REACTOR NOISE MEASUREMENTS IN THE SAFETY AND REGULATING SYSTEMS OF CANDU STATIONS

O. GLÖCKLER

Station Performance Monitoring Section, Technical Services Department
Inspection Services Division, Ontario Power Generation Nuclear
700 University Avenue, H15, Toronto, Ontario M5G 1X6, Canada
oszvald.glockler@opg.com

ABSTRACT

Reactor noise measurements of safety and regulating system instrumentation are performed in the CANDU nuclear power stations of Ontario Power Generation (OPG) and Bruce Power. Station signals included in the noise measurements are in-core flux detectors (ICFD), ion chambers (I/C), flow transmitters, pressure transmitters, and resistance temperature detectors (RTD). Their frequency dependent noise signatures are regularly measured during steady-state operation, and are used for parameter estimation and anomaly detection.

The specific applications include the following areas:

- Flux noise measurements to detect and characterize (a) anomalies of in-core flux detectors, ion chambers and their electronics, (b) mechanical vibration of fuel channels and in-core detector tubes induced by coolant/moderator flow.
- Pressure and flow noise measurements to estimate the in-situ response times of flow/pressure transmitters and their sensing lines installed in the reactor's coolant loops.
- Temperature noise measurements to estimate the in-situ response times of thermal-well or strap-on type RTDs installed in the reactor's coolant and moderator loops.

KEYWORDS

Reactor noise analysis, in-core flux detectors, flow transmitters, response time, fuel channel vibration, detector tube vibration, detector fault monitoring.

1. INTRODUCTION

Noise measurements are carried out at full-power operation before scheduled outages or maintenance work. Several multi-channel portable data acquisition systems are installed temporarily throughout the station and their noise data recordings are synchronized via the headset communication system of the station. The information gained on the dynamics and health of reactor components and their instrumentation is utilized in the following areas: condition-based maintenance, commissioning new installations, licensing requirements, trouble-shooting abnormal performance, and periodic follow-up measurements required by the regulator, CNSC (Canadian Nuclear Safety Commission).

2. IN-CORE FLUX DETECTOR NOISE MEASUREMENTS

ICFD noise measurements are performed regularly. The measured noise signatures are compared to baselines, and the sources of noise components are identified. The most apparent noise source is the vibration of core components, generating flux fluctuations that can be detected in the noise signatures of ICFDs. Other noise sources include moderator temperature noise and the level fluctuations of light water liquid control zones. The following two vibration-related areas are monitored regularly:

- The vibrations of ICFD tubes, induced by the moderator flow, cause strong peaks in the auto power spectral density (APSD) and coherence functions of ICFD noise signals in the frequency range of 2-5 Hz. Noise signals of detectors located in the same vibrating detector tube have high coherence and zero phase difference at the fundamental frequency of tube vibration. Depending on the locations of the ICFDs inside the guide tube, the detectors may have zero or 180 degree phase differences at the frequencies of the higher harmonics, with high coherence. The wide and periodic peaks seen in Figure 1 are suspected to be caused by detector impacting on the surrounding fuel channels.
- Routinely performed ICFD noise measurements also detected the flow-induced vibration of fuel channels at frequencies around 4.5-7.5 Hz and at 15 Hz. In-core flux detectors lined up perpendicularly along the same group of horizontal fuel channels showed common vibration peaks with high coherence. At these frequencies, the phase difference between the ICFD noise signals was either 0 or 180 degree, depending on whether the detectors were on the same side, or different sides of the vibrating fuel channel(s). In many cases, multiple vibration peaks at slightly different frequencies were seen in the coherence functions, indicating that there were several vibrating fuel channels among the common neighboring channels of the two in-core flux detectors. Such a case is shown in Figure 2.

3. ESTIMATION OF FLOW TRANSMITTER TRANSFER FUNCTION BY PRESSURE SENSORS

The transfer function of flow transmitters can be measured in-situ (without removing them from the process) by temporarily installing high-frequency, high-sensitivity pressure sensors at the end of the high-pressure side and the low-pressure side sensing lines (at transmitter input). These pressure sensors record the natural pressure fluctuations in the sensing lines, which are the differential pressure input fluctuations to the transmitter. Signal fluctuations of the pressure sensors are recorded along with the signal fluctuations of the transmitter output. The transmitter's transfer function and the response time of the sensing lines are calculated from the APSD and coherence functions of the measured input and output noise signals, as described in the Appendix.

Using the above pressure sensor noise technique, the dynamic transfer functions and the response times of transmitters were estimated in-situ by noise measurements in the following applications:

- In Darlington Unit 3, the transfer functions of Rosemount, Gould, and Bailey flow transmitter were estimated, along with the assessment of their effect on sensing line resonances and response times. The flow noise measurements were performed at various sensing line configurations at full flow and full power (Glöckler 1998a, Koslowsky *et al* 1998). The measured APSDs and transfer functions of the transmitters are shown in Figures 3 and 4.

- In Bruce-B Unit 6, all reactor outlet header pressure, coolant inlet flow and reactor core differential pressure transmitters and their sensing lines were measured (Glöckler 2000a). The transfer function estimation was part of a "Safe Operating Envelope" project on the dynamic response of shutdown system trip parameters.
- In Pickering-B Unit 6, abnormally long response times of sensing lines were investigated and the in-situ transfer functions of flow transmitters and their sensing lines were estimated (Glöckler 2001).
- In Darlington Unit 3, the transfer functions of new Bailey flow transmitters were estimated after installation for the purposes of validating a response time tester method (bench test) to be used in future installations (Hinds and Glöckler, 2002)

4. NOISE MEASUREMENTS OF FLOW TRANSMITTER OUTPUT SIGNALS

Transmitter output noise measurements, without the measurements of input pressure noise signals, were also successfully used in the estimation of in-situ response times. The estimation is based on the APSD function of the flow transmitter output fluctuations: a functional form with unknown time constants is fitted to the measured APSD function by a non-linear iterative curve-fit algorithm (Hinds *et al* 1998). These flow noise measurements served as acceptance tests for placing the transmitters back into service in the safety system. The technique was used in the following applications:

- In Darlington, the response times of all safety system flow transmitters (Rosemount and Gould types) were measured in-situ via APSD noise analysis, while the reactor units were at 50% of full power. As a prerequisite to return to high power, the response times of all flow transmitters in all four Darlington units were adjusted in noise measurements to a certain range, over a two-month period (Glöckler 1998b)
- Recently, all Gould flow transmitters were replaced by Bailey transmitters in Darlington Unit 3. The response times of the new transmitters were set to 400 msec in bench tests. The post-installation acceptance tests of transmitter and sensing line response times were based on the measurements of the transmitter output noise APSDs (Glöckler 2002). A typical APSD curve-fit result is shown on Figure 5.
- The same estimation technique was applied in the installation of new Rosemount transmitters in certain reactor inlet coolant flow loops in Pickering-B units 6, 7 and 8. New flow transmitters with increased response time were installed to reduce the effect of frequent "flow dips" causing spurious trips in certain flow channels. The response times of the transmitters were set to 500 msec by the manufacturer. The post-installation response times of the transmitters and their sensing lines were estimated in noise measurements at full-flow full-power conditions (Glöckler 1999).

5. RTD TEMPERATURE NOISE MEASUREMENTS

Noise analysis also provides a non-intrusive method for monitoring and estimating the dynamic response of RTDs installed in the process, and for isolating the cause of RTD signals anomalies, such as slow response and signal spikes induced by electrical effects and ground fault detectors. The noise-based technique was used in the following applications:

- A comprehensive measurement of moderator RTD noise signals were carried out at various power levels in Bruce-B Unit 8. Signal fluctuations from the following twelve RTDs were recorded simultaneously: (a) six RTDs located at core outlet, and (b) three RTDs in each of the two moderator loops located at the outlet of the two heat exchangers (inlet to the core). The response times of both thermal-well and strap-on type RTDs were estimated from the APSD functions of the RTD noise signals by curve-fit techniques. Typical APSD functions are shown in Figure 6. The transit times of the moderator flow between RTDs were also estimated from the linear phase measured between RTD noise signals (Glöckler, 2000b).
- The response times of RTDs located at fuel channel exits were estimated at full power in pre-outage noise measurements in Pickering-B Units 6 and 8 in 2001. The purpose of the noise measurement was to estimate the response times of RTDs and to identify RTDs with abnormal response.

6. CONCLUSION

In the past ten years, noise analysis became a routinely used inspection tool for system diagnostics and response time estimation. High-performance data acquisition systems were developed and station procedures for multi-location synchronized noise measurements were established. Most of the noise measurements are required by station commitments or licensing requirements. Additional noise analysis applications are being developed as need for non-intrusive diagnostics at full power operation increases.

REFERENCES

Glöckler O. (1998a), *Statistics of Flow Noise in Loop DNGS 3-68334-FT3J, Measured with Various Line Length and Transmitter Types – Measurement Data Report*, NK38-REP-68334-985103-R00.

Glöckler O. (1998b), *DNGS Flow Transmitter Noise Analysis Report, Units 1-4 "As-Left", October 1997*, Report NK38-03610.02-985022/23/24/25-R00.

Glöckler O. (1999), *SDS1 Low Gross Flow Noise Monitoring and Flow Transmitter Replacement on Loops 8-63724 F3D and F2E in Pickering-B Unit 8*, Report NK30-REP-63724-10001-R00.

Glöckler O. (2000a), *Estimating the Response Times of SDS Pressure/Flow Transmitters and Their Sensing Lines via In-Situ At-Power Noise Measurements in Bruce-B Unit 6,* Report NK29-REP-63700-00001-R00.

Glöckler O. (2000b), *Estimating the Moderator Transit Times Between Moderator RTDs and Their Response Time via In-Situ At-Power Noise Measurements in Bruce-B Unit 8,* Report NK29-REP-63210-00001-R00.

Glöckler O. (2001), *Response Times of SDS1 LGF Loops FT-2D and FT-4D Measured In-Situ in Pickering-B Unit 6,* Report NK30-REP-63724-00001-R00.

Glöckler O. (2002), *Validation of the Response Times of Bailey Flow Transmitters Installed in SDS2 Darlington Unit 3,* Report NK38-REP-68334-10003-R00.

Hinds H.W. and Glockler O. (2002), *Validation of the Response Time Tester,* Report NK38-REP-68334-10004-R00.

Hinds H.W., Koslowsky V., Kumli P. (1998), *Validation of the Auto-Power-Spectral-Density Method of Determining the Response Time of Rosemount, Gould, and Bailey Flow Transmitters,* Report COG-98-323, AECL, Chalk River.

Koslowsky V., Hinds H.W., Glöckler O. (1998), *Effect of Instrument-Line Length on Differential Pressure Measurements*, Report CS-NAH-TN-33.

APPENDIX

In the frequency domain, it is assumed that the measured output noise of a differential pressure transmitter, $V_{OUT}(\omega)$ is composed of two terms:

(1) the measured differential pressure input noise, $V_{IN}(\omega)$ acting through the transmitter's complex transfer function, and

(2) an unknown noise component, $N_{OUT}(\omega)$ independent of the input noise.

$$V_{OUT}(\omega) = TRF_{IN,OUT}(\omega) \times V_{IN}(\omega) + N_{OUT}(\omega) \tag{1}$$

The magnitude of the transmitter's unknown transfer function is expressed as a function of three measured frequency dependent terms

$$\left|TRF_{IN,OUT}(\omega)\right|^2 = \frac{APSD_{OUT}(\omega)}{APSD_{IN}(\omega)} \times COH^2{}_{IN,OUT}(\omega) \tag{2}$$

where the functions of APSDs and COH have the usual meaning. The phase function of the complex transfer function is identical with the phase function of the CPSD function measured between the transmitter's input-output noise signals.

The following functional form was fitted to the measured transfer function in Eq.(2) using a non-linear iterative least-squares regression (χ^2 minimization) algorithm

$$TRF_{IN,OUT}(\omega) = \frac{(1+i\omega\tau_4)}{(1+i\omega\tau_1)(1+i\omega\tau_2)(1+2i\omega\varsigma\tau_3-\omega^2\tau_3^2)} \tag{3}$$

The fitted parameters are the time constants $\tau_1, \tau_2, \tau_3, \tau_4$, and damping factor ς associated with τ_3. These parameters uniquely determine the "ramp-equivalent" response time of the transmitter. It is defined as the time delay between input and output for a ramp input, after the output became parallel to the input (asymptotic case). The response time is calculated from the fitted parameters of the measured transfer function as

$$T_{ramp} = \tau_1 + \tau_2 + 2\varsigma\tau_3 - \tau_4 \tag{4}$$

The general functional form in Eq. (3) covers the transfer functions of all three types of flow transmitters used in CANDUs, Rosemount, Gould, and Bailey.

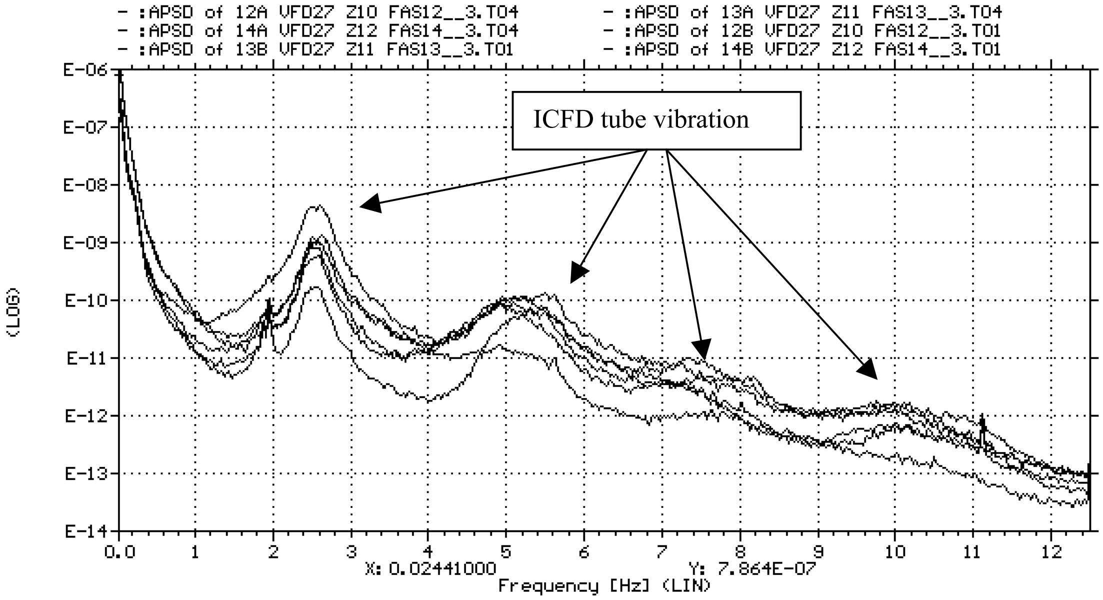


Fig. 1. APSD functions of six ICFD noise signals in vertical detector tube VFD27 measured in Darlington Unit 4

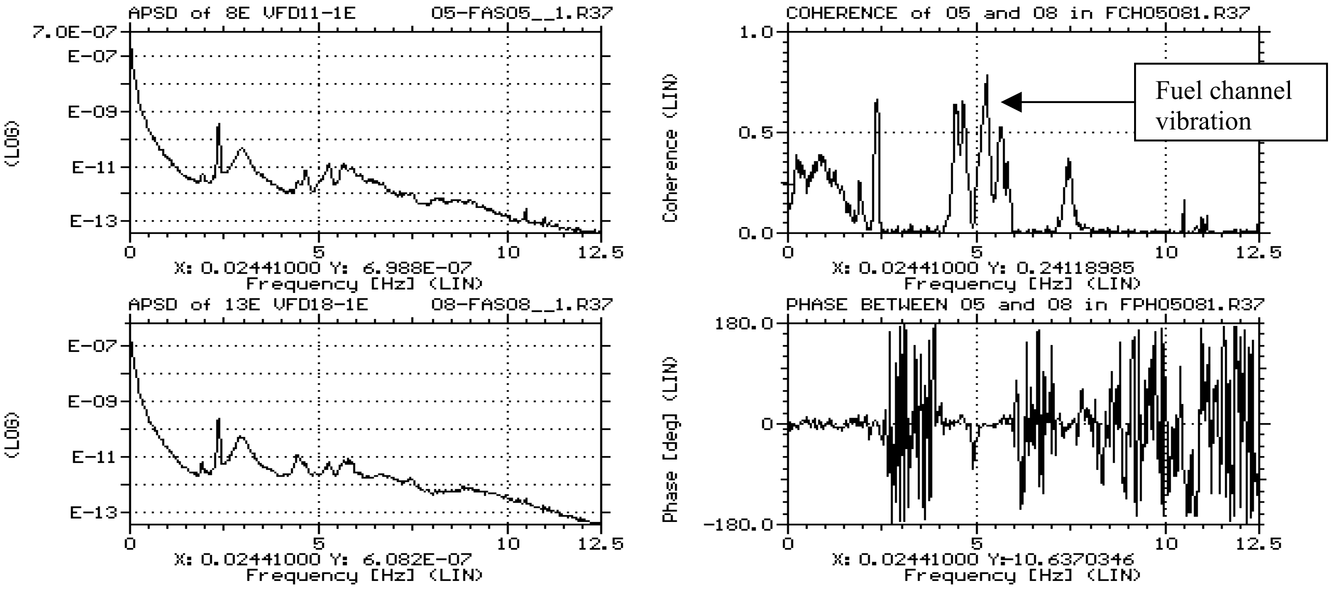


Fig. 2. APSD, coherence and phase functions of noise signals of two vertical ICFDs lined up along the same set of horizontal fuel channels in Darlington Unit 2

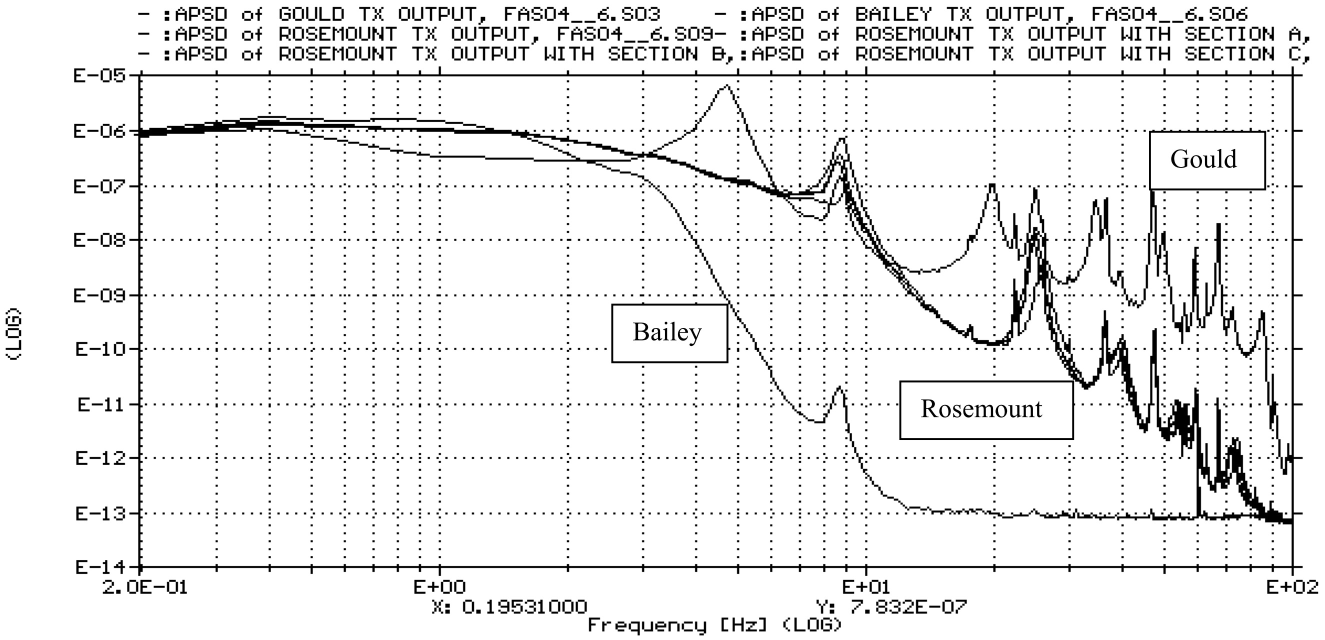


Fig. 3. Normalized APSD functions of flow noise signals from Rosemount, Gould, and Bailey flow transmitters installed on safety system flow loop FT-3J in Darlington Unit 3

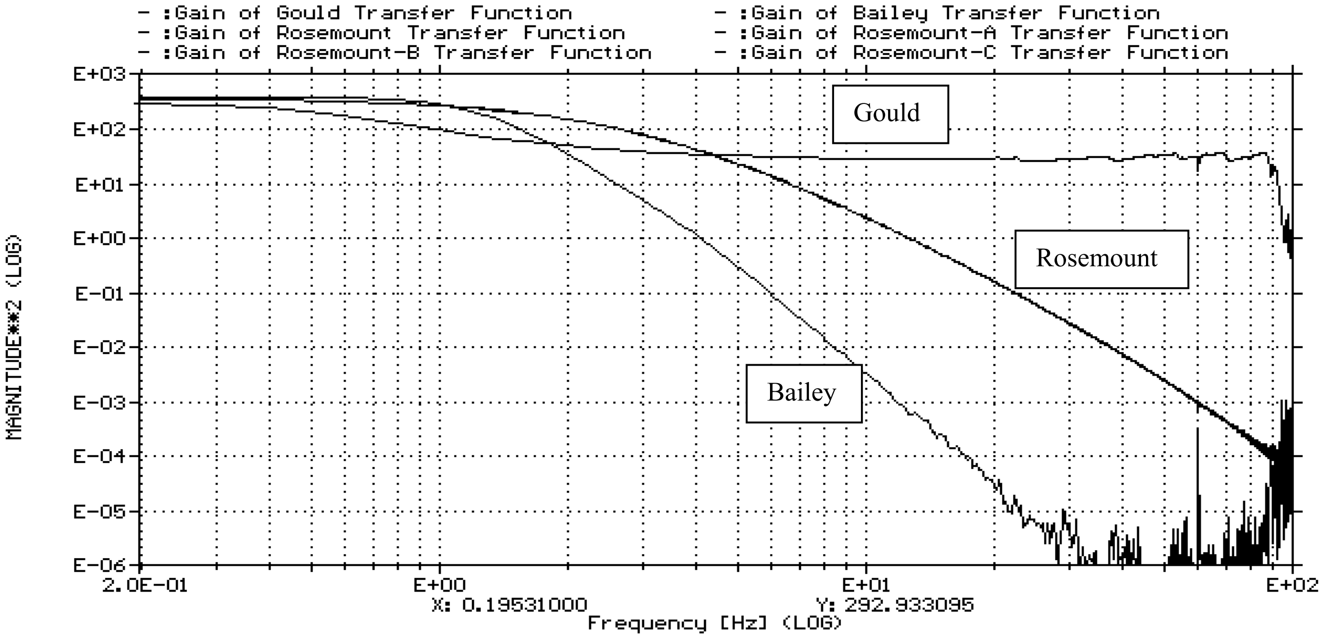
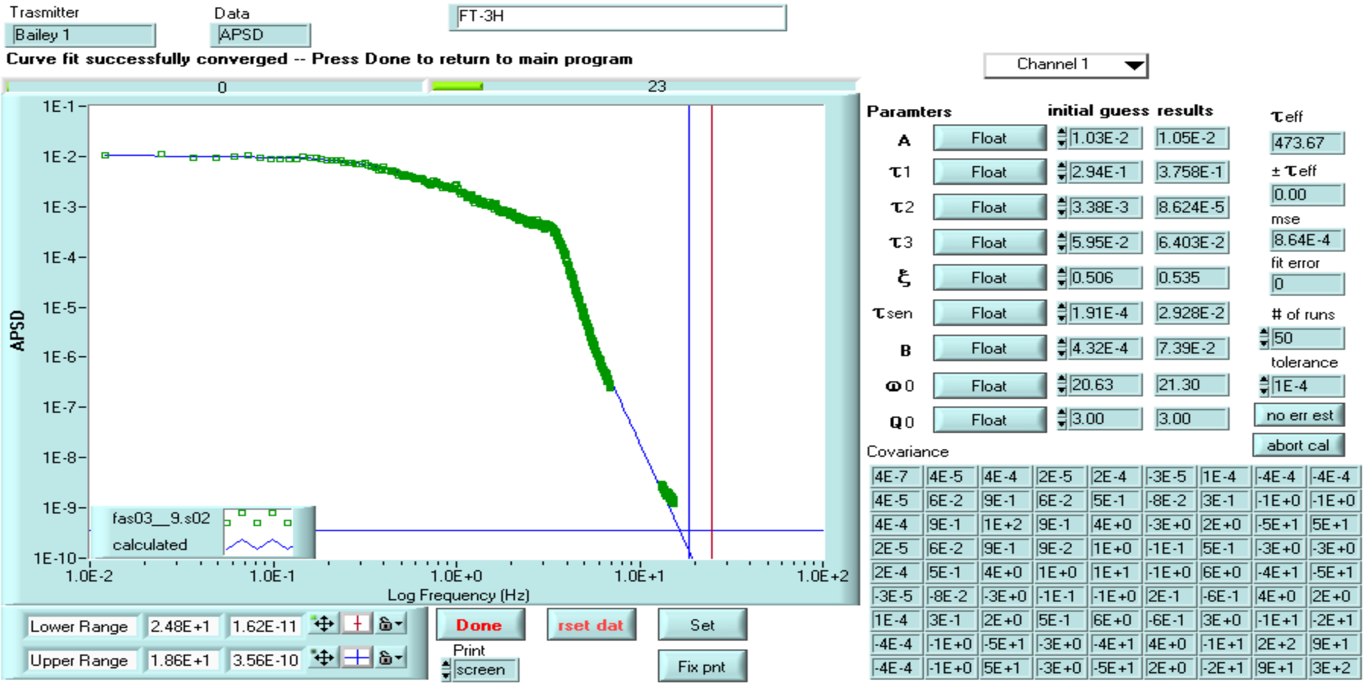


Fig. 4. Magnitude of the dynamic transfer functions of Rosemount, Gould, and Bailey flow transmitters derived from in-situ pressure sensor noise measurements in safety system flow loop FT-3J in Darlington Unit 3



Trasmitter: Bailey 1
Data: APSD
FT-3H

Curve fit successfully converged -- Press Done to return to main program

Lower Range	2.48E+1	1.62E-11
Upper Range	1.86E+1	3.56E-10

Print: screen

Paramters		initial guess	results
A	Float	1.03E-2	1.05E-2
τ1	Float	2.94E-1	3.758E-1
τ2	Float	3.38E-3	8.624E-5
τ3	Float	5.95E-2	6.403E-2
ξ	Float	0.506	0.535
τsen	Float	1.91E-4	2.928E-2
B	Float	4.32E-4	7.39E-2
ω0	Float	20.63	21.30
Q0	Float	3.00	3.00

τeff: 473.67
± τeff: 0.00
mse: 8.64E-4
fit error: 0
# of runs: 50
tolerance: 1E-4

Covariance

4E-7	4E-5	4E-4	2E-5	2E-4	-3E-5	1E-4	-4E-4	-4E-4
4E-5	6E-2	9E-1	6E-2	5E-1	-8E-2	3E-1	-1E+0	-1E+0
4E-4	9E-1	1E+2	9E-1	4E+0	-3E+0	2E+0	-5E+1	5E+1
2E-5	6E-2	9E-1	9E-2	1E+0	-1E-1	5E-1	-3E+0	-3E+0
2E-4	5E-1	4E+0	1E+0	1E+1	-1E+0	6E+0	-4E+1	-5E+1
-3E-5	-8E-2	-3E+0	-1E-1	-1E+0	2E-1	-6E-1	4E+0	2E+0
1E-4	3E-1	2E+0	5E-1	6E+0	-6E-1	3E+0	-1E+1	-2E+1
-4E-4	-1E+0	-5E+1	-3E+0	-4E+1	4E+0	-1E+1	2E+2	9E+1
-4E-4	-1E+0	5E+1	-3E+0	-5E+1	2E+0	-2E+1	9E+1	3E+2

Fig. 5. Example of the curve fit applied to the measured APSD function of safety system flow loop FT-3H in Darlington Unit 3. The ramp-equivalent response time of the flow loop was estimated in the range of 430 msec to 475 msec

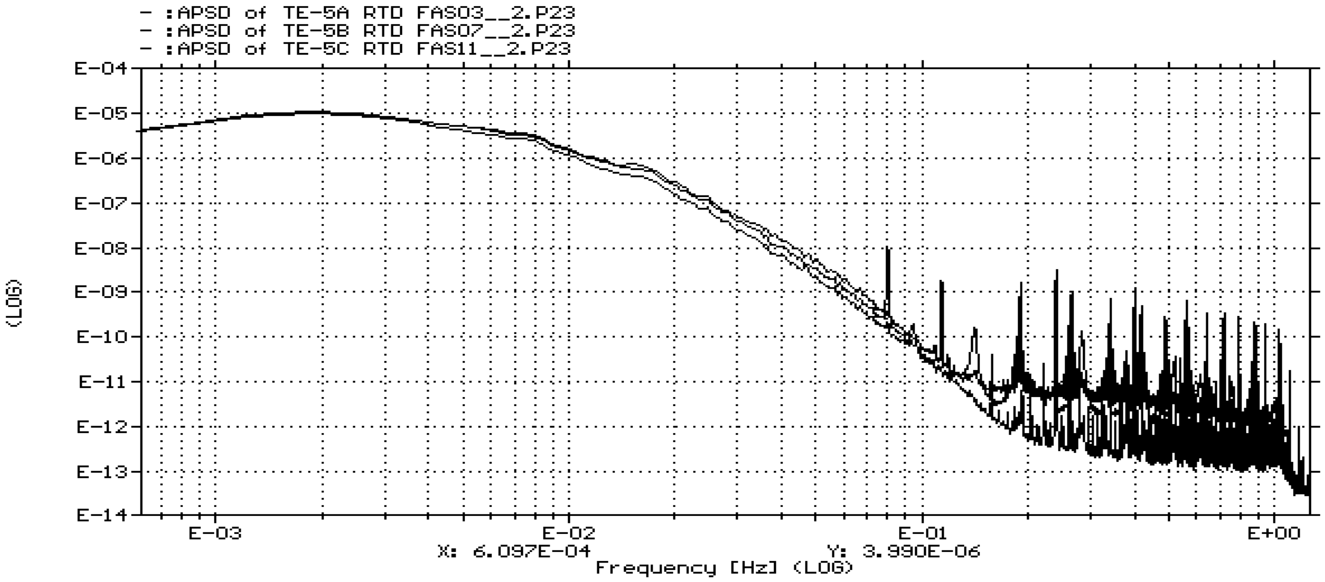


Fig. 6. APSD functions of moderator temperature fluctuations at core outlet measured by thermal-well RTDs of the Reactor Regulating System