21st Annual Conference of the Canadian Nuclear Society
Toronto, Ontario, Canada / June 11-14, 2000

Estimating the Response Times of Pressure/Flow Transmitters and RTDs via In-Situ Noise Measurements

O. Glockler, D.F. Cooke, G.J. Czuppon, K.K. Kapoor

Reactor Performance Monitoring Section, Nuclear Analysis Department
Nuclear Operation Support Services, Ontario Power Generation Nuclear
700 University Avenue, H11-E26, Toronto, Ontario M5G 1X6

Introduction

The dynamics of reactor instrumentation can be tested during steady-state at-power operation in a non-intrusive way by applying signal noise analysis techniques. This inspection technology can be applied in in-situ, on-line testing, without removing the instrumentation from the process.

Reactor noise analysis is a statistical technique regularly used in system surveillance, diagnostics and in actual operational I&C problems. Information on the dynamics of reactor systems and their instrumentation can be extracted from signal fluctuations (noise) measured during steady-state operation. The present paper discusses specific results related to the dynamics and the response time of pressure, flow and temperature transmitters used in the primary heat transport and moderator systems.

The signal noise analysis applications included the following areas: (1) estimating the response times of flow, pressure, differential pressure transmitters, RTDs, and validating their dynamics, (2) estimating the resonance frequencies and the time constants of pressure sensing lines, (3) validating coolant flow dynamics in SDS and FINCH flow channels, and (4) characterizing the root cause of flow anomalies, such as “signal dips” and oscillations found in orifice-based reactor coolant inlet flow signals [1,2]. Certain flow signals exhibit large, negative, aperiodic flow-signal transients, called “flow dips”. The signal transients are random in occurrence. Their width is less than 100 msec, and their amplitude could be as big as 10% of full flow.

1. Estimating the Response Times of Flow Transmitters and Investigating the “Flow-Dip” Problem in In-Situ Flow Noise Measurements in Darlington and Pickering-B

In the fall of 1997, the technique of signal noise analysis was successfully used in the Loss-of-Flow (LOF) trip-coverage project at Darlington. In collaboration with AECL Chalk River Laboratories, the response times of all SDS safety flow transmitters were measured in-situ (without removing them from the process), re-adjusted to a specific value, and validated across all four reactor units with non-intrusive flow-noise measurements performed at steady-state operation. The signals of the flow transmitters (Rosemount and Gould) are used in the SDS1 and

SDS2 shutdown systems. The response time estimation was based on the spectral properties of the fluctuations of the flow transmitter output signals [3].

As a follow-up to the 1997 flow noise measurements, additional flow and sensing line pressure noise measurements were performed in-situ in Unit 3 on the SDS2 flow loop FT-3J, one of the most "flow-dip" prone channels. The goal of the measurement was to investigate the effect of various flow transmitters (Rosemount, Gould, and Bailey) and various sensing line modifications on the statistics of "flow dips". The statistical signatures of the sensing line pressure signals, the differential pressure input signal to the flow transmitter, and the transmitter output signal were measured and analyzed. The noise signatures evaluated in the study included the frequencies and noise amplitudes of sensing line resonances, amplitude distribution of flow-dips, attenuation of frequency components, time constants, and overall response times [4, 5, 6]. Figure 1 shows the auto power spectral density functions (APSD spectra) of the output signal fluctuations of the three different types of flow transmitters tested in flow loop FT-3J. The corresponding dynamic transfer functions, derived from the noise measurements, are shown in Figure 2.

In 1999, the noise-based estimation of flow transmitter response time was also used in the installation of new Rosemount transmitters in certain SDS1 Low Gross Flow (LGF) 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 channels. The response times of these transmitters were set to 500 msec by the manufacturer. The "as-left" response times of the new transmitters and sensing lines were obtained from in-situ flow noise measurements at full power [7].

2. Estimating the Response Times of Flow and Pressure Transmitters in In-Situ Noise Measurements in Bruce-B Unit 6

In October 1999, the response times of all reactor outlet header pressure, coolant inlet flow and reactor core differential pressure transmitters and their sensing lines, used in the SDS1 and SDS2 systems, were estimated in in-situ noise measurements at steady-state full power. Special high-frequency, high-sensitivity pressure transducers were temporarily installed at the end of the sensing lines (at transmitter input) to estimate the response times of the sensing lines and to measure the transfers functions of the flow/pressure transmitters. Signal fluctuations of these pressure transducers were recorded along with the signal fluctuations of the transmitters' output at steady-state full power operation. The in-situ response time estimation was part of a "Safe Operating Envelope" (SOE) project on the dynamic response of SDS trip parameters.

A brief overview of the response time results obtained from the pressure and flow noise measurements is given below.

2.1. PHT Flow Transmitters

The dynamic transfer function of the Rosemount flow transmitter was estimated by measuring the spectral functions of both the input and output signal fluctuations of the transmitter. The SDS1 PHT flow transmitters were found to be third order systems with an average response time of 106 msec. The average third order transmitter can be lumped into an equivalent second order system with time constants of 88 msec and 18 msec (the third time constant is very small, therefore the equivalent second order system is a true representation). The estimates of transmitter response times have an uncertainty of +\- 5 msec. Figure 3 shows the APSD spectra of the output signal fluctuations of the six SDS1 flow transmitters. The dynamic transfer functions of the six SDS1 flow transmitters, derived from the noise measurements, are shown in Figure 4. The functions obtained from the measurements are the true representations of the dynamic transfer functions of the flow transmitters installed in the process (in-situ).

The sensing line time constant also contributes to the overall signal response. The time constant of the sensing line pair was estimated from the spectral attenuation of the differential pressure noise measured at the input of the flow transmitter. The SDS1 PHT flow sensing line *pairs* were found to be first order systems with an average response time of 2 msec. The response time estimates of the SDS1 PHT flow sensing line pairs have an uncertainty of +\- 0.5 msec.

Note that the closely matched sensing lines of the high-pressure and low-pressure sides of the flow transmitter have a very short response time as a pair, compared to the time response of the single pressure sensing lines. The individual sensing lines connected to the high-pressure and low-pressure sides of the flow transmitters have the average response times of 45 msec and 30 msec, respectively, with a +\- 5 msec uncertainty.

The sum of the transmitter response time and the response time of the sensing line pair is considered to be the overall response time of the PHT flow signal (106 msec + 2 msec = 108 msec, average).

This overall signal response time was also estimated from the APSD spectrum of the transmitter output signal fluctuations. The response time estimated from the flow transmitter's output alone does not require the use of the special high-sensitivity pressure transducers, therefore this alternative estimation is more suitable for routine and periodic trend monitoring of transmitter response times. The average of the overall response time given by this technique was 108 msec.

The combined system of the flow transmitter and the sensing line pair shows a specific attenuation in the transmitter output noise spectrum, characteristic to third order systems.

2.2. ROH Pressure Transmitters

The dynamic transfer function of the Rosemount pressure transmitter was estimated by measuring the spectral functions of both the input and output signal fluctuations of the transmitter. Both the SDS1 and SDS2 ROH pressure transmitters were found to be second order systems with an average response time of 25 msec. The average transmitter is represented by two first order systems with the time constants of 22 msec and 3 msec. The estimates of transmitter response times have an uncertainty of +\- 2 msec. Figure 5 shows the APSD spectra of the output signal fluctuations of the SDS1 pressure transmitters. The dynamic transfer functions of the SDS1 pressure transmitters, derived from the noise measurements, are shown in Figure 6. Similarly, the APSD spectra of the output signal fluctuations of the SDS2 pressure transmitters are shown in Figure 7. The dynamic transfer functions of the SDS2 pressure transmitters are shown in Figure 8.

The time constant of the sensing line was estimated independently, from the spectral attenuation of the pressure noise measured at the input of the transmitter by high-sensitivity pressure transducers. Both the SDS1 and SDS2 ROH pressure sensing lines were found to be first order systems with an average response time of 38 msec and a statistical uncertainty of +\- 10 msec.

The sum of the transmitter response time and the sensing line response time is considered to be the overall response time of the ROH pressure signal (25 msec + 38 msec = 63 msec, average).

This overall signal response time was also estimated from the APSD spectrum of the transmitter output signal fluctuations alone. The response time estimated by this technique gives an upper limit for the overall response time. The average estimate in this case was 79 msec.

The combined system of the pressure transmitter and the sensing line shows a specific attenuation in the transmitter output noise spectrum, characteristic to third order systems.

2.3. Core Differential Pressure Transmitters

The dynamic transfer functions of the SDS2 core differential pressure (dp) Rosemount transmitters were estimated by measuring the spectral functions of both the input and output signal fluctuations of the transmitter. The SDS2 core dp transmitters were found to be first order systems with an average response time of 750 msec and a statistical uncertainty of +\- 50 msec. Figure 9 shows the APSD spectra of the output signal fluctuations of the SDS2 core differential pressure transmitters. The dynamic transfer functions of the SDS2 dp transmitters, derived from the noise measurements, are shown in Figure 10.

The time constant of the sensing line pair was estimated from the spectral attenuation of the differential pressure noise measured at the input of the dp transmitter. The SDS2 core differential pressure sensing line pairs were found to be first order systems with an average response time of 24 msec and a statistical uncertainty of +\- 5 msec.

The sum of the core dp transmitter response time and the sensing line pair response time is considered as the overall response time of the core dp signal (750 msec + 24 msec =774 msec, average).

This overall signal response time was also estimated from the APSD spectrum of the core dp transmitter output signal fluctuations alone, giving an upper limit for the overall response time. The average of the overall response time given by this technique was 829 msec.

The combined system of the core dp transmitter and the sensing line pair shows a specific attenuation in the transmitter output noise spectrum, characteristic to second order systems.

3. Estimating the Response Times of Moderator RTDs in In-Situ Noise Measurements in Bruce-B Unit 8

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 spikes induced by EMI and ground fault detectors.

In November 1999, a comprehensive measurement of RRS and SDS1 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 the calandria outlet (three RRS RTDs and three SDS1 RTDs), and (b) three RTDs in each of the two moderator loops located at the outlet of the two heat exchangers (inlet to the calandria). The response times of both thermal-well (RRS) and strap-on (SDS1) type RTDs were estimated from the spectral functions of the RTD noise signals. Also, the transit times of the moderator between RTDs were estimated by noise analysis.

The APSD spectra of the signal fluctuations of the three SDS1 strap-on RTDs located at the calandria outlet are shown in Figure 11. The temperature fluctuations are slow and they contribute to the very low frequencies only (below 0.02 Hz). The sharp peaks above 0.03 Hz are electrical effects (EMI, ground fault detectors). The response times of the strap-on RTDs estimated from the APSD functions were within the range of 60-100 sec. The measured temperature fluctuations in all three SDS1 RTD signals showed strong coherence only below 0.02 Hz. As an example, Figure 12 shows the two APSD functions, coherence and phase functions measured between the Channel D and E RTD signal fluctuations, TE-1D and TE-1E.

Figures 13 and 14 show the APSD spectra of the signal fluctuations of the thermal-well RTDs: TE-5A, TE-5B, TE-5C (calandria outlet, Figure 13), and TE-15, TE-19, TE-21 (heat exchanger outlet in loop 1, Figure 14), TE-16, TE-18, TE-20 (heat exchanger outlet in loop 2, Figure 14). Again, the temperature fluctuations contribute to the low frequencies only (below 0.04 Hz). The sharp peaks above 0.04 Hz in the spectra of TE-15 and TE-16 are electrical effects.

Figure 15 shows the typical APSD functions, coherence and phase functions measured between the RRS RTD signal fluctuations (TE-5A, TE-5B). All three RRS RTDs showed strong coherence and close to zero phase difference below 0.15 Hz. Their estimated response times were within the range of 31-45 sec.

Similarly, Figure 16 shows the two APSD functions, coherence and phase functions measured between the RTD signal fluctuations, TE-5A and TE-19. Although the two RTDs are separated by a long distance in the moderator loop, they showed strong coherence and a linear phase difference below 0.05 Hz. Linear phase function between two noise signals is typical in propagation effects. The temperature fluctuations carried by the moderator flow affect both RTD signals with a time delay. The transit time estimated from the slope of the phase function in Figure 16 is 6.9 sec. The transit times between any two measured RTDs in the two moderator loops were estimated by noise analysis, and used to assess moderator flow. The response times of the six RTDs located at the outlet of the two heat exchangers were within the range of 12-22 sec.

Figure 17 shows the phase function measured between the fluctuations of the calandria outlet RTD TE-5A and the six RTDs located at the outlet of the two heat exchangers (inlet to the calandria). The slope of the linear phase over the frequency range of 0.015 - 0.065 Hz was used to estimate the moderator transit times between RTDs. The calculated transit times were within the range of 6.9 – 13.0 sec. The linear phase at very low frequencies (below 0.015 Hz) were distorted by the additional time delays caused by the differences in the RTD response times (RTDs with the same response time should have zero phase difference at zero frequency). Similar results were obtained when the temperature fluctuations of the other two calandria outlet RTDs, TE-5B and TE-5C, were compared to the heat exchanger outlet RTDs (see Figure 18). Also, the direct comparisons of the heat exchanger RTD noise signals gave transit time results, which were consistent with the above calandria outlet-inlet transit time values.

Conclusion

CANDU noise measurements carried out over the past eight years have proved that (a) fault detection, (b) validation of process/instrumentation dynamics, and (c) estimation of dynamic parameters can be based on the existence of multi-channel complex patterns of statistical noise signatures. These signatures are obtained from the multi-channel time series measurements performed at steady-state operating conditions. Signal noise analysis provides a non-intrusive method for monitoring and estimating the dynamic response of pressure/flow transmitters and RTDs installed in the process.

The technique is being successfully applied now in a wide variety of actual station problems as a powerful troubleshooting and diagnostic tool. CANDU reactors provide a unique opportunity, in that the amount of detailed information contained in their noise spectra far surpasses that typically observed in light water reactors. There is significant potential to develop many more sophisticated and useful core surveillance tools by exploiting this information using noise analysis technology.

Acknowledgements

The noise measurements were performed in Pickering-B, Darlington and Bruce-B units with an active support of plant personnel. In particular the authors would like to acknowledge the contribution of A.V. Campbell, Sonya von Svoboda, M. Tulett, R. Vilkko, D. Williams, M. Woitzik of Pickering-B; F. Amantea, B. Cunningham, F. Dermarkar, D. Guernsey, E. Sadok, M. Ramphal, M. Wightman of Darlington; J. King, A. Kozak, H. Parsons, R. Quirk, J. Schut, P. Wright of Bruce-B.

References

1. O. Glockler, "Pressure and Flow Noise Measurements in Pickering-B Unit 6," In-Service Report, PB-IR-63700-8, February (1994).
2. H.W. Hinds, "Report on the Root Cause of Flow Dips at Pickering B," Report COG-95-571 (1995).
3. O. Glockler, "DNGD Flow Transmitter Noise Analysis Report, Units 1-4 As Left," NK38 03610.02 985022-26 R00, January 27 (1998).
4. O. Glockler, "Statistics of Flow Noise in DNGD 3-68334-FT3J Measured with Various Sensing Line Lengths and Transmitter Types – Measurement Data Report," NK38-REP-68334-985103 (1998).
5. V. Koslowsky, H.W. Hinds, O. Glockler, "Effect of Instrument-Line Length on Differential Pressure Measurements," CS-NAH-TN-33 (1998).
6. H.W. Hinds, V. Koslowsky, P. Kumli, "Validation of the Auto-Power-Spectral-Density Method of Determining the Response Time of Rosemount, Gould and Bailey Flow Transmitters," COG-98-323 (1998).
7. O. Glockler, "SDS1 Low Gross Flow Noise Monitoring and Flow Transmitter Replacement on Loops 8-63724 F3D and F2E in Pickering-B Unit 8," NK30 REP 63724 10001 (1999).

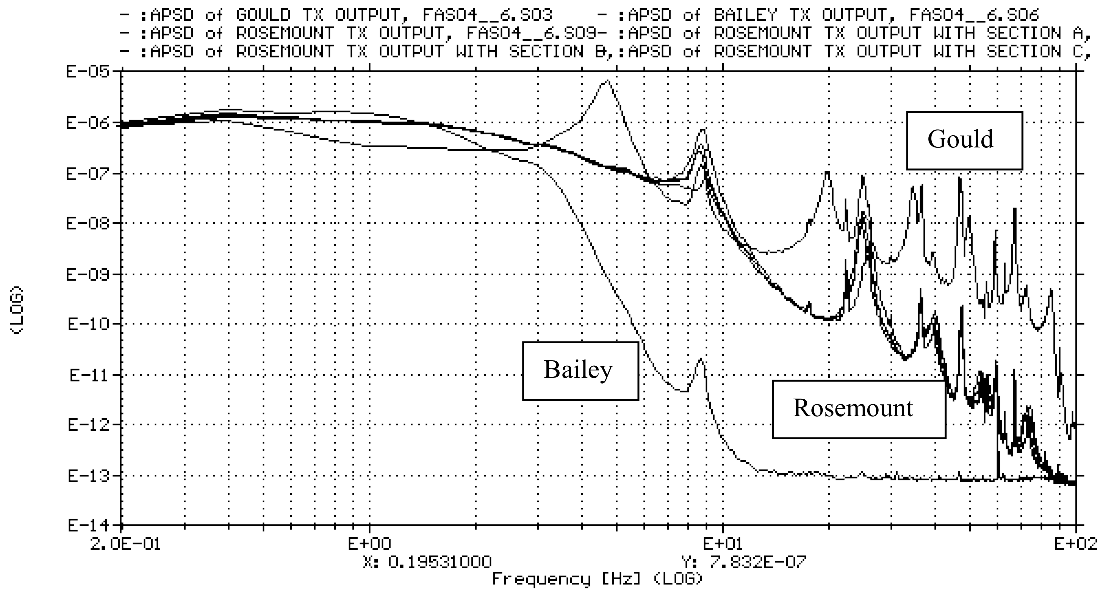

Figure 1. APSD spectral functions of flow noise signals from Rosemount, Gould, and Bailey flow transmitters installed on safety system flow loop FT-3J in Darlington Unit 3.

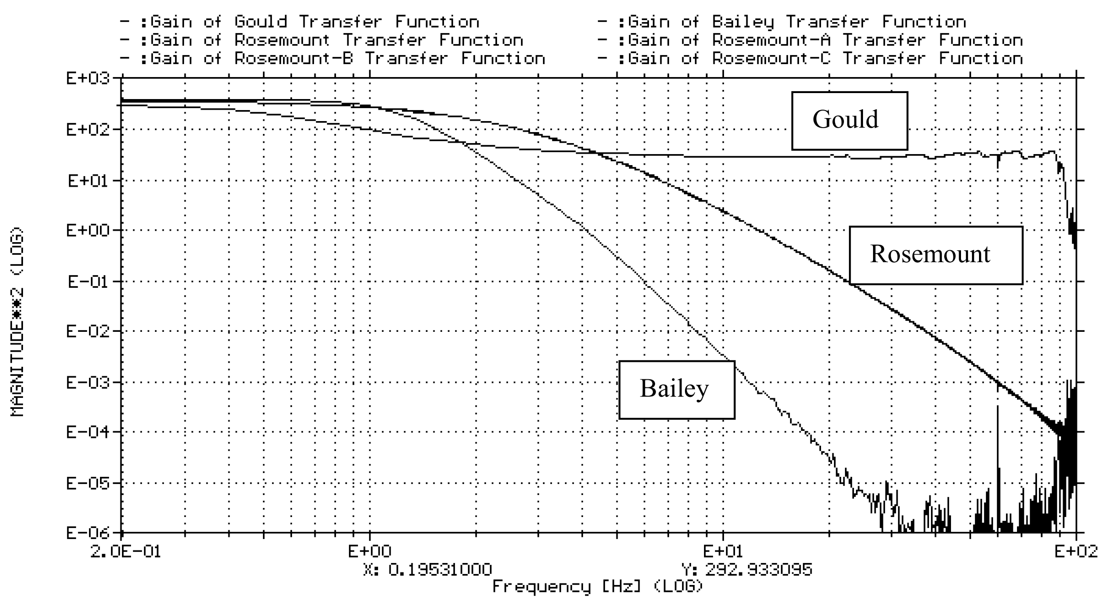

Figure 2. Magnitude of the dynamic transfer functions of Rosemount, Gould, and Bailey flow transmitters derived from in-situ noise measurements in safety system flow loop FT-3J in Darlington Unit 3

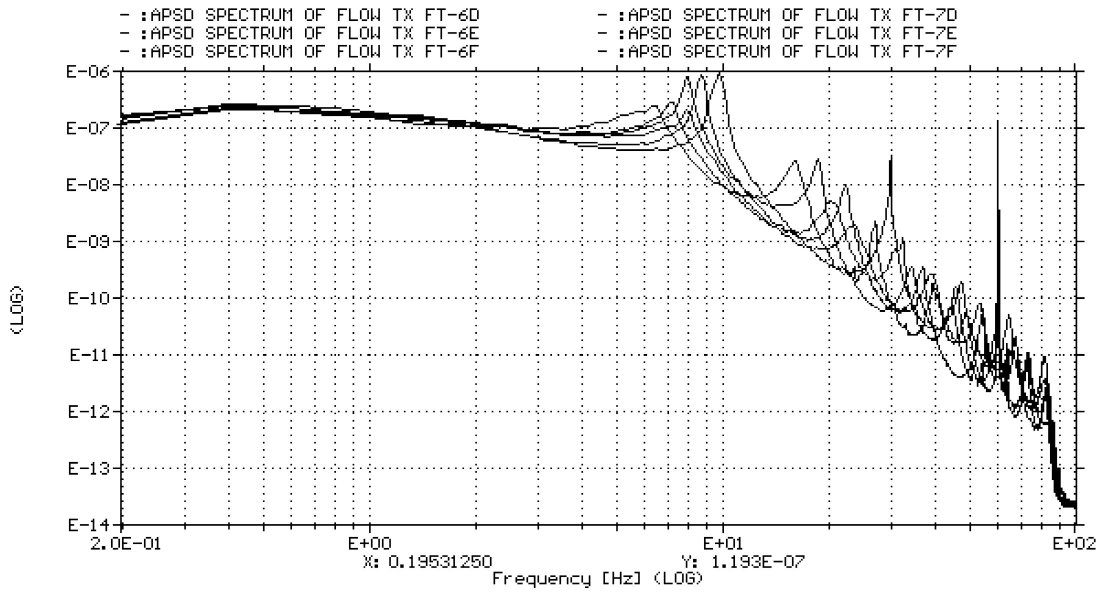

Figure 3. APSD spectral functions of the output signals of the six SDS1 flow transmitters in Bruce-B Unit 6.

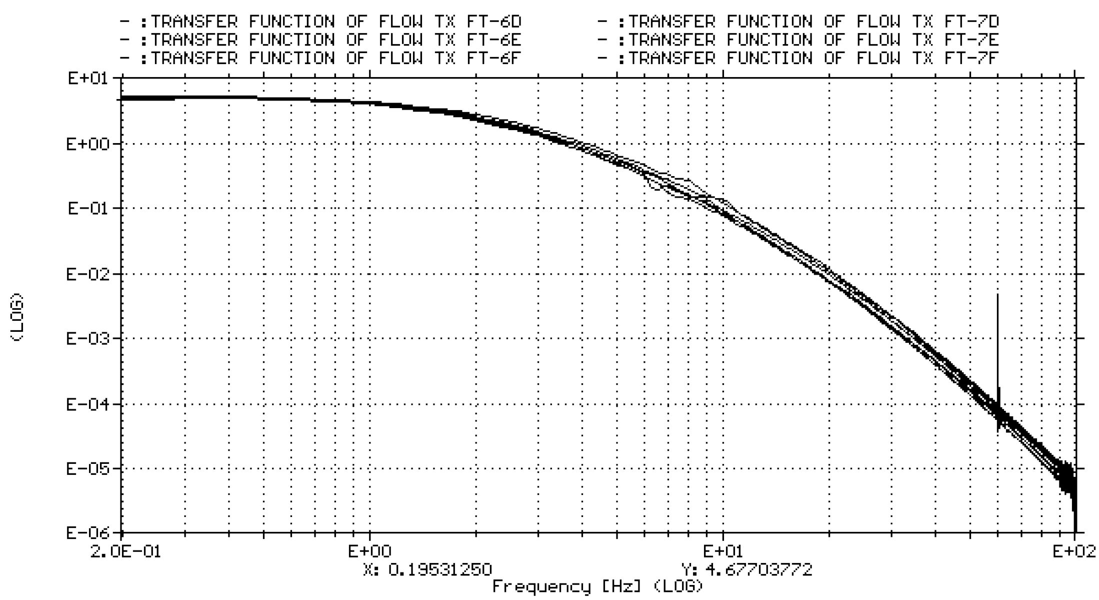

Figure 4. Magnitude of the dynamic transfer functions of the SDS1 flow transmitters derived from in-situ noise measurements in Bruce-B Unit 6.

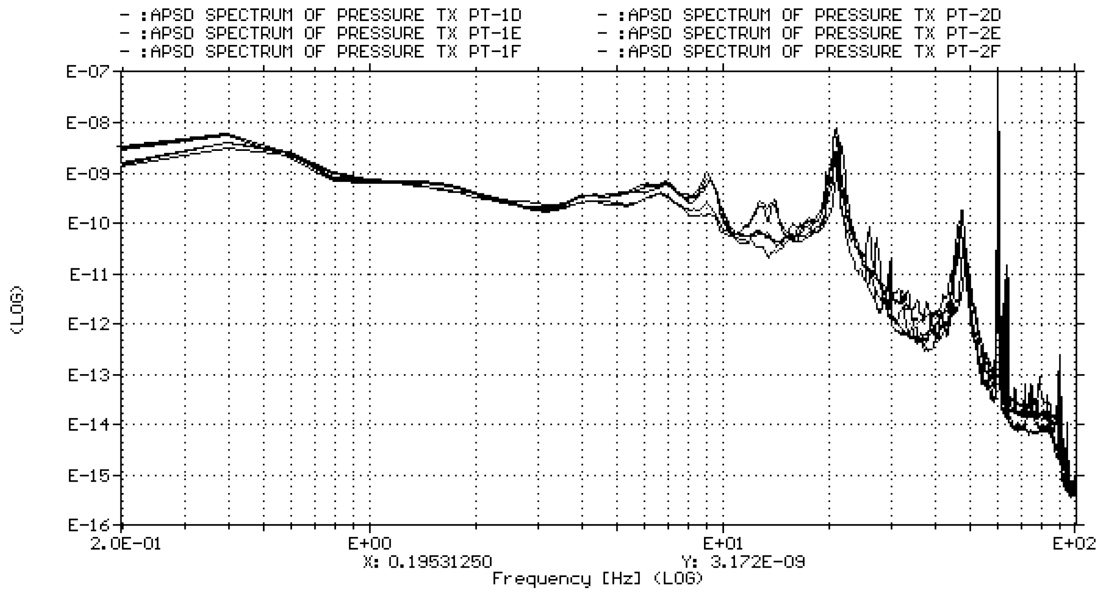

Figure 5. APSD spectral functions of the output signals of the SDS1 pressure transmitters in Bruce-B Unit 6.

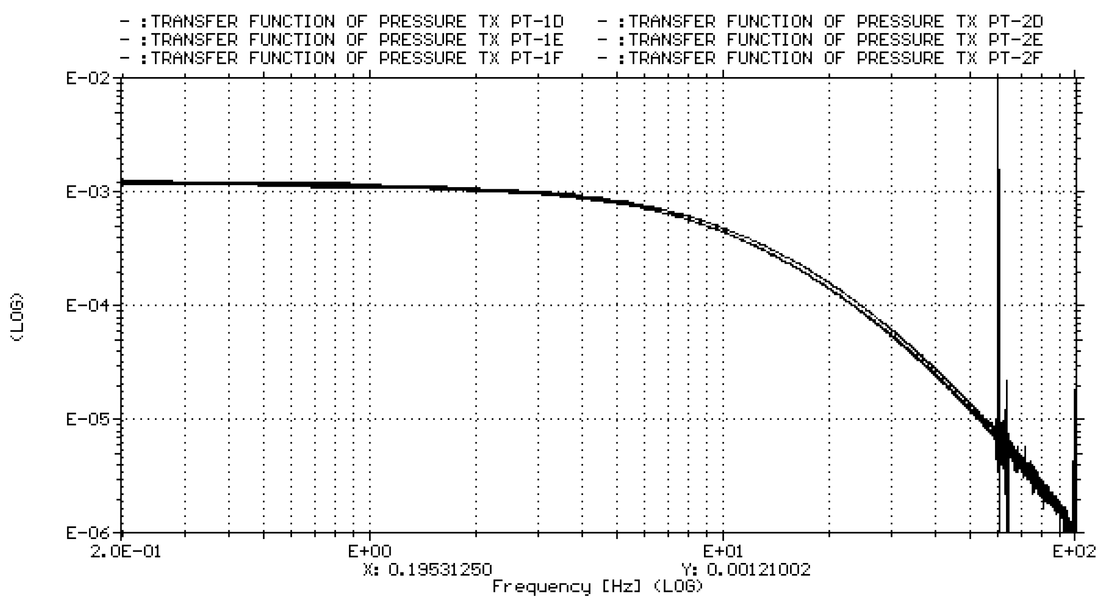

Figure 6. Magnitude of the dynamic transfer functions of the SDS1 pressure transmitters derived from in-situ noise measurements in Bruce-B Unit 6.

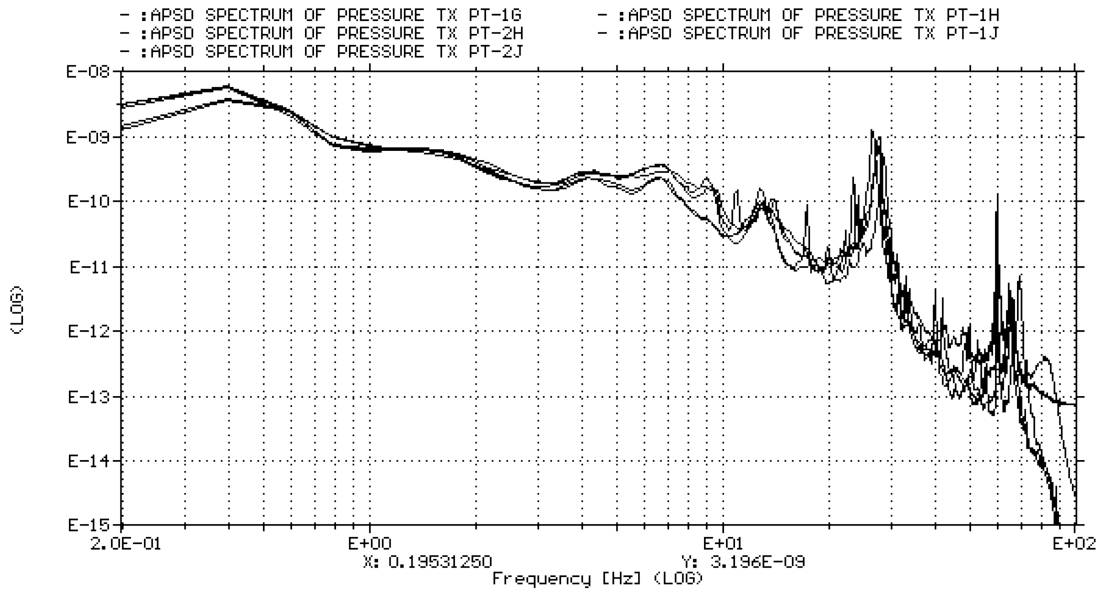

Figure 7. APSD spectral functions of the output signals of the SDS2 pressure transmitters in Bruce-B Unit 6.

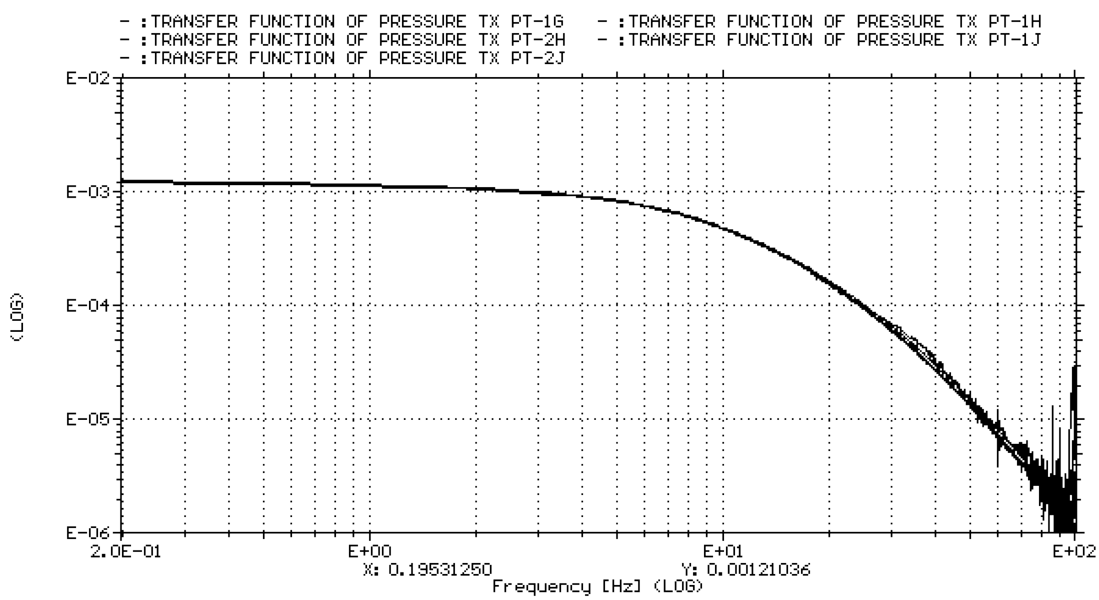

Figure 8. Magnitude of the dynamic transfer functions of the SDS2 pressure transmitters derived from in-situ noise measurements in Bruce-B Unit 6.

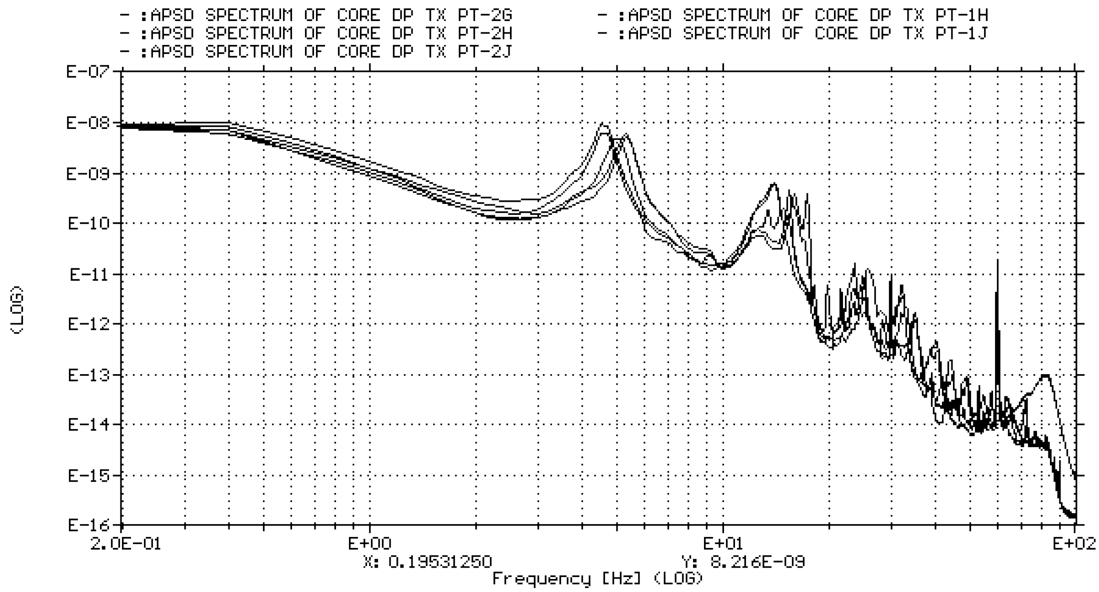

Figure 9. APSD spectral functions of the output signals of the SDS2 core differential pressure transmitters in Bruce-B Unit 6.

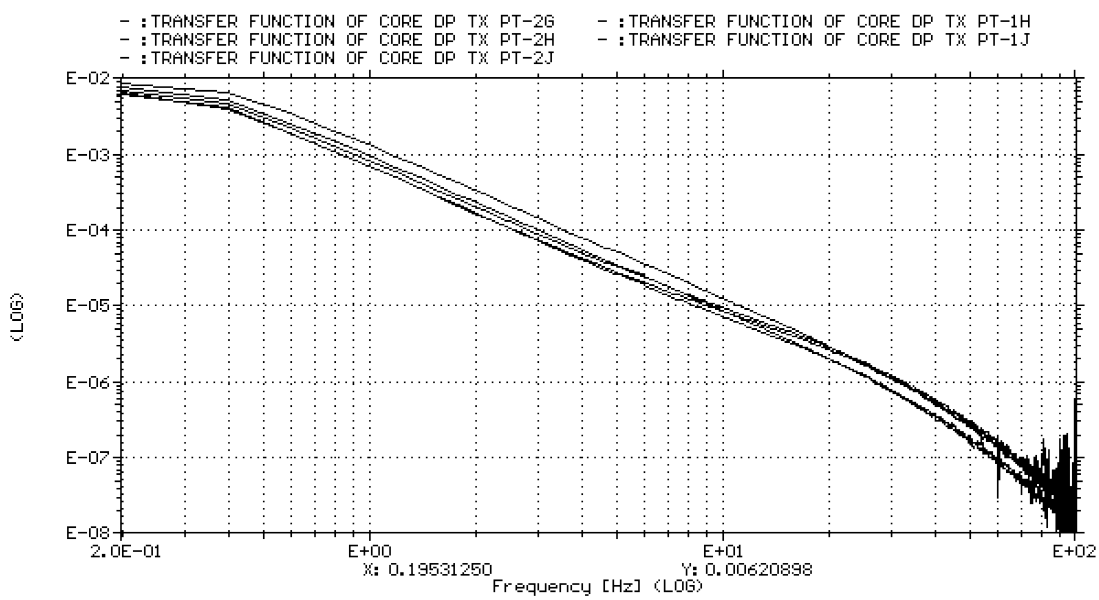

Figure 10. Magnitude of the dynamic transfer functions of the SDS2 core differential pressure transmitters derived from in-situ noise measurements in Bruce-B Unit 6.

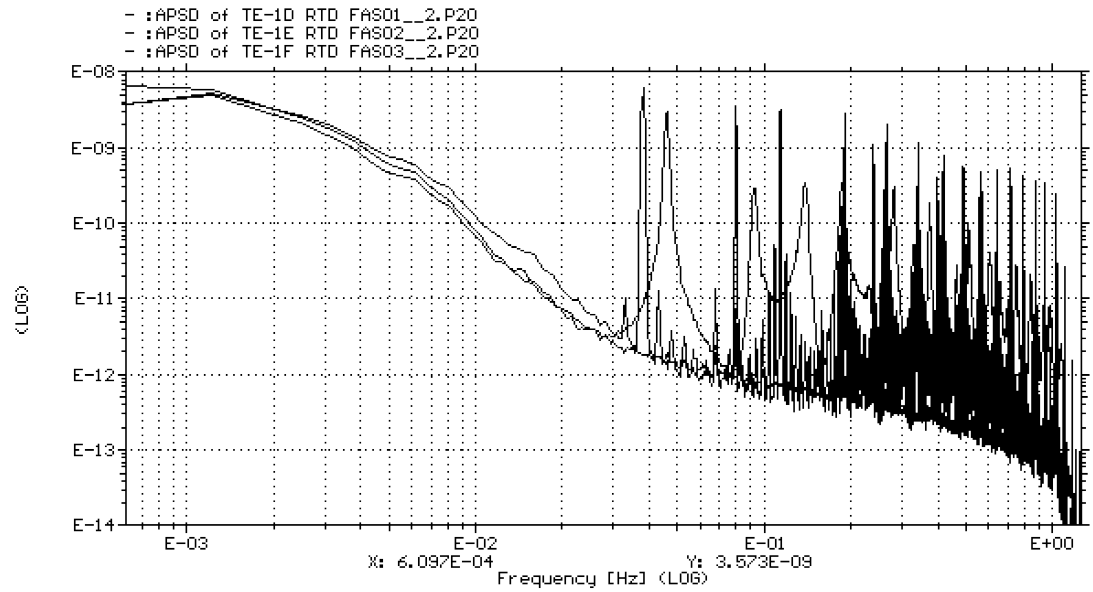

Figure 11. APSD spectra of moderator temperature fluctuations measured by SDS1 strap-on RTDs at caladria outlet (TE-1D, TE-1E and TE-1F).

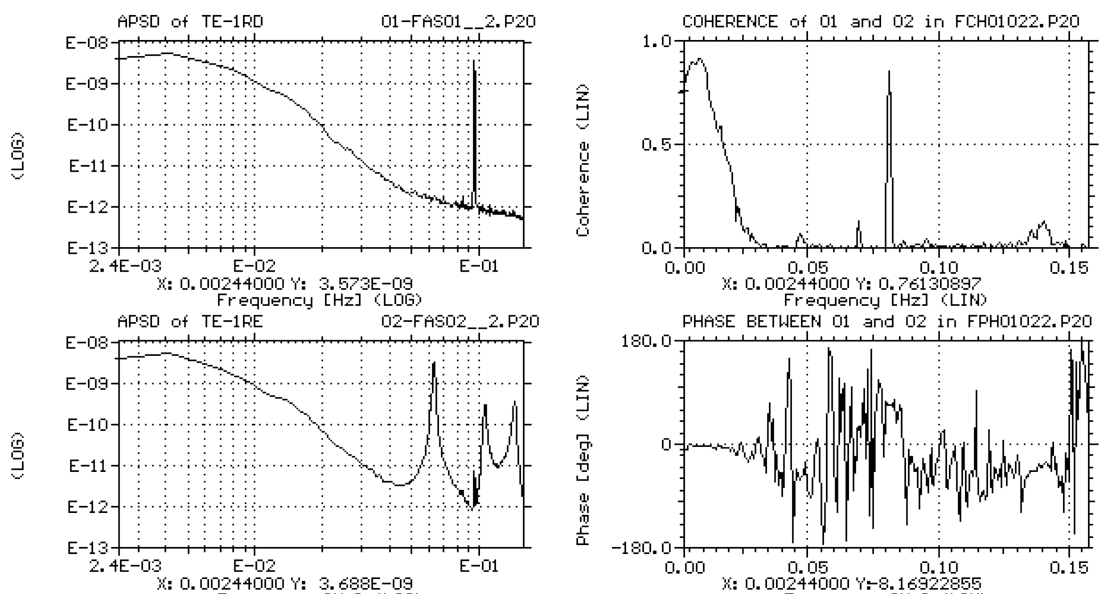

Figure 12. APSD, coherence and phase functions of SDS1 strap-on RTDs, TE-1D and TE-1E.

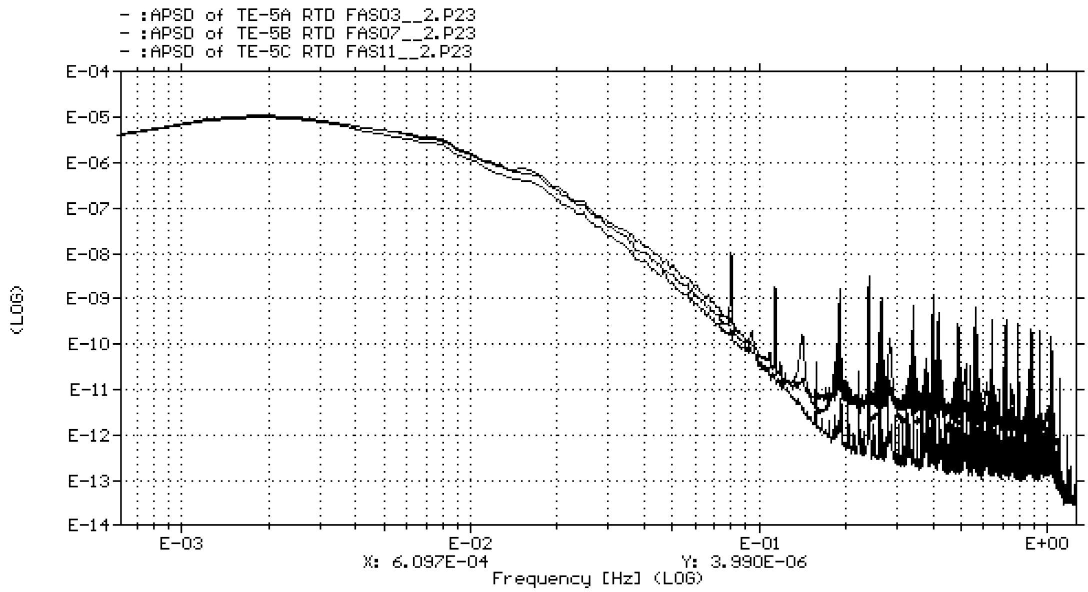

Figure 13. APSD spectra of moderator temperature fluctuations at calandria outlet measured by RRS thermal-well RTDs TE-5A, TE-5B and TE-5C.

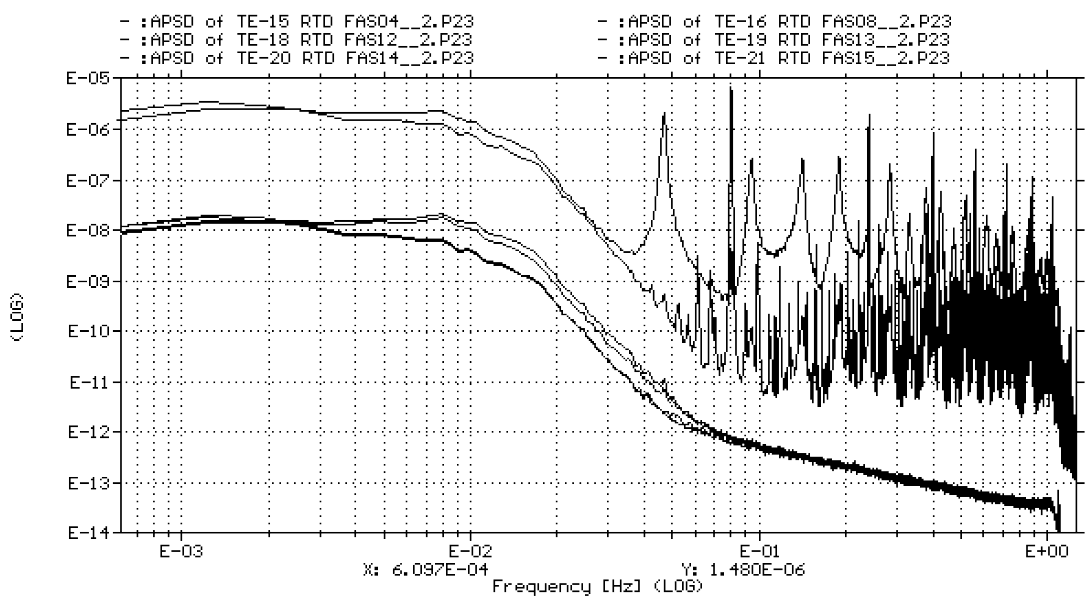

Figure 14. APSD spectra of moderator temperature fluctuations at calandria inlet (heat exchanger outlet) measured by thermal-well RTDs (TE-15, TE-19, TE-21, and TE-16, TE-18, TE-20).

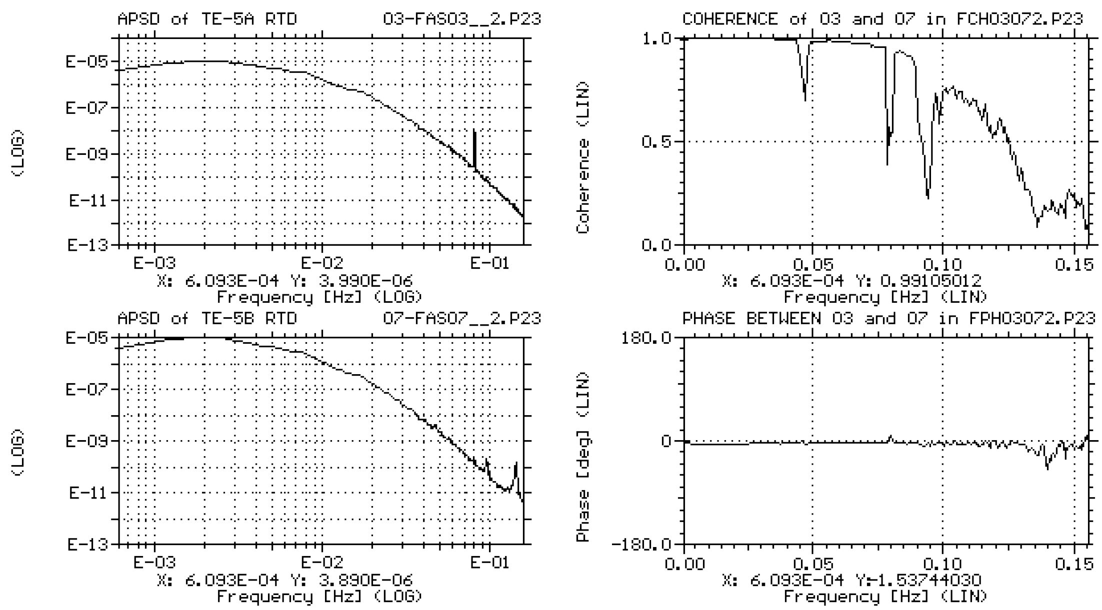

Figure 15. APSD, coherence and phase functions of RRS thermal-well RTDs TE-5A and TE-5B located at calandria outlet.

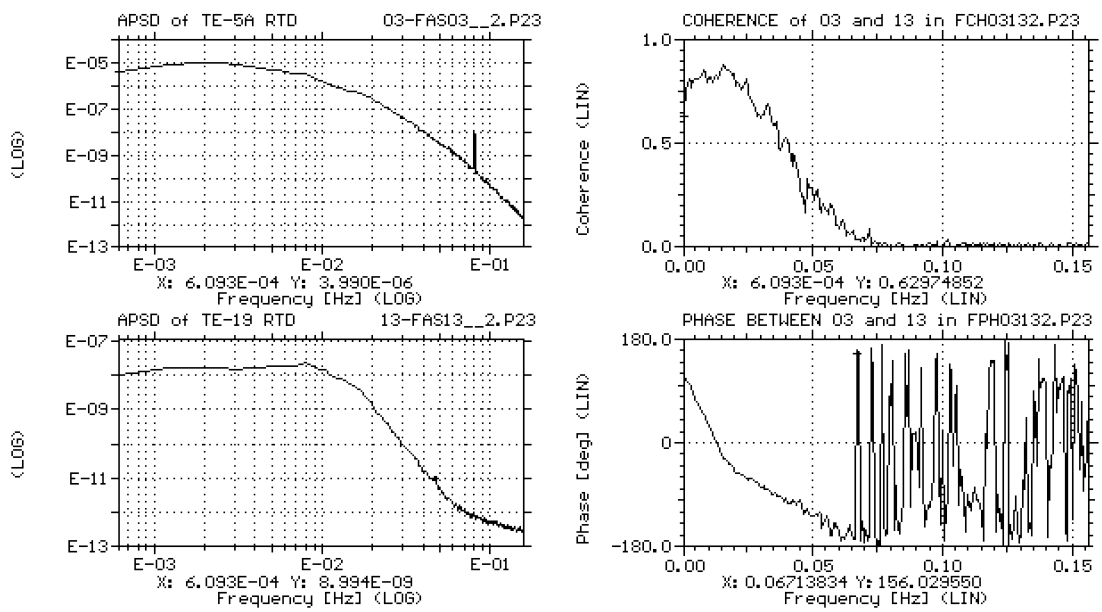

Figure 16. APSD, coherence and phase functions of RTD TE-5A located at calandria outlet and RTD TE-19 located at the heat exchanger outlet of moderator loop 1.

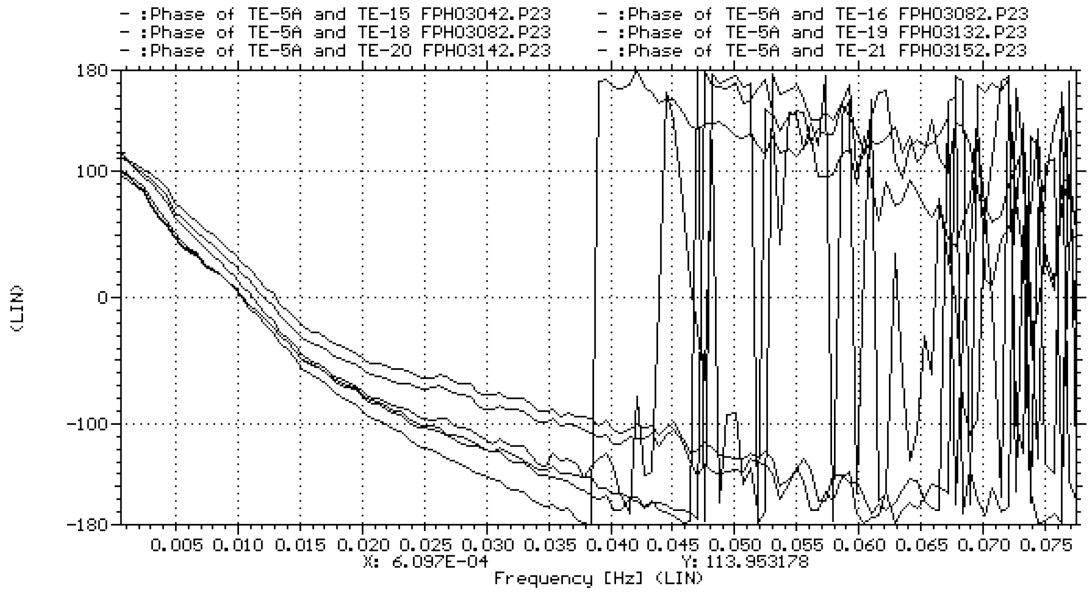

Figure 17. Phase functions between moderator temperature fluctuations measured by the calandria outlet RTD TE-5A and the six RTDs located at the outlet of the two heat exchangers.

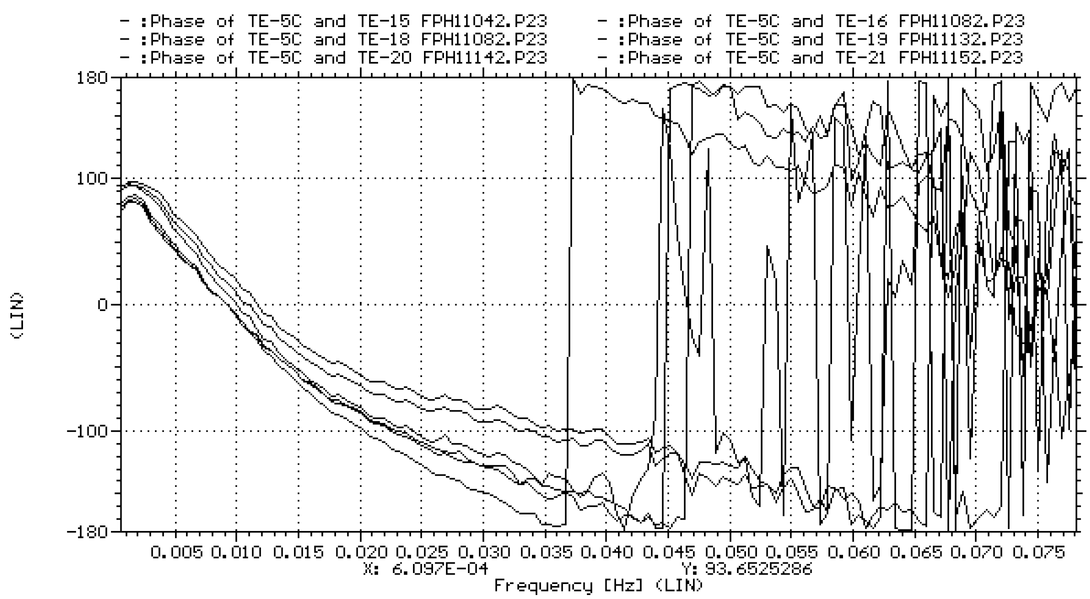

Figure 18. Phase functions between moderator temperature fluctuations measured by the calandria outlet RTD TE-5C and the six RTDs located at the outlet of the two heat exchangers.