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CANADIAN EXPERIENCE IN THE AREA OF REACTOR NOISE

by

K.J. SERDULA

Paper presented at "Specialist Meeting on Reactor Noise
from Critical Assemblies to Power Plants," SMORN-1,
October 21-25, 1974, at CSN Casaccia, CNEN, Rome

Chalk River Nuclear Laboratories
Chalk River, Ontario

January 1975

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Expérience canadienne dans le domaine des bruits de réacteur

par

K.J. Serdula

Résumé

L'auteur de ce rapport donne un aperçu du programme relatif aux bruits et à la dynamique des réacteurs et il passe en revue une partie de l'expérience acquise au Canada dans l'application des techniques de mesure des bruits de réacteur au développement de la filière CANDU (Canada Deutérium Uranium) caractérisée par ses tubes de force. On se propose de développer les connaissances techniques dans le domaine des bruits et de la dynamique des réacteurs et d'appliquer la compétence ainsi acquise au développement accru de la filière CANDU. Pour atteindre cet objectif on procédera à des travaux dans les domaines suivants:

- Développement
- Application
- Expansion
- Avancement

L'application des techniques d'analyse des bruits de réacteur au réacteur de la centrale Gentilly 1, est commentée du fait que ce travail a démontré le rôle important que les mesures de bruit jouent dans les centrales commerciales.

Le réacteur de la centrale Gentilly 1, qui emploie de l'eau légère bouillante comme caloporteur et qui se caractérise par une rétroaction sous vide positive a été idéal pour évaluer l'emploi des techniques d'analyse des bruits de réacteur dans les systèmes électronucléaires. On a donc effectué des études avec excitation 1) inhérente et 2) imposée. Les résultats de ces deux types d'études sont présentés et la mesure dans laquelle ils répondent aux objectifs est indiquée.

L'Energie Atomique du Canada, Limitée
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ABSTRACT

This report outlines the reactor noise and dynamics program and reviews some Canadian experience in applying reactor noise measurement techniques to the development of the CANada Deuterium Uranium (CANDU) pressure tube reactor system. Our general objective is to develop technical competence in the area of reactor noise and dynamics and apply it to the further development of the CANDU reactor system. To achieve this objective, work is directed towards the following areas:

- Development
- Application
- Expansion
- Advancement

Application of reactor noise analysis techniques in the CANDU-BLW power reactor, Gentilly-1, is discussed since the work has demonstrated the role of noise measurements in commercial stations.

Gentilly-1 with boiling light water (BLW) coolant in the channels and a positive void feedback provided an ideal opportunity for assessment of the use of reactor noise techniques in power reactor systems. Consequently programs using both (1) inherent and (2) imposed excitation were carried out. Results from both programs are presented and their significance in satisfying program objectives is discussed.

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CANADIAN EXPERIENCE IN THE AREA OF REACTOR NOISE *

by

K.J. Serdula (AECL)

1. INTRODUCTION

This report outlines the reactor noise and dynamics program and reviews some Canadian experience in applying reactor noise measurement techniques to the development of the CANada Deuterium Uranium (CANDU) pressure tube reactor system. This program, initiated in 1966 with measurement of noise from a zero-power research reactor and loop (both in-and out-of-reactor) experiments, was extended to include noise measurements during the commissioning of the CANDU Boiling Light Water (BLW) coolant reactor Gentilly-1 (G-1).

Some results obtained during the program evolution are presented with emphasis on our power station applications. However, transfer of measurement programs to power stations requires an evolution in experimental philosophy and this aspect is discussed. Additional areas for expansion of noise techniques are also presented.

2. REACTOR NOISE AND DYNAMICS PROGRAM

Our mission is to develop technical competence in the area of reactor noise and dynamics and apply it to the further development of the CANDU reactor system.

2.1 Program Objectives

The objectives that evolved in this program are:

(a) Development - to develop technical competence in laboratory applications.

* Paper presented at "Specialist Meeting On Reactor Noise - From Critical Assemblies to Power Plants", SMORN-1, October 21 - 25, 197[illegible] at CSN Casaccia, CNEN, Rome.

(b) Application - to apply promising measurement methods to CANDU nuclear systems.

(c) Expansion - to expand the Canadian technological base by transferring proven technology to the utilities and industry for implementation by their staff.

(d) Advancement - to continue advancing the state-of-the-art and broadening the application areas on an expanding technological base.

2.2 Program Results

Results of the program related to the objectives are:

(a) Development A data acquisition and signal conditioning system is available for measurement of noise from all commonly used sensors.Also a comprehensive off-line analysis capability has been established and our limited portable on-line capability is being upgraded and expanded for use at any site.

Noise and system dynamics measurements have been made during the following experimental programs:

- Simulated boiling in ZED-2 (zero power research reactor),
- Dry out experiments, U-105 and U-111 (U-1 loop in the NRU research reactor),
- Fuel test experiments, X-639 and X-4 (X-6 and X-4 loops in the NRX research reactor),
- NRU reactor regulating and zonal control dynamics (1,2),
- NPD transfer function measurements (3),
- Coolant transit studies, Task 119 (out-of-reactor loop facility, FLARE),
- Fuel fretting studies (out-of-reactor loops, SWAFT and Power Projects Fuel Test Loop).

During the above programs noise has been measured from a wide range of sensors in systems and under conditions typical of those expected to be encountered in power reactors.

(b) Application A noise measurement program was successfully undertaken during the commissioning of the G-1 250 MWe reactor.

(c) Expansion The utility, Hydro-Quebec, has acknowledged the usefulness of noise measurements and has approved another program to be undertaken during re-commissioning of G-1 and its subsequent operation. During this period the utility staff will take an active role to build up in-house competence in this area.

(d) Advancement Some of the new areas under development or being considered using noise techniques are:

(i) In addition to measurements of noise from inherent sources and application of PRBS+ to control absorbers, a program will be undertaken at Gentilly to modulate the core coolant flow. Also, frequency response testing of the drum-level control system (through modulation of the feed-water valve stem positions) can be undertaken if required.

(ii) Determination of the prompt fraction of the signal from in-core self-powered detectors through application of noise analysis techniques.

(iii) Application of noise analysis techniques to the development of a clamp-on flowmeter to measure liquid flows in heavy water plants. This work is being carried out under contract to a Canadian industrial firm.

From the above program results, only applications in the power reactor Gentilly-1 will be discussed in detail, since this work has demonstrated the role of noise measurements in commercial power stations.

3. POWER REACTOR APPLICATIONS

Application of reactor noise analysis techniques to power reactors has been limited to the Gentilly-1 reactor. This reactor with boiling coolant in the channels and a positive void feedback provided an ideal opportunity for assessment of the use of reactor noise techniques in power reactor systems.

However, extension of measurement programs to power stations is influenced by many requirements, some of which differ from those for laboratory programs. These requirements are discussed in the context of the program on the Gentilly-1 reactor.

+ PRBS - pseudo-random binary sequences

3.1 Acceptance of Measurement Program

To be acceptable, the program should satisfy the diverse interests of the many groups involved. These were:

- designers of the installation,
- commissioning teams,
- operating staff,
- owner,
- designers of future installations.

Because of these acceptability requirements our program objectives were to:

- provide information useful in commissioning the nuclear power station,
- indicate potential problem areas and provide information to eliminate the problems or reduce their potential consequences,
- provide information of use to operating staff in establishing routine operating procedures and in applying diagnostic noise measurement techniques,
- provide information of use to designers for the further development of the CANDU reactor concept.

3.2 Program Constraints

To be acceptable the measurement program was limited by constraints set by:

(1) reactor operation - measurements had in general, to be performed within normal operating limits and procedures and not increase the probability of reactor shutdown.

(2) station hardware - the program had to be performed with the physical hardware available for normal station operation.

(3) station schedule - the program was not to disrupt the reactor construction or commissioning schedule.

(4) measurement time - the measurements had to be done in minimal time and result in minimal interference with the commissioning and power production.

Because of the above constraints, the only requirements of the Gentilly-1 program were:

(1) an additional computer program for the station's direct digital computer control systems.

(2) installation of a few duplicate sensors.

3.3 Planning, Execution and Processing of Data

The planned program was to measure noise in system parameter signals for:

- Excitation of the system parameters by inherent disturbances.
- Excitation of selected systems by pseudo-random sequences.

3.3.1 Noise Due to Inherent Excitation

The proposed program was to measure noise characteristics of selected parameters for a range of reactor operating conditions. Fig. 1 is a schematic of the reactor core showing the monitored channels. The signals used in this program are listed in Table I.

Measurements were planned at the following reactor power and flow conditions:

(1) shutdown - system hot and pressurized with all pumps in operation

(2) 0.1% full power (F.P.) - system hot and pressurized with all pumps in operation.

(3) 10% F.P. and 100% full flow (F.F.)

(4) 25% F.P. and 100% F.F.

(5) 25% F.P. and reduced flow.

(6) 50% F.P. and 100% F.F.

(7) 50% F.P. and reduced flow.

(8) 75% F.P. and 100% F.F.

(9) 75% F.P. and reduced flow.

(10) 100% F.P. and 100% F.F.

Data acquisition and analysis facilities made available at-site had the capability to:

- record and condition signals from up to 14 parameters simultaneously in frequency-modulated format (A-1).
- record and condition in a digital format signals from up to 18 parameters simultaneously for sample intervals greater than or equal to 64 ms with a total of 640 data samples for each parameter.
- measure true or exponential time-averaged mean values (A-2).

- measure true or exponential time-averaged r.m.s. values (either high or low-pass band filter) (A-2).
- obtain power spectral densities (A-3).
- obtain auto- or cross-correlation functions (A-3).
- obtain probability distribution functions (A-3).

A-1 to A-3 denote the three additional systems used in the general noise program at CRNL and that were made available at-site.

Off-site analysis capability consisted of use of the MAC/RAN† computer program system on the CDC-6600. In addition to the above functions, this program has the capability to analyze single or multiple data records for:

- probability density functions,
- cross-spectral density functions,
- response functions (gain and phase),
- coherence functions,
- data conditioning (calibration, trend removal, filtering and formation of new data channels which are an algebraic or functional combination of the initial data channels).

During the initial power increase in the commissioning phase, key parameters were to be monitored for significant unexpected changes in their:

(1) amplitude vs time traces,
(2) mean and r.m.s. values.

If significant changes occurred then a complete set of measurements would be obtained and further analyses carried out.

3.3.2 Noise Due to Imposed Excitation

The initial program was to measure the controlled and uncontrolled response of the neutron flux to spatial reactivity perturbations.

Initial design studies used a space-time modal model and therefore planning, execution and analysis of the measurements was also based on the modal model to facilitate comparison of results.

This model expresses a space-time dependence of the flux as a series of spatial modes, each with its own time-dependent

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† A computer code developed by Measurement Analysis Corporation for comprehensive analysis of time series data from RANdom noise.

characteristic. Fig. 2 shows typical spatial neutron flux modes in schematic form. Since the fundamental mode response characteritics were known, measurements were to be concentrated on measuring the characteristics of the next most responsive mode, the first azimuthal. Details on the use of this model in the planning, execution and analysis of the measurements are given in references (4,5).

Results from these measurements were to be used to verify the theoretical models used in the design studies. Since the G-1 nuclear station is the CANDU-BLW prototype, no operating experience or information was available to verify at-power predictions.

The program that evolved used the existing reactor instrumentation and the regular control absorbers under the control of the station's dual digital computer control system. The dynamic excitation function applied to the absorbers was a modified pseudo-random binary sequence of 16 bits. More details on the characteristics of the PRBS are given in references (4,5).

A special computer program written for the computer control system controlled the amplitude and duration of the disturbances to be sent to each absorber in addition to synchronous sampling, filtering and storing of the data from 18 of the approximately 650 variables available to the computer. Data were recorded on punched paper tape for off-line analysis using the MAC/RAN system on the CDC-6600 at CRNL+.

A schematic diagram of the core is shown in Fig. 1. Bulk control of the reactor is by signals from the three ion chambers which are then normalized to total thermal power output. Bulk and spatial control of the neutron flux is accomplished by simultaneous (bulk) or differential (spatial) movement of the absorbers. Spatial control signals are derived from measurement of the power produced in 40 channels located throughout the core.

Booster rods containing fissile-enriched fuel enter the core perpendicular to the fuel channels and symmetrically from both sides of the core. This enriched fuel in the booster rods is used to:

- overcome the negative reactivity which arises upon collapse of voids resulting upon shutdown or a significant power reduction.
- provide xenon override capability.

Measurements were initially proposed for the reactor operating conditions listed in Section 3.3.1 (except (1), the shutdown condition). For these measurements, a pattern of

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\+ CRNL - Chalk River Nuclear Laboratories.

absorber movement was determined to establish a tilt axis through ion chamber C. Additional measurements with the booster fuel partially inserted in the core used an absorber movement pattern to establish an axis of flux tilting perpendicular to the direction of booster movement.

4. RESULTS AND THEIR INTERPRETATION

The initial program was broadened during commissioning to include application of noise measurements to additional parameters and reactor operating conditions. This diversity in application of noise measurement techniques will be illustrated by some of the results.

4.1 Results from Inherent Noise Measurements

4.1.1 System Pressure Oscillations

In the initial stages of the power increase during commissioning, significant resonances in nearly all system parameters were found to occur. A resonance at a frequency of 1 Hz occurred at approximately 6% F.P., disappeared at 8.5% F.P. and was replaced by a resonance at 1.5 Hz upon a further power increase to 9% F.P. This latter 1.5 Hz resonance then disappeared and was replaced by the resonance at 1 Hz for further power increases.

Typical power spectral densities obtained for reactor power levels of 6.5%, 8.5% and 9% full power (F.P.) are shown in Fig. 3 and 4. These results show that at a power level of 8.5% F.P., no resonances existed but for a 0.5% power increase a new significant resonance at 1.5 Hz appeared. The 1.5 Hz resonance was found to exist for only a narrow range of reactor power. The ratio of the 1.5 Hz resonance amplitude to the 1 Hz resonance amplitude, as detected by the flux sensors was less than their ratio as detected by the steam drum and header pressure signals (see Fig. 4). This was a direct result of the 180^{o} phase shift between 1.5 Hz resonances of the north and south coolant loops. If the pressure oscillation at 1.5 Hz in each of the loops was of equal magnitude, then the net effect of changes in core void (hence reactivity) would have only a small effect on induced flux changes. This observed 180^{o} phase difference and the narrow power range over which this resonance existed indicated that it probably arose in the system pressure control loop. This postulate was confirmed and the effect of the resonance significantly reduced by adjustment of the cams on the actuators of the steam by-pass valves.

This action reduced the effect of the 1.5 Hz resonance but the 1.0 Hz resonance still existed and continued to increase in amplitude with increasing reactor power.

Response function and cross-correlation analysis of the measured noise signals showed that the noise was nearly in-phase in both loops and was originating either in the steam drums and/or the systems external to the steam drums (steam supply to turbine and/or pressure control system).

On the basis of these analyses, at 25% F.P. a program was established to determine the source of the 1 Hz resonance. Within 3 hours of starting the measurements, it was found that the resonance could be eliminated by adjusting one of the gain factors of the system pressure controller. However, subsequent reactor operation showed that the required value of the gain factor to eliminate the oscillation reduced the response of the pressure controller to an unacceptable level. Therefore the power increase continued with some 1 Hz oscillation in the system. Increasing reactor power continued until 40% F.P. during which the amplitude of the oscillation continued to increase with power. Although the turbine had been operated for short intervals up to this power level, most of the steam generated was diverted directly to the condenser (turbine by-pass system) because the detailed turbine commissioning schedule had not been completed.

Measurements of noise at 40% F.P. as a function of coolant flow showed the amplitude of the oscillation depended on flow which determines core void volume and, therefore, continued growth in the amplitude of this oscillation upon further power increases could affect overall system control. Previous work had established that the oscillation originated in the pressure control system which included the regulation of the by-pass and turbine valves, etc. Since reducing the frequency response of the pressure controller by adjusting the gain apparently did not remove the source but only alleviated its consequences, it was deduced that the pressure controller was not the source of the oscillation. A schematic block diagram of the pressure control system is given in Fig. 5. It can be seen from this figure that reducing the response of the pressure controller at 1.0 Hz effectively decouples this frequency from the closed loop.

A second program was set up to determine the source of the oscillation in the complete pressure control system. Monitored parameters are shown schematically in Fig. 5 and given in Table II. Two sets of measurements were made with different gain settings of the significant pressure controller gain factor. Results from these measurements (Fig. 6 and 7) show that the noise at 1 Hz in all sensor signals is reduced with the change in the controller gain settings. However, Table III giving the ratio of the 1 Hz amplitude (before/after adjustment) shows that all components of the system respond in a similar manner (reduction in amplitude by a factor of 20 to 25) except for the servo-motor oil pressure signal where the amplitude was reduced by a factor of only 6. This indicated that attention should be concentrated in the area of the servo system activating the by-pass valves. Corrective actions to this system have resulted in very satisfactory control of system pressure to within 0.1% r.m.s. during normal steady-state operation.

This example illustrates a successful application of noise analysis techniques to a type of unexpected problem that can arise during commissioning of a power reactor.

4.1.2 Other Applications

Other areas where inherent noise measurements were also used successfully included use of:

- noise characteristics in the signals from the DP(flow) transmitters to set the level of mechanical damping of the DP transmitters.
- noise in the channel flow parameters to assess the probability of approaching "parallel channel instability".
- "noise characteristics" in signals from in-core detectors to assess the response of the in-core flux detectors.
- noise in parameters to determine signal/noise ratio in some of the "trip" circuits and therefore establish margins to "trip".
- noise analysis measurement techniques to obtain Lissajous figures giving the orbits of the centers of the primary heat transport motor-pump shaft assembly.

In addition to the above applications, noise measurements of the selected parameter set were taken for a range of reactor operating conditions. These showed that "boiling noise" was only of secondary importance; the primary contributors to noise were external disturbances originating in process systems entering the core and being amplified by the positive void effect. As a result of this effect it was found that adjustments to the pressure control system resulted in significant changes in measured noise characteristics.

4.2 Results from Imposed Noise Measurements

The objective of the program using imposed excitation of the control absorbers was to determine the response of the reactor to spatial disturbances. In the modal model of G-1 the first azimuthal mode after the fundamental was the most responsive and therefore the program was directed toward determining the response of the controlled and uncontrolled first azimuthal flux mode to spatial reactivity perturbations.

The response of the first azimuthal flux mode was measured for 13 reactor operating conditions covering the expected operating range. Data were analyzed to determine frequency response (gain and phase) functions. Comparison of some of the measured results to those obtained from a theoretical model (6) are shown in Fig. 8 and 9. Fig. 8 shows the measured first azimuthal response (gain and phase) of the uncontrolled flux for two different reactor operating conditions, 95% full power, 100% full flow; and 75% full power, 68% full flow. The solid lines are calculations using the modal model. Agreement of the shape of the measured gain curves and the absolute values of the phase with the model is reasonable. The measured gain values have been normalized to the theoretical predictions at 0.2 Hz. The major difference in the two theoretical curves is a 10% change in the reactivity coefficient associated with coolant density changes.

Fig. 9 shows the first azimuthal flux response (perpendicular to the booster axis) for both the controlled and uncontrolled reactor at 30% full power, 50% full flow and with the top 4 booster assemblies partially inserted. Partially inserting the booster assemblies into the core results in flattening the core flux in the direction of the boosters. This gives rise to an increased first azimuthal response in this direction. This increased response is characterized by the increased phase lag shown in Fig. 9 for the uncontrolled reactor.

In the G-1 reactor the spatial power distribution is measured at 40 channel locations representative of the active core. These measurements feed the control algorithm in the digita computer control system which sends drive signals to each o the 7 control absorbers. All 40 channel power measurements are used to determine the drive signal to each absorber (7).

Fig. 9 also shows a comparison of the measured to the calculated results for the controlled first azimuthal response. The agreement for both conditions is good except for larger deviations at the lower frequencies. In this frequency range the spatial control system, in operation during the measurements, severely attenuated the perturbations with a consequent lowering of the S/N ratio. This could account for the differences at the low frequencies.

In addition to first azimuthal flux to reactivity response functions, response functions were also obtained between:

- spatial thermal power to spatial reactivity.
- spatial thermal power to spatial neutron flux.
- out-of-core flux to in-core flux.
- various sectors of the control system.

The spatial response measurements were used in the commissioning of the present spatial control system and have indicated areas for improvement.

The present spatial control system has performed adequately under most operating conditions; however, control capabilities, required during certain transient operating modes to achieve high station performance, were considered to be insufficient. The measurements assisted in the design of an improved spatial control system, to be commissioned shortly, which will eliminate these deficiencies.

In addition to verification of theoretical space-time models, results have been used to obtain a map of the first azimuthal response as a function of reactor power and core coolant flow. This map should be useful to operations staff.

COMMUNICATION OF CONCLUSIONS TO COMMISSIONING, OPERATING AND DESIGN STAFF

The success of a program is dependent on prompt communication of results and conclusions to those personnel with a need-to-know and later to those people with a general interest.

In the case of the G-1 inherent noise measurements, results and conclusions were directly communicated to commissioning and operating staff as soon as available. In fact, some of the unscheduled measurements were done at the request of the commissioning staff and in these cases prompt action was taken on the basis of the results (e.g. the oscillation in the pressure system, adjustment of mechanical damping of the transmitters, etc.). Results from measurements which were not requested were communicated to the people concerned if action was considered warranted or for information purposes.

In the imposed noise measurement program, the amplitude versus time responses observed during the measurements were compared to expected responses. Relative and absolute differences were interpreted in terms of asymmetries in the spatial flux and power distributions and/or performance of the spatial control system. This enabled corrective actions to be undertaken promptly. Results from the off-line analyses were communicated to design and commissioning staff as soon as available and assisted in changing the control algorithm during commissioning to improve spatial control.

All measurements of significance to station operation have been analyzed. However, owing to the large amount of data, analyses are still continuing in areas which will yield information of use in the design of future CANDU systems.

6. SUMMARY

Our mission is to develop technical competence in the area of reactor noise and dynamics and in its application to the future development of the CANDU reactor system. Such expertise can contribute significantly to improved nuclear station performance. However, success in this area requires a considerable breadth and depth of experience in the field and consistent significant successes have been obtained mainly by workers who have devoted considerable effort to the topic.

Recognizing that to be successful a program will require growth of continuing support, our continuing general objectives are:

- Development - of the required technology.
- Application - of promising programs to nuclear systems.
- Expansion - of effort by transfer of the technology to interested users.
- Advancement - of the state-of-the-art and extension of the application areas.

A major part of this program is in the successful application of programs to nuclear systems. This involves transfer of promising technology from laboratories to nuclear power stations. A successful program requires:

- Acceptance - of the measurement program by the various groups involved.
- Formulation - of the experimental program within the imposed constraints.
- Development - of the required analytical tools for planning, execution and processing data.
- Interpretation - of data.
- Communication of conclusions to design, commissioning and operating staff.

A measurement program based on these factors has been successful at the G-1 station. This success has led us to conclude that some (maybe not all) of the forecast benefits attainable through exploitation of nuclear system noise may come true.

ACKNOWLEDGEMENTS

I am extremely grateful to all the people who contributed to the noise program.

I would like to thank A. Dahlinger (AECL) and P.A. Léger (Hydro-Quebec) for their co-operation in making the measurement program at Gentilly-1 possible. Contributions to success have been made by the following groups: The Gentilly-1 Operations (C. Boulay) and Technical (L.F. Monier) staffs of Hydro-Quebec, Reactor Control (W.R. Cooper), Systems Analysis (D.B. Primeau), NRU and NRX Operations (C.A. Herriot), Electronics, Control and Instrumentation (A. Pearson), Reactor Physics (E. Critoph), all of AECL. Significant individual contributions have been made by: P.J. Smith and D.G. Stewart of AECL, J.D. Kendall (James D. Kendall Consultants Ltd.) and P.M. Cloutier (CANATOM, formerly of Hydro-Quebec).

I would also like to acknowledge contributions by C.H. Millar in initiating this program in 1966 and for suggestions on the presentation of this report.

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TABLE I

SENSORS USED IN GENTILLY-1 NOISE (INHERENT) MEASUREMENT PROGRAM

SENSOR	OUTPUT (VOLTS)	RANGE (UNITS)
CHANNEL K9(S)[1]		
DP INLET	-1 → -5	0 → 100% (F.S.)[2]
DP OUTLET	-1 → -5	0 → 100% (F.S.)
INLET PRESS.	-1 → -5	0 → 1000 (psig)
OUTLET PRESS.	-1 → -5	0 → 900 (psig)
CHANNEL L12(N)[3]		
DP INLET	-1 → -5	0 → 100% (F.S.)
DP OUTLET	-1 → -5	0 → 100% (F.S.)
INLET PRESS.	-1 → -5	0 → 1000 (psig)
OUTLET PRESS.	-1 → -5	0 → 900 (psig)
CHANNEL T14(N)		
DP INLET	-1 → -5	0 → 100% (F.S.)
DP OUTLET	-1 → -5	0 → 100% (F.S.)
INLET PRESS.	-1 → -5	0 → 1000 (psig)
HEAT TRANSPORT SYSTEM		
NORTH STEAM DRUM PRESS.	-1 → -5	0 → 900 (psig)
NORTH INLET HEADER PRESS.	-1 → -5	0 → 1000 (psig)
SOUTH STEAM DRUM PRESS.	-1 → -5	0 → 900 (psig)
SOUTH INLET HEADER PRESS.	-1 → -5	0 → 1000 (psig)
NEUTRON FLUX		
OUT-OF-CORE ION CHAMBER	0 → +3	0 → 100% (F.S.)
SELECTED IN-CORE DETECTORS	0 → -1	0 → 100% (F.S.)

(1) S = South coolant loop
(2) F.S. = Full Scale
(3) N = North coolant loop

TABLE II

PRESSURE CONTROL SYSTEM SIGNALS

SIGNAL SOURCE AND IDENTIFICATION	DATA NAME	PRESSURE RANGE (psig)	SIGNAL RANGE (VOLTS)
P601 Steam Pressure	South By-Pass P601	600 → 900	-1 to -5V
PRF M50 Output	M50 Out	0 → 72.5	-1 to -5V
Pu Selector Relay Output to Servo	Pu Select	0 → 72.5	-1 to -5V
P_s Servo Motor(2) Oil [Left (North) By-Pass]	Servo Motor	0 → 500	-1 to -5V
P_p 8, Control Oil	Control Oil	0 → 100	-1 to -5V
P_p 30, Servo Oil	Servo Oil	0 → 600	-1 to -5V
South Steam Drum Press	South Drum Press.	0 → 900	-1 to -5V
South Header Press	South Head Press.	0 → 1500	0 to +5V

TABLE III

<u>RATIO OF PRESSURE CONTROL AND TURBINE SYSTEM PARAMETERS</u>

<u>BEFORE ADJUSTMENT/AFTER ADJUSTMENT OF M50 CONTROLLER</u>

RATIO $\left(\frac{\text{BEFORE}}{\text{AFTER}}\right)$	SOUTH BY-PASS	M50 OUTPUT	SELECTOR RELAY OUTPUT	CONTROL OIL	SERVO OIL	SERVO MOTOR	SOUTH DRUM PRESS	SOUTH HEAD PRESS
MEAN	1.001	1.006	1.004	1.000	0.999	0.992	0.989	0.990
r.m.s.	5.64	1.10	4.82	2.31	5.94	2.89	3.41	1.13
pk-pk	4.10	1.28	3.83	1.70	3.08	1.85	2.89	1.31
$\sqrt{AMP^2}$ @ 1.11 Hz	23.2	28.7	25.3	15.3	26.4	5.92	25.1	18.8

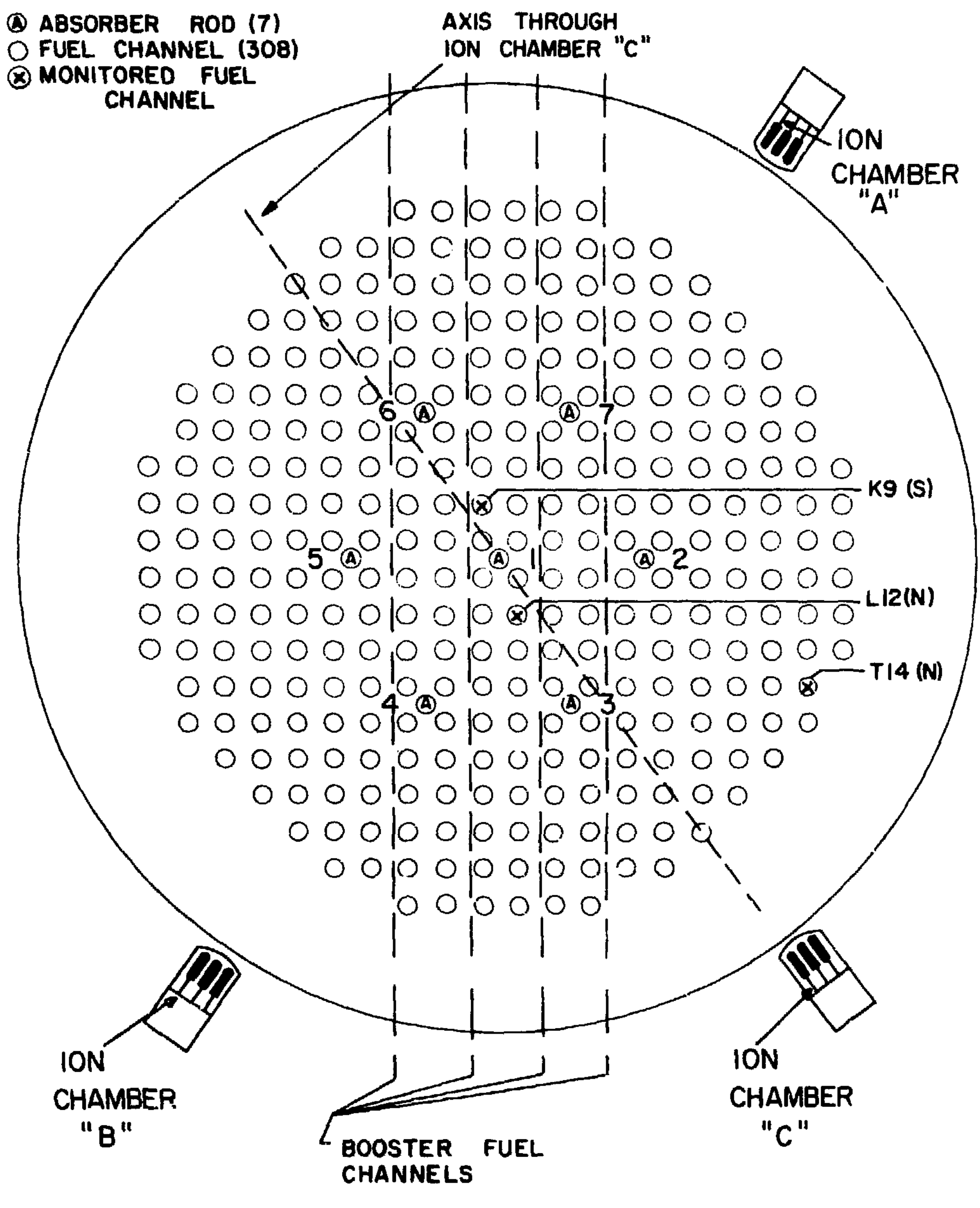

Fig. 1 Schematic Diagram of the Gentilly Reactor Core.

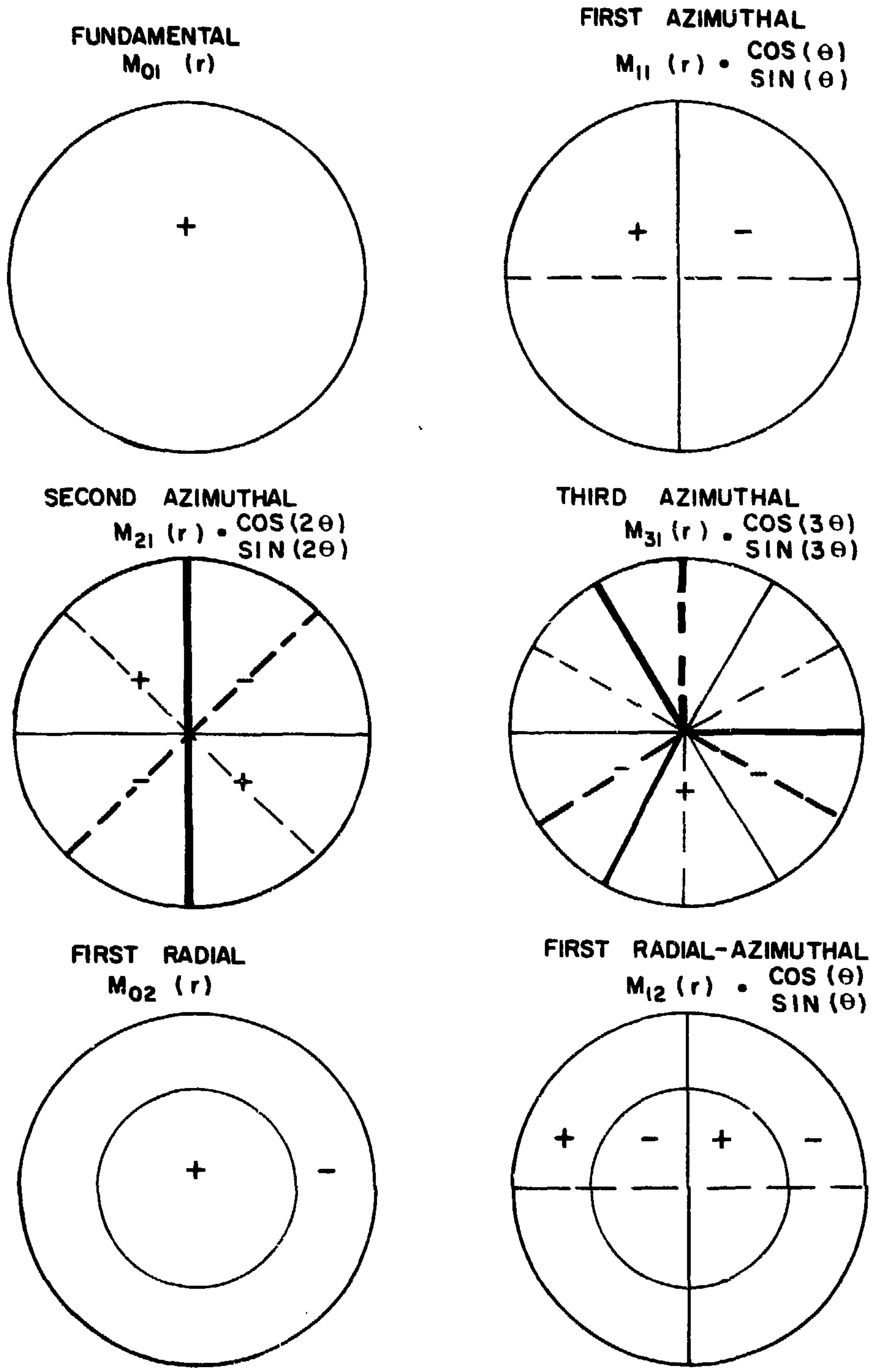

Fig. 2 Schematic Diagram of Typical Spatial Neutron Flux Modes.

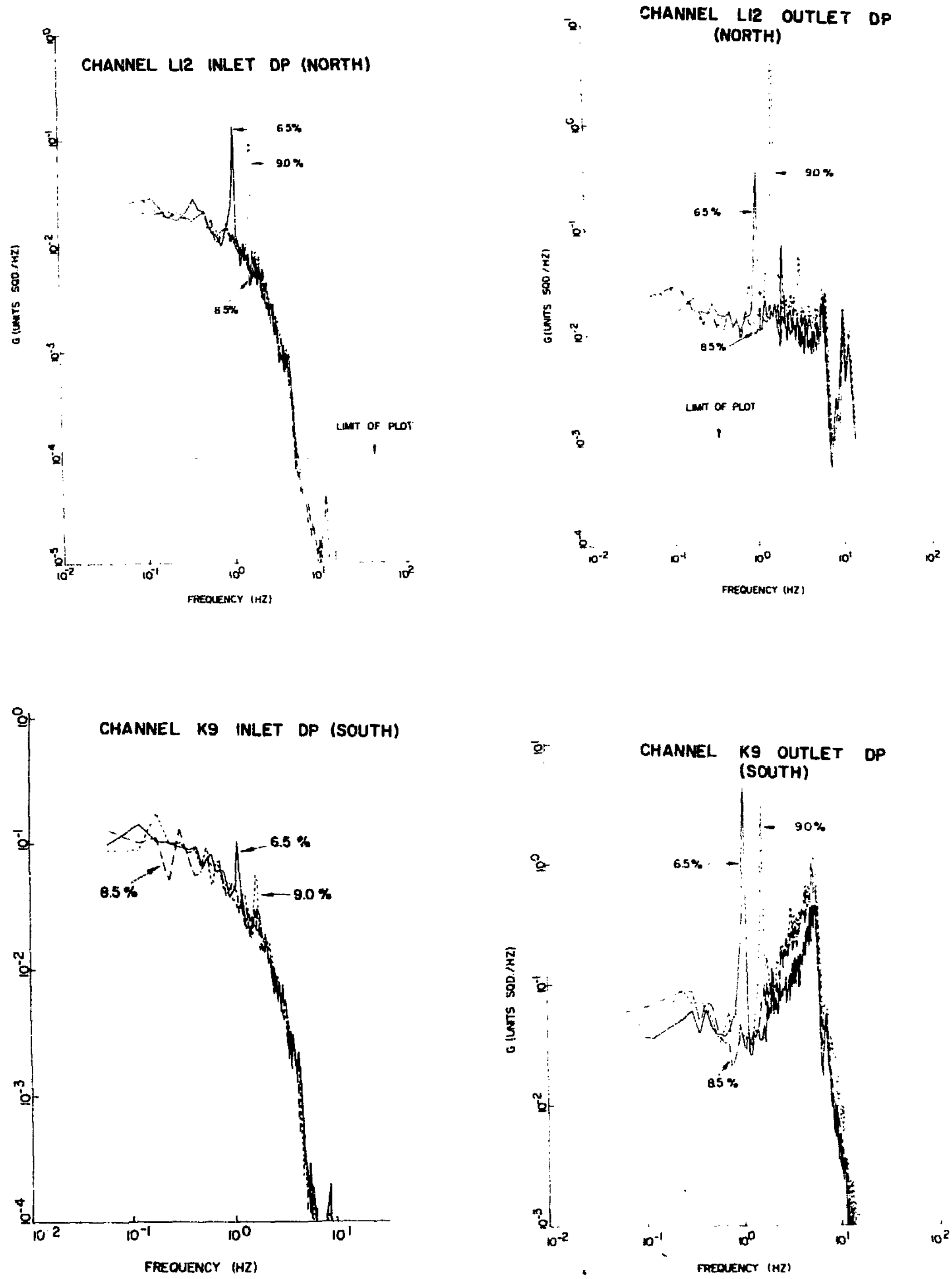

Fig. 3 Power Spectral Densities Obtained from Channel Parameter Signals During Low-power Reactor Operation.

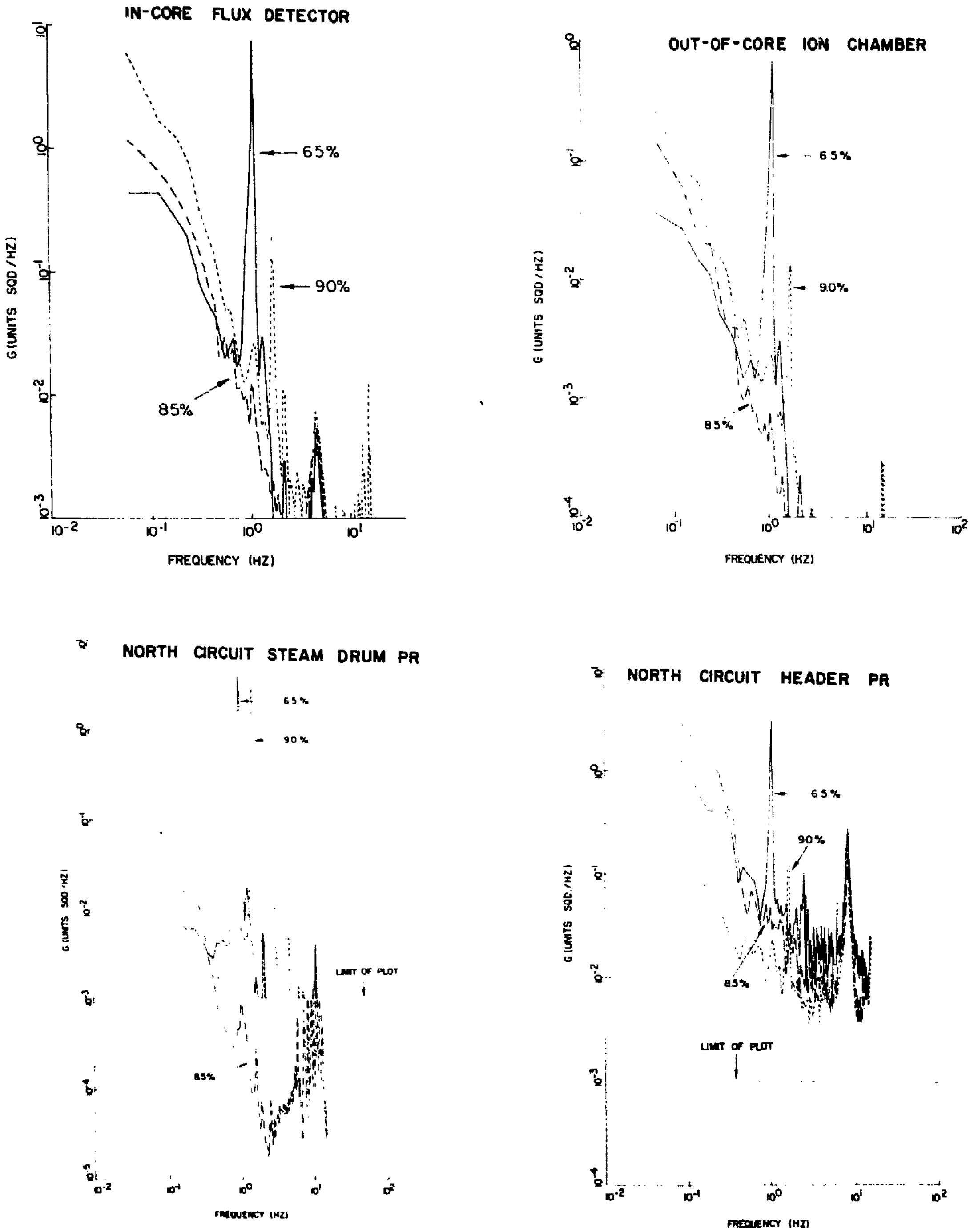

Fig. 4 Power Spectral Densities Obtained From Nuclear System Parameters During Low-power Reactor Operation.

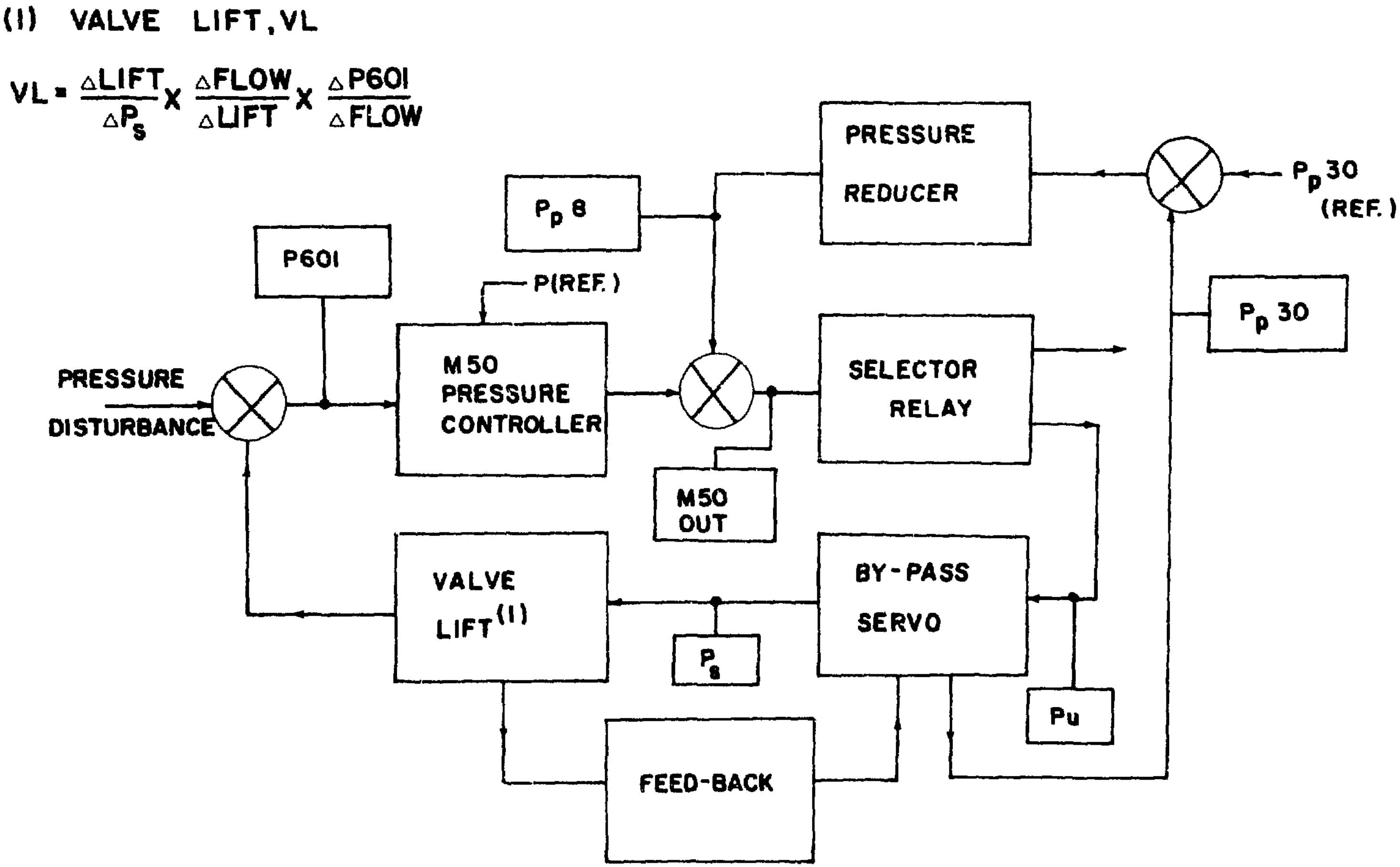

Fig. 5 Schematic Diagram of the Pressure Control System in By-pass Operation.

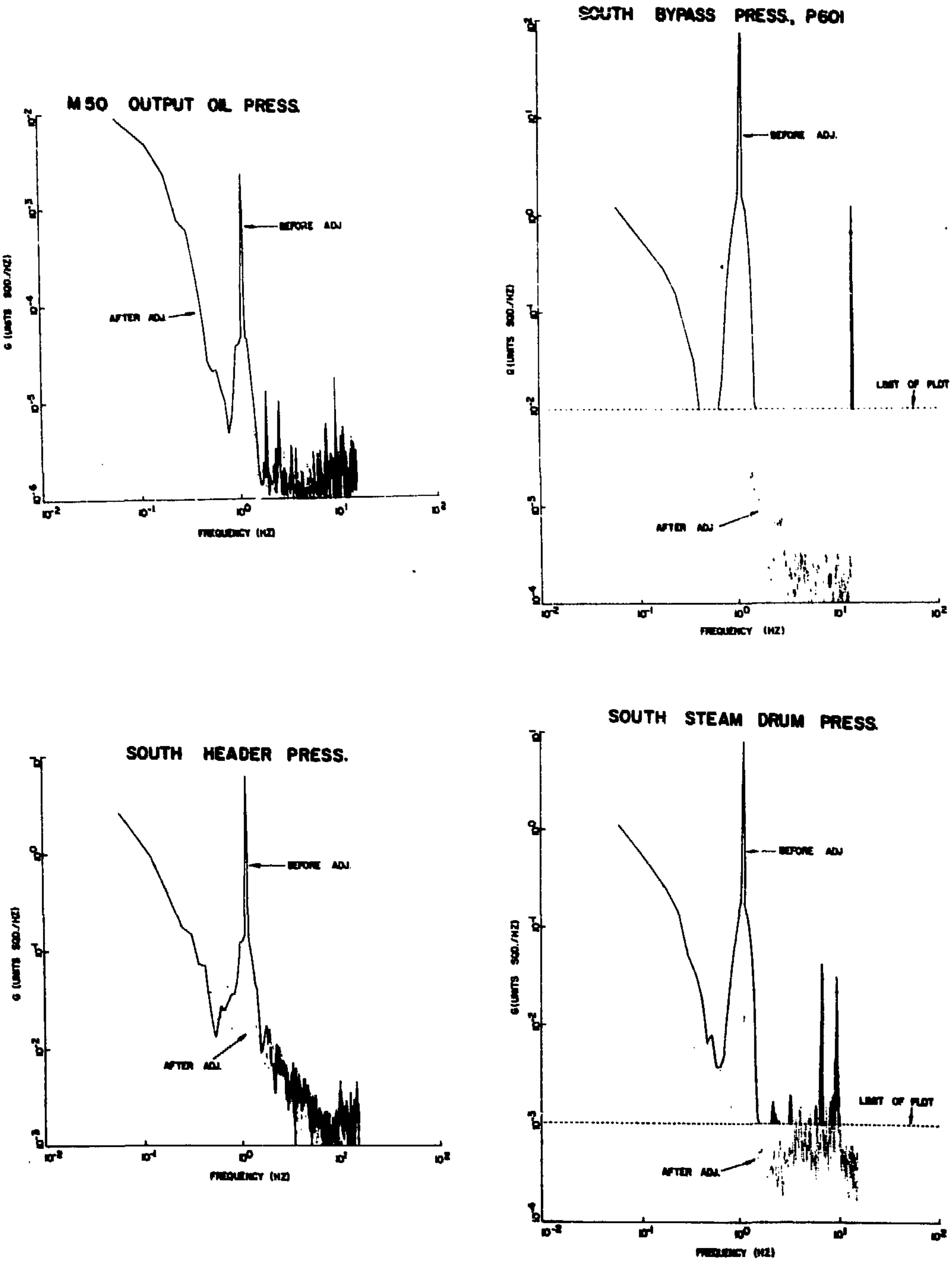

Fig. 6 Power Spectral Densities Obtained from Pressure Control System Parameters During the 1 Hz Investigation.

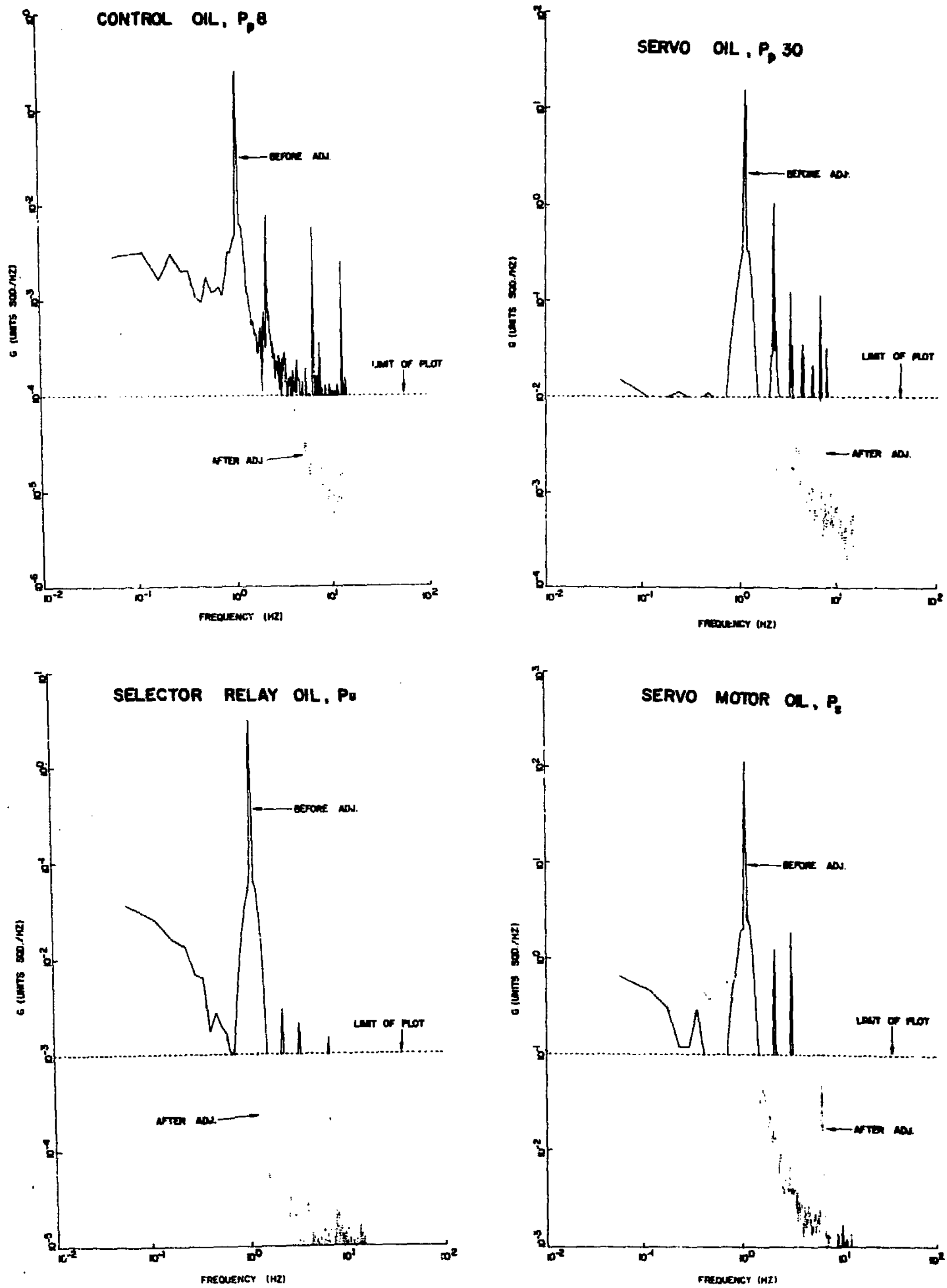

Fig. 7 Power Spectral Densities Obtained From Pressure Control System Parameters During the 1 Hz Investigation.

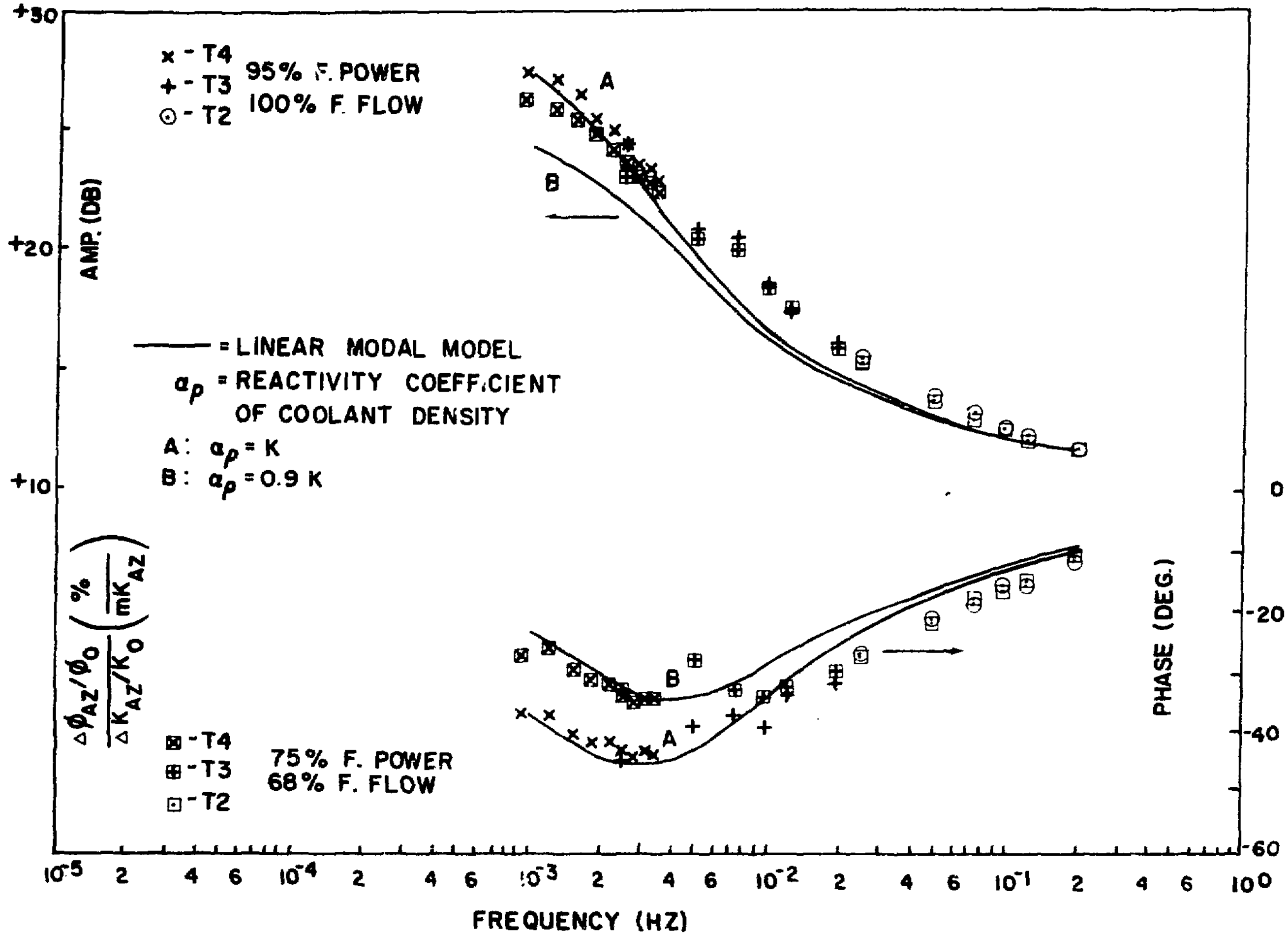

Fig. 8 First Azimuthal Uncontrolled Response Functions for Reactor Conditions of 95% Full Power, 100% Full Flow; and 75% Full Power, 68% Full Flow.

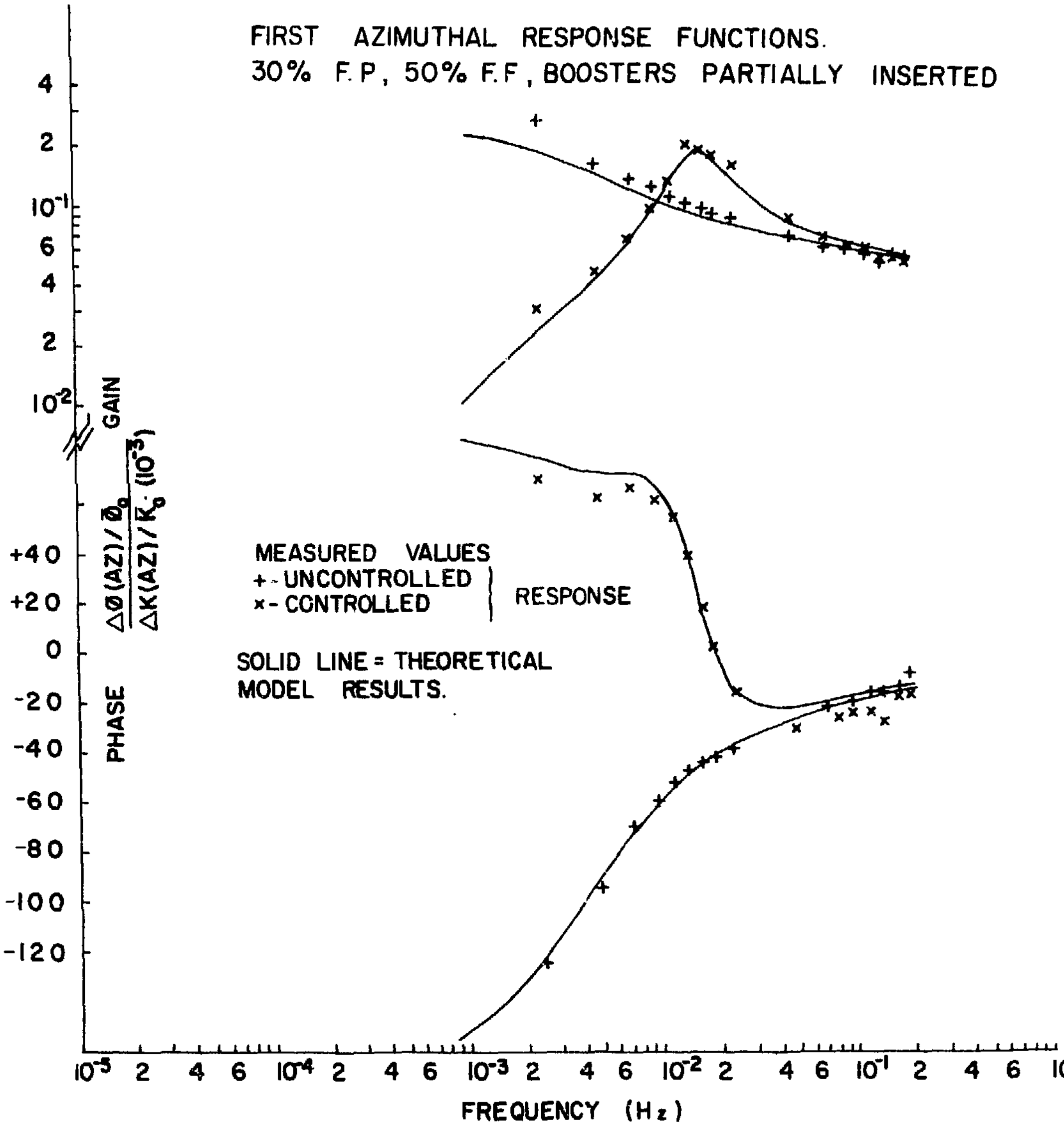

Fig. 9 First Azimuthal (Uncontrolled and Controlled) Response Functions for a Reactor Condition of 30% Full Power, 50% Full Flow and Top Booster Assemblies Partially Inserted.

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