency has been observed when core exit thermocouple temperature noise is cross correlated with in-core or ex-core neutron detector noise in pressurized water reactors (PWRs).[1,2] This linear behavior of the phase angle indicates a pure time delay process between the neutron flux and the core exit temperature noise.

To study the relationship between the time delay inferred from this phase angle and core coolant flow velocities, noise measurements were performed at the Loss of Fluid Test Facility (LOFT) reactor and at a commercial PWR. In-core, self-powered neutron detector (SPND) noise at LOFT and ex-core ionization chamber noise at the commercial PWR were cross correlated with core exit temperature noise. Time delays were inferred from the slope of the phase angle versus frequency plots over the frequency range from 0.05 to 2.0 Hz, as shown in Figs. 1 and 2 for LOFT and the commercial PWR respectively.

The time delay inferred from the phase versus frequency plots and the 119.4-cm (47 in.) distance from the SPND to the core exit thermocouple were used to experimentally determine coolant velocities for two different flow rates at LOFT. These experimentally determined values were compared with velocities calculated from LOFT flow venturi measurements. The results are summarized in Table 1. The excellent agreement between the velocities inferred from noise analysis and the calculated velocities indicates that the neutron-flux to temperature-noise phase is an accurate indicator of coolant flow velocity in the core.

In a similar manner, time delays and velocities were inferred from the phase between an ex-core ionization chamber and the core exit thermocouple temperature noise. The inferred coolant flow velocities were lower than the calculated values by 37% for an assumed distance of 304.8 cm (120 in.) between the ionization chamber midplane and the thermocouple location. A similar discrepancy between velocities inferred from ex-core neutron noise and core-exit temperature noise has also been observed in other PWRs.[1]

A multinodal model of heat transfer dynamics was developed to remove the effect of the thermocouple time response on the inferred coolant velocity. A thermocouple time constant of 0.677 s was first obtained from a 10th-order autoregressive (AR) model fit to the commercial PWR temperature noise data by techniques described in ref. 3. This time constant was used in the dynamic heat transfer model to remove the thermocouple time response effect on the phase between the ex-core ionization chamber and the core exit thermocouple noise. The resulting inferred velocity was ~9% below the calculated coolant velocity.

A similar procedure was followed with the LOFT data, resulting in a negligible change in the inferred velocities. In this case, the thermocouple time constant was 0.241 s.

We concluded from these results that the large discrepancy between the calculated and inferred velocities obtained from the commercial PWR data was due to the relatively slow thermocouple time response.

In summary:

1. The linear phase relationship of neutron flux to temperature noise is a direct function of the coolant flow velocity in the core.

2. Slow response times of the thermocouple temperature sensor will result in inferred velocities lower than actual flow velocities.

Table I. LOFT velocities inferred from the phase between neutron and temperature noise compared to measured flow velocities

Flow Rate (%)	Coolant Flow Velocities* [m/s (ft/s)]	
	Inferred	Measured
100	3.7 (12.2)	3.8 (12.6)
65	2.7 (8.7)	2.6 (8.4)

*Based on a separation of 119.4 cm (47 in.) between the neutron detector and core exit thermocouple.

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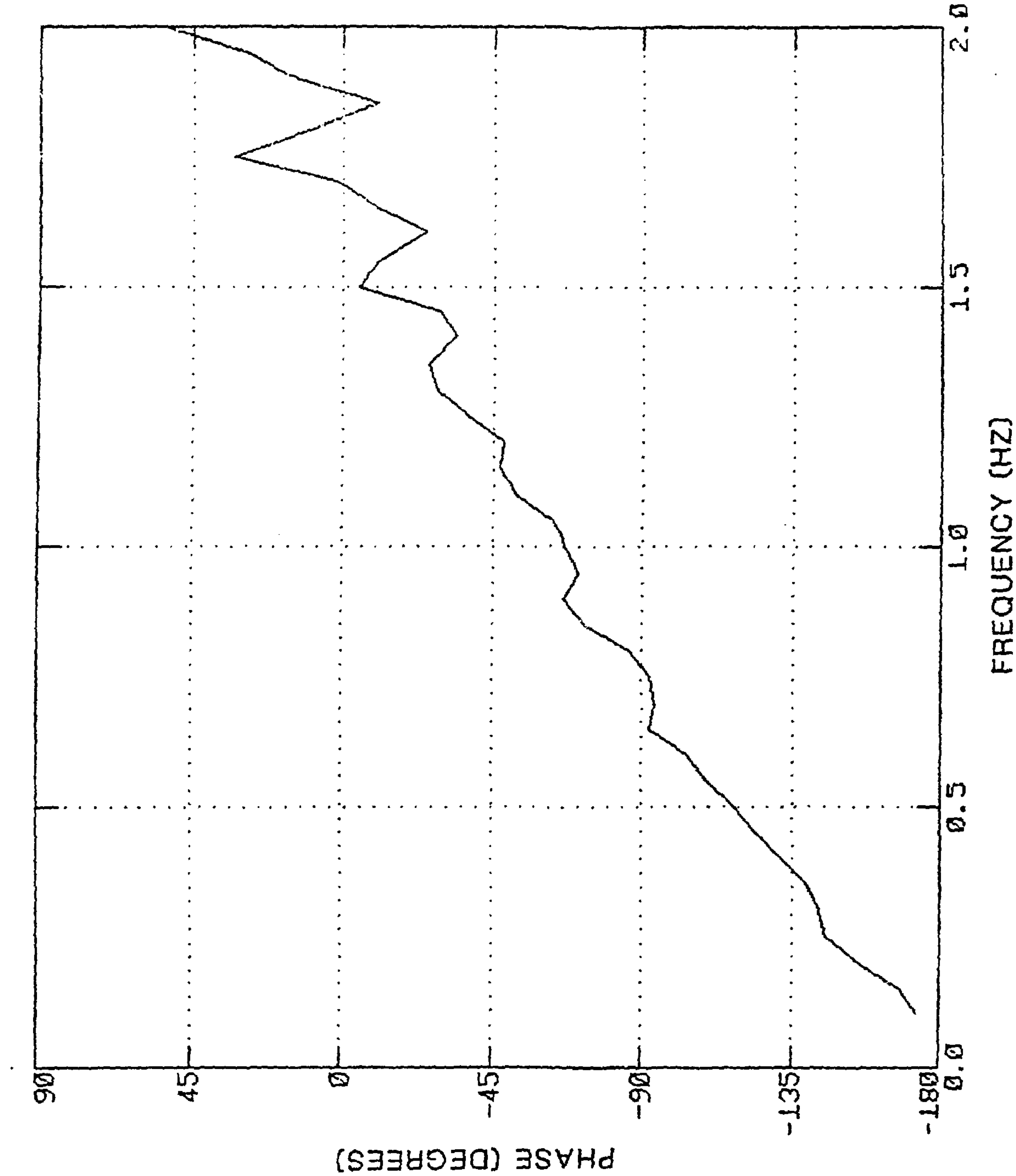

Fig. 1. Linear phase versus frequency between core exit temperature and in-core neutron noise at LOFT.

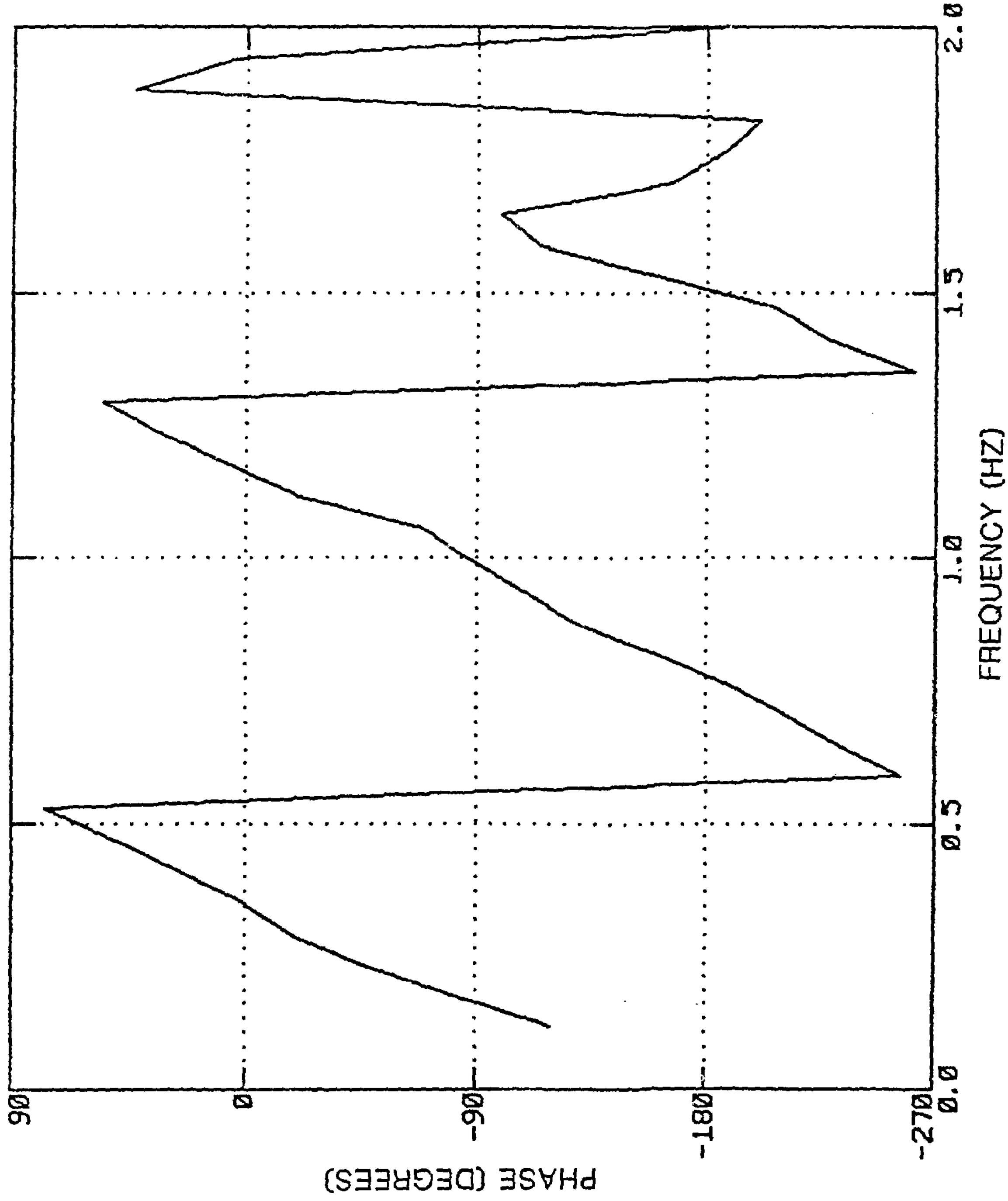

Fig. 2. Linear phase versus frequency between core exit temperature and ex-core neutron noise at a commercial PWR.

List of Figures

List of Tables