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LICENSING TOPICAL REPORT

ASSESSMENT OF REACTOR INTERNALS VIBRATION IN BWR/4 AND BWR/5 PLANTS (AMENDMENT NO. 2)

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ABSTRACT

This second amendment to the General Electric Company Licensing Topical Report NEDE-24057-P, "Assessment of Reactor Internals Vibration in BWR/4 and BWR/5 Plants", is to document a summary of results of the Tokai-2 Instrumented Reactor Internals Vibration Testing Program.

Tokai-2 is a 251-in. BWR/5 plant. All results are shown to be within acceptable limits.

1. INTRODUCTION

Vibration of reactor internals was monitored during pre-operational and startup testing at the Japan Atomic Power Company's Tokai-2 Plant. This testing occurred from October 12, 1977 to July 12, 1978.

Tokai-2 is a General Electric Company BWR/5 of 251-in. vessel diameter containing 764 fuel assemblies.

2. SUMMARY

Section 3 of this report contains a brief description of the BWR reactor internals including differences between BWR/4 and BWR/5 plants. Section 4 describes the vibration test program conducted at Tokai-2. This includes a description of sensor types and locations and a definition of the various test conditions. Section 5 presents a summary of the vibration measurement program results for Tokai-2. General vibration characteristics of the various components and assemblies are discussed, and measured vibration amplitudes are compared with test acceptance criteria. Section 6 describes the data analysis method used in the evaluation of test results and the analytical basis for the test acceptance criteria. Application of the test results is discussed in Section 7.

The key conclusions in Section 8 are summarized as follows:

1. The test results demonstrate the adequacy of BWR/5 251-in. vessel size internals with respect to vibration.

2. All quantitative measurements were found to be within acceptable limits.

3. The BWR/5 jet pump design, which differs from the BWR/4 jet pump design, showed vibration amplitudes within acceptable limits and exhibited vibration characteristics similar to that observed in other BWR plants.

3. DESCRIPTION OF INTERNALS

Figure 3-1 shows the BWR reactor internals and the locations of instrumented components at Tokai-2. A comparison of BWR/4 and BWR/5 reactor internals design is as follows:

(1) The shroud and shroud head assembly - includes the steam separator and standpipe assemblies, which are attached to each other and to the shroud head. Steam separators are of the same design in all BWR/4 and BWR/5 plants.

(2) The fuel assemblies - are supported vertically by the fuel support castings and control rod guide tubes and laterally by the shroud through the core plate and the top guide. The same standard fuel design is used in BWR/4 and BWR/5 plants.

(3) The jet pump assemblies - each consists of a riser pipe and two jet pumps. Support points are at the inlet nozzle, the riser brace, and the shroud support plate. The BWR/5 jet pump design differs from the BWR/4 design, including the use of a 5-hole nozzle.

(4) The control rod guide tubes - provide vertical support to the fuel assemblies and are, in turn, supported by the control rod housings, the stub tubes, and the bottom head. These are of the same design in all BWR/4 and BWR/5 plants. The design of the Δ pressure/liquid control line is different for BWR/5 plants.

(5) The incore housing, guide tube, and stabilizer assembly - the housings extend up through the bottom head and are welded to the guide tubes which extend up to the core plate. The incore guide tubes are attached to each other at approximately midspan by stabilizer bars. This design is also common to BWR/4 and BWR/5 plants.

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(6) The incore instrument tubes - extend up through the incore housings and guide tubes and between the fuel channels in the core region. These are the same for BWR/4 and BWR/5 plants.

(7) The feedwater spargers - supported at the inlet thermal sleeve and at each end of the header. Feedwater sparger attachment methods include welded, interference fit and triple thermal sleeve designs (see Table 4-1).

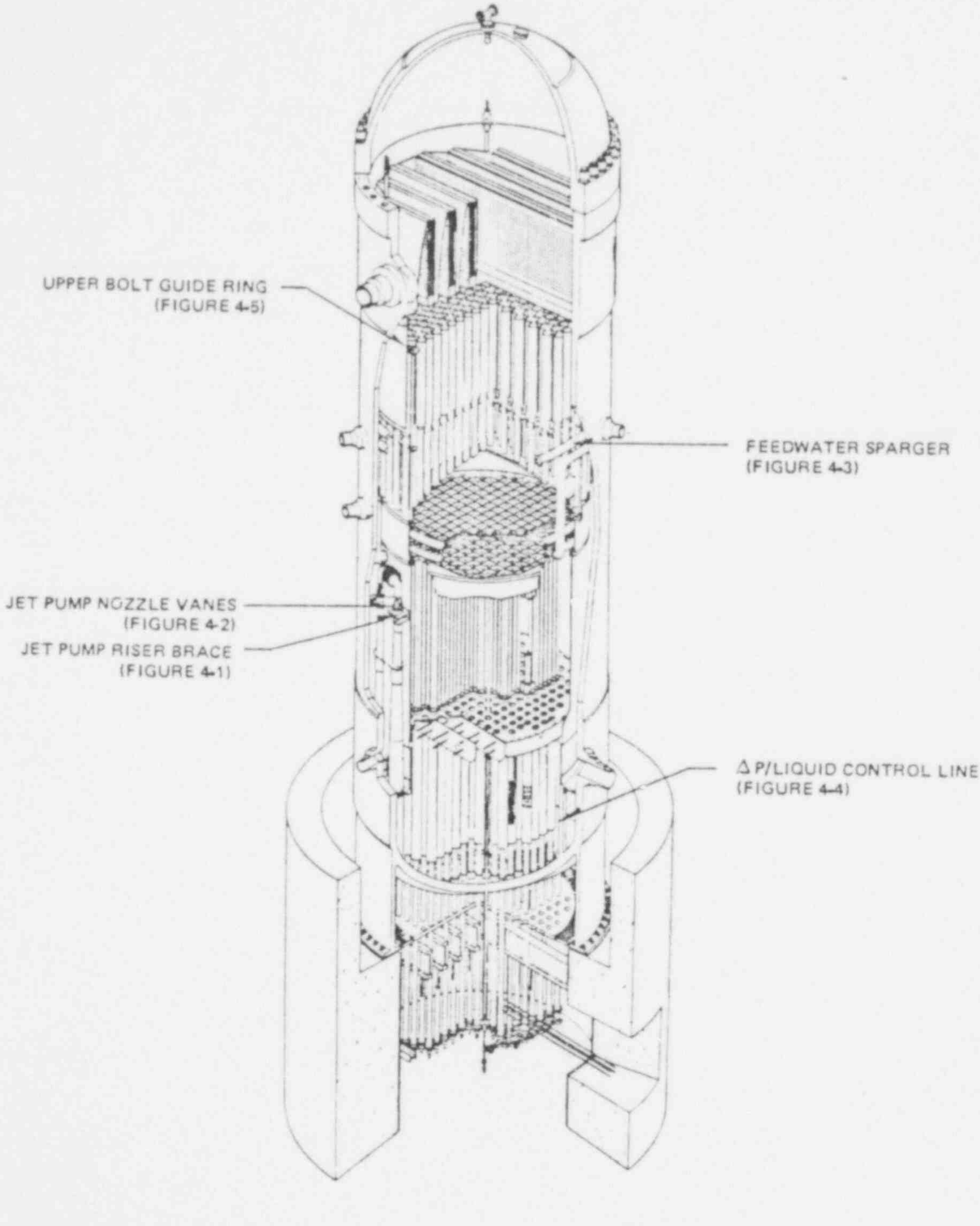

Figure 3-1. Locations of Instrumented Components

4. TEST DESCRIPTION

4.1 TEST SCOPE

Table 4-1 is an updated summary of the internals vibration test program for BWR/4 and BWR/5 plants. This table describes the components which are instrumented and the tests and measurements which are performed.

For Tokai-2, the test scope was as follows:

- 251-BWR/5 Prototype (Tokai-2)

  Shroud Head Assembly
  Jet Pump Assemblies
  Feedwater Spargers (Welded)
  ΔP and Liquid Control Line

Section 7 discusses future vibration program test plans outlined in Table 4-1.

4.2 SENSOR TYPES AND LOCATIONS

Vibration measurement sensors used at Tokai-2 were strain gages and accelerometers. In addition, photocell sensors were used as recirculation pump speed indicators.

Table 4-2 summarizes the location of internal vibration instrumentation sensors installed at Tokai-2. Sensor numbers are prefixed by A for accelerometer and S for strain gages.

The strain gages, which were manufactured by Ailtech (Model SG 125), consist of a nickel-chrome alloy filament in a Type-321 stainless steel tube of 0.040-in.

diameter, with an integral flange for spot welding. The effective gage length is one inch. The strain gages were used to measure the dynamic strain in the following components:

(1) Jet Pump Riser Braces - the Tokai-2 installation is shown in Figure 4-1.

(2) Jet Pump Nozzle Vanes - the Tokai-2 installation is shown in Figure 4-2.

(3) Feedwater Sparger - Figure 4-3 shows the as-installed sensor locations for the Tokai-2 spargers.

(4) Differential Pressure and Liquid Control Line - Figure 4-4 shows the sensor locations for Tokai-2.

Vibration of the shroud head and steam separator assembly was measured using Validyne variable reluctance accelerometers located on the upper bolt guide ring. Figure 4-5 gives the guide ring sensor locations. The sensitive axis of the accelerometers is in the tangential direction. The specified frequency response of these sensors is 0 to 50 Hz. They are used in conjunction with a double integrator to provide the dynamic displacement response from 2 to 50 Hz.

Recirculation pump speeds, which have been found to correlate with vibration frequency in some cases, were measured with two photocell and lamp assemblies which sense changes in light caused by black marks on the pump-motor coupling. Electrical pulses are produced and recorded once per revolution. The frequency of the pulses is the pump rotational speed.

4.3 TEST CONDITIONS

At Tokai-2, vibration measurements were made during preoperational, precritical, and power operational test conditions. Data were recorded during preoperational testing from October 12 to October 15, 1977. Precritical testing, following fuel loading, began January 27 and ended January 29, 1978. Vibration data were taken at various flow rates during preoperational and precritical testing. Operational testing included 75% load line testing on May 9, 1978 and 100% load line testing from June 6 to July 12, 1978.

During operational testing, vibration measurements were made at various flow rates while keeping the rod pattern at 75% and 100% power configurations. Operating condition during each test period included steady-state balanced flow, unbalanced flow, single loop operation, and transient tests consisting of one-pump and two-pump trips from rated flow conditions.

4.4 DATA ACQUISITION SYSTEM

The vibration measurement system is composed of the transducers, the signal conditioning units, magnetic tape recorders, and chart recorders. Figures 4-6 and 4-7 are block diagrams of the strain gage and accelerometer systems.

Strain gages are used either singly or in pairs, to form a quarter or half of a Wheatstone bridge circuit. Excitation is provided at 5V and 3kHz. The modulated 3kHz signal is converted to ± 1 Vdc for ± 100 microstrain (με) by the demodulator. The oscillator and demodulator are Validyne models MC 1-20 and CD-19, respectively.

A 3kHz excitation voltage is provided to the accelerometer by the special balance unit. A linear amplifier and double integrator is used to convert the accelerometer output to displacement units. These Validyne Model AM49 units have a frequency response of 2 Hz to 5 kHz.

The demodulated signals are recorded on tape and chart recorders. The 14-channel FM tape recorders, operated at 15 inches per second, have a center frequency of 27 kHz and an information frequency range of zero to 5 kHz. The 6-channel brush chart recorders have channel widths of 40 mm with 50 divisions per channel. The frequency response of the pen is 40 Hz at full scale and 100 Hz at 10 divisions. Data can also be recorded on a high-speed 6-channel oscillograph recorder (Honeywell model 1858, 0 to 5 kHz).

System calibration procedures provide an overall sensitivity of 0.0005 inch (1/2 mil) per chart division for the double-integrated accelerometer output, and 5 $\mu\epsilon$ per chart division for the strain gages. The tape recorder input sensitivity is 0.010 inch per volt for the accelerometers and 100 $\mu\epsilon$ per volt for strain gages.

Table 4-1

REACTOR INTERNALS VIBRATION PROGRAM FOR BWR 4 AND 5 PLANTS

	INTERNALS DESIGN CHARACTERISTICS Core and Shroud Structure									Jet Pumps							VIBRATION TEST PROGRAM Instrumented Components							Tests and Measurements				Note
	Vessel Diameter (I.D., inches)	Product Line	Power, MWt	Recirculation Flow lb/hr, x 10^6	Number of Fuel Assemblies	Shroud Diameter (O.D., inches)	Number of Steam Separators	Shroud Support Legs	FW Sparger Attachment	Nozzle Type (holes per Nozzle)	Nozzle Velocity ft/sec	Length of Mixer, inches (approx.)	Length of Diffuser, inches (approx)	Diameter at Discharge, inches	Discharge Velocity, ft/sec	Ratio of Driven Flow to Drive Flow (M)	Jet Pumps	Shroud	Shroud Head	Control Rod and In-Core Guide Tubes	Feedwater Spargers	Fuel Channels	In-Core Instrument Tuves	Preoperational Flow Test and Inspection	Preoperational Vibration Measurements	Precritical Vibration Measurements	Startup Vibration Measurements	
Duane Arnold	183	4	1593	49.0	368	145	108	yes	I	1	159	89	119	14.1	16.9	1.39	X	X	X	X				X	X	X	X	(1)
Chinshan I	201	4	1775	53.0	408	165	130	yes	W	1	162	89	107	14.1	14.6	1.30	X	X	X		X			X	X	X	X	(1)
Bailly	201	5	1931	61.5	444	165	130	no	T	5	191	56	145	14.1	16.9	1.92	X		X					X	X	X	X	
Fitzpatrick	218	4	2436	77.0	560	178	163	no	T	1	160	100	100	17.1	14.4	1.25	X	X	X			X		X	X	X	X	(1)
Cooper	218	4	2381	73.5	548	178	151	no	T*	1	160	100	100	17.1	13.2	1.15	X		X							X	X	(1)
Hatch 1	218	4	2436	78.5	560	178	163	no	T	1	160	100	100	17.1	14.7	1.30	X		X								X	(1)
Hatch 2	218	4	2436	77.0	560	178	163	no	W	1	160	100	100	17.1	14.4	1.25								X				(1)
Brunswick 1	218	4	2436	77.0	560	178	163	yes	W	1	160	100	100	17.1	14.4	1.25	X		X		X						X	(1)
Brunswick 2	218	4	2436	77.0	560	178	163	yes	I	1	160	100	100	17.1	14.4	1.25	X		X		X					X	X	(1)
Shoreham	218	4	2436	77.0	560	178	163	no	T	1	160	100	100	17.1	14.4	1.25								X				
Zimmer	218	5	2436	78.5	560	178	163	yes	W	5	208	57	142	17.1	14.7	2.19	X		X					X	X	X	X	
Browns Ferry 1	251	4	3293	102.5	764	207	211	yes	T*	1	187	110	87	19.1	15.3	2.00	X	X	X	X				X	X	X	X	(1)
Browns Ferry 2	251	4	3293	102.5	764	207	211	yes	T	1	187	110	87	19.1	15.3	2.00	X		X		X						X	(1)
Browns Ferry 3	251	4	3293	102.5	764	207	211	yes	T*	1	187	110	87	19.1	15.3	2.00	X		X		X		X			X	X	(1)
Peach Bottom 2 and 3	251	4	3293	102.5	764	207	211	yes	T*	1	187	110	87	19.1	15.3	2.00	X	X									X	(1)
Susquehanna 1 and 2	251	4	3293	100.0	764	207	225	yes	T	1	187	110	87	19.1	15.0	1.92								X				
Hope Creek 1 and 2	251	4	3293	100.0	764	207	225	yes	T	1	187	110	87	19.1	15.0	1.92								X				
Limerick 1 and 2	251	4	3293	100.0	764	207	225	yes	T	1	187	110	87	19.1	15.0	1.92								X				
E Fermi 2	251	4	3293	100.0	764	207	225	no	T	1	187	110	87	19.1	15.0	1.92								X				
Tokai 2	251	5	3293	106.5	764	207	225	yes	W	5	228	67	132	19.0	15.9	1.98	X		X		X		X	X	X	X	X	(1)
Lasalle 1	251	5	3293	108.5	764	207	225	no	T	5	228	61	132	19.0	16.2	2.04	X							X	X	X	X	
Lasalle 2	251	5	3293	108.5	764	207	225	yes	T	5	228	61	132	19.0	16.2	2.04								X				
Hanford 2	251	5	3323	108.5	764	207	225	yes	W	5	228	61	132	19.0	16.2	2.04	X		X								X	
Nine Mile Point 2	251	5	3323	108.5	764	207	225	yes	T	5	228	61	132	19.0	16.2	2.04								X				

Notes: (1) Test Complete

I = Interference fit.
T = Triple thermal sleeve.
W = Welded.
*Operating plants which have committed to a triple thermal sleeve but hardware not yet installed.

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Table 4-2

TOKAI-2 SENSOR LOCATIONS

Location	Sensor
SHROUD HEAD	
Tangential motion at upper bolt guide ring	A1, A2, A3, A4
JET PUMPS	
Jet Pump Pair 5-6	S25, S26, S27, S28
Jet Pump Pair 9-10	S29, S30, S31, S32
Jet Pump Pair 11-12	S33, S34, S35, S36
Jet Pump Pair 15-16	S37, S38, S39, S40
NOZZLE VANES*	
Jet Pump 5	S1, S2, S3
Jet Pump 6	S4, S5, S6
Jet Pump 9	S7, S8, S9
Jet Pump 10	S10, S11, S12
Jet Pump 11	S13, S14, S15
Jet Pump 12	S16, S17, S18
Jet Pump 15	S19, S20, S21
Jet Pump 16	S22, S23, S24
CORE PLATE DIFFERENTIAL PRESSURE AND LIQUID CONTROL LINE	
Top	S59, S60, S61, S62
Bottom	S63, S64, S65, S66

Table 4-2 (Continued)

Location	Sensor
FEEDWATER SPARGERS	
30° Sparger	S41, S42
90° Sparger	S43, S44
150° Sparger	S45, S46, S47, S48 S49, S50, S51, S52
210° Sparger	S53, S54
270° Sparger	S55, S56
330° Sparger	S57, S58

*One sensor on each jet pump nozzle vane is used as a spare.

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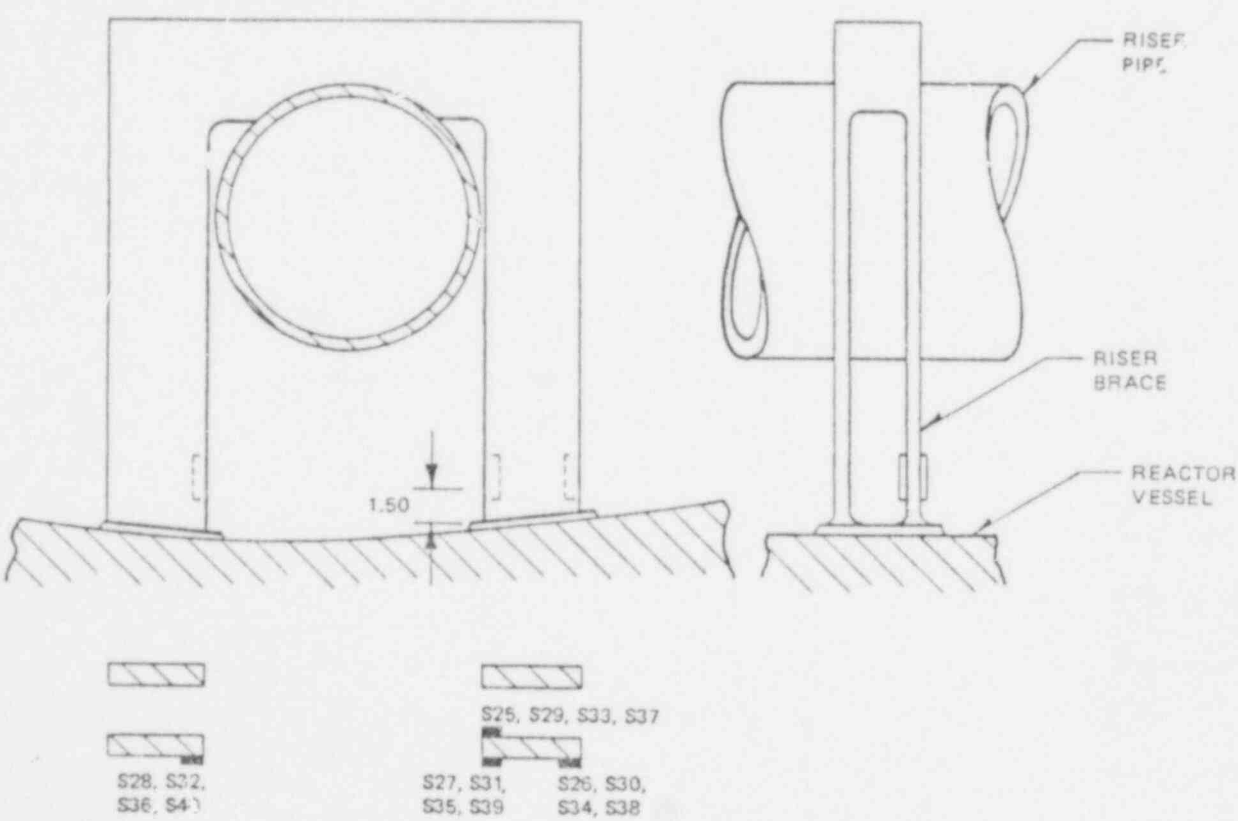
TYPICAL SENSOR CONNECTIONS	
S25 } S27 }	BENDING BRIDGE CONNECTION
S26 } S28 }	SWITCHABLE BRIDGE CONNECTION



NOTE: Sxx DENOTES STRAIN GAGE LOCATION

Figure 4-1. Strain Gage Locations on Jet Pump Riser Braces

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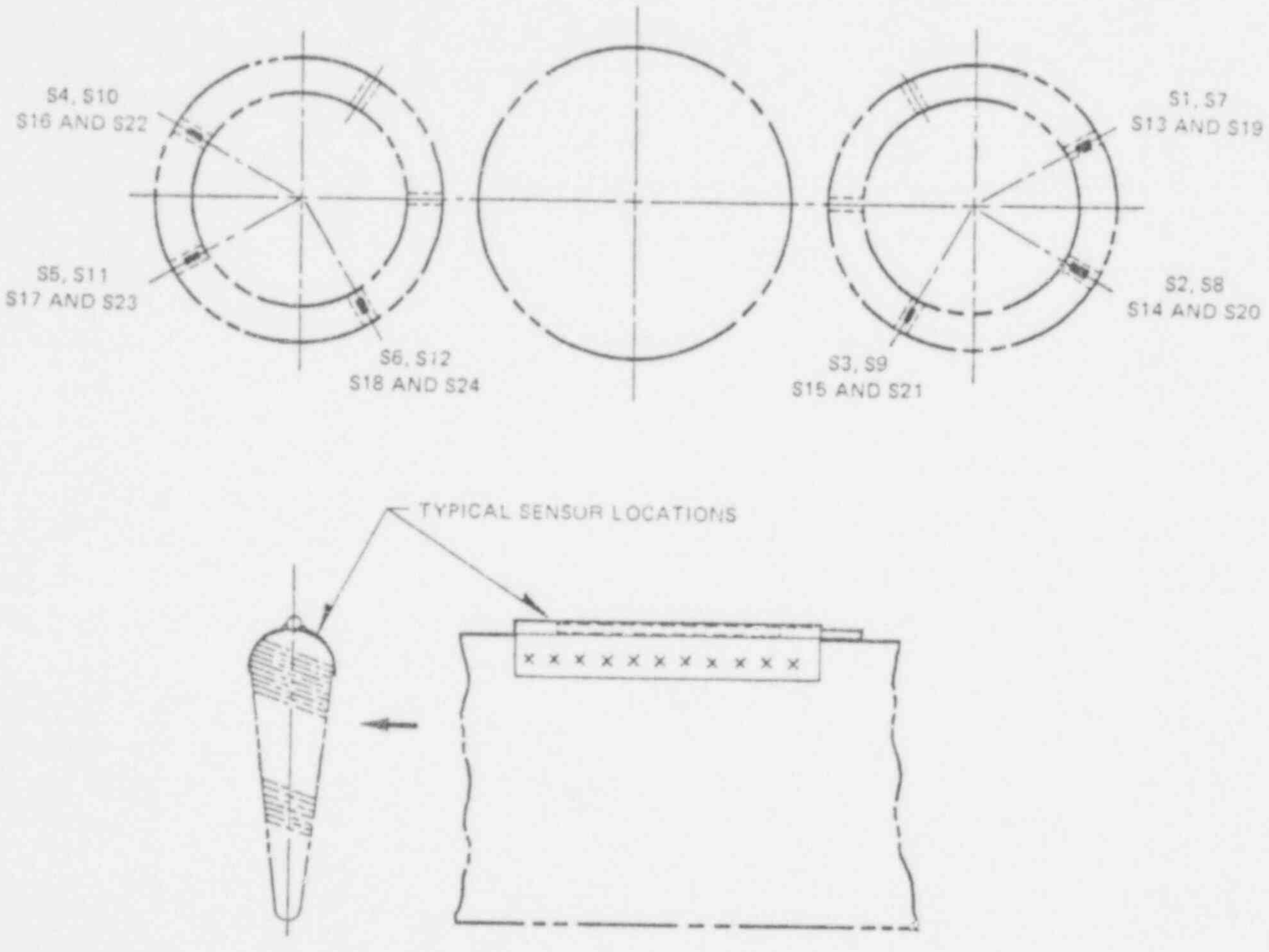
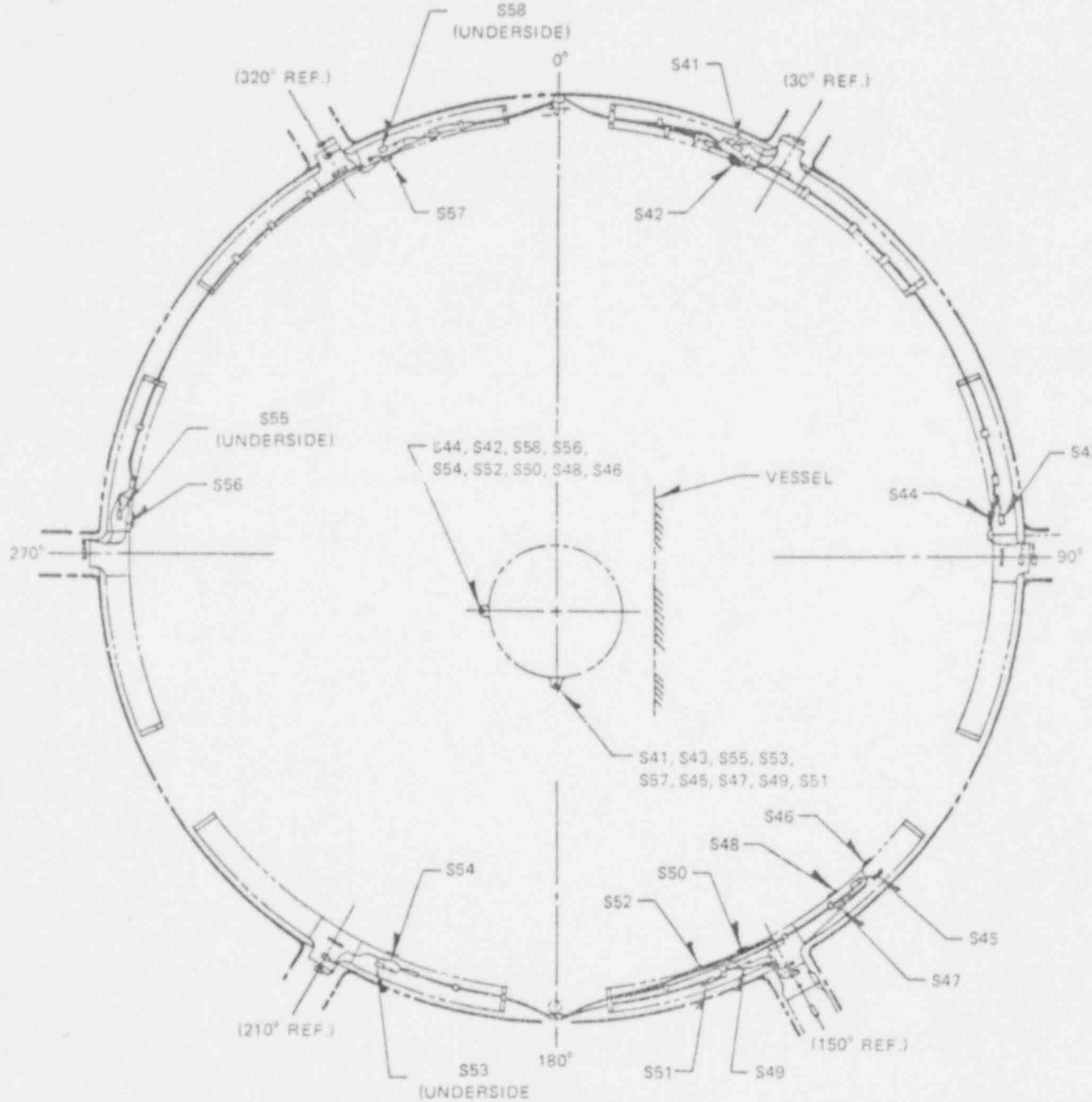


NOTE: Sxx DENOTES STRAIN GAGE LOCATIONS.

Figure 4-2. Jet Pump Vane Sensor Locations



NOTE: Sxx DENOTES STRAIN GAGE LOCATIONS.

Figure 4-3. Strain Gage Locations on Feedwater Spargers

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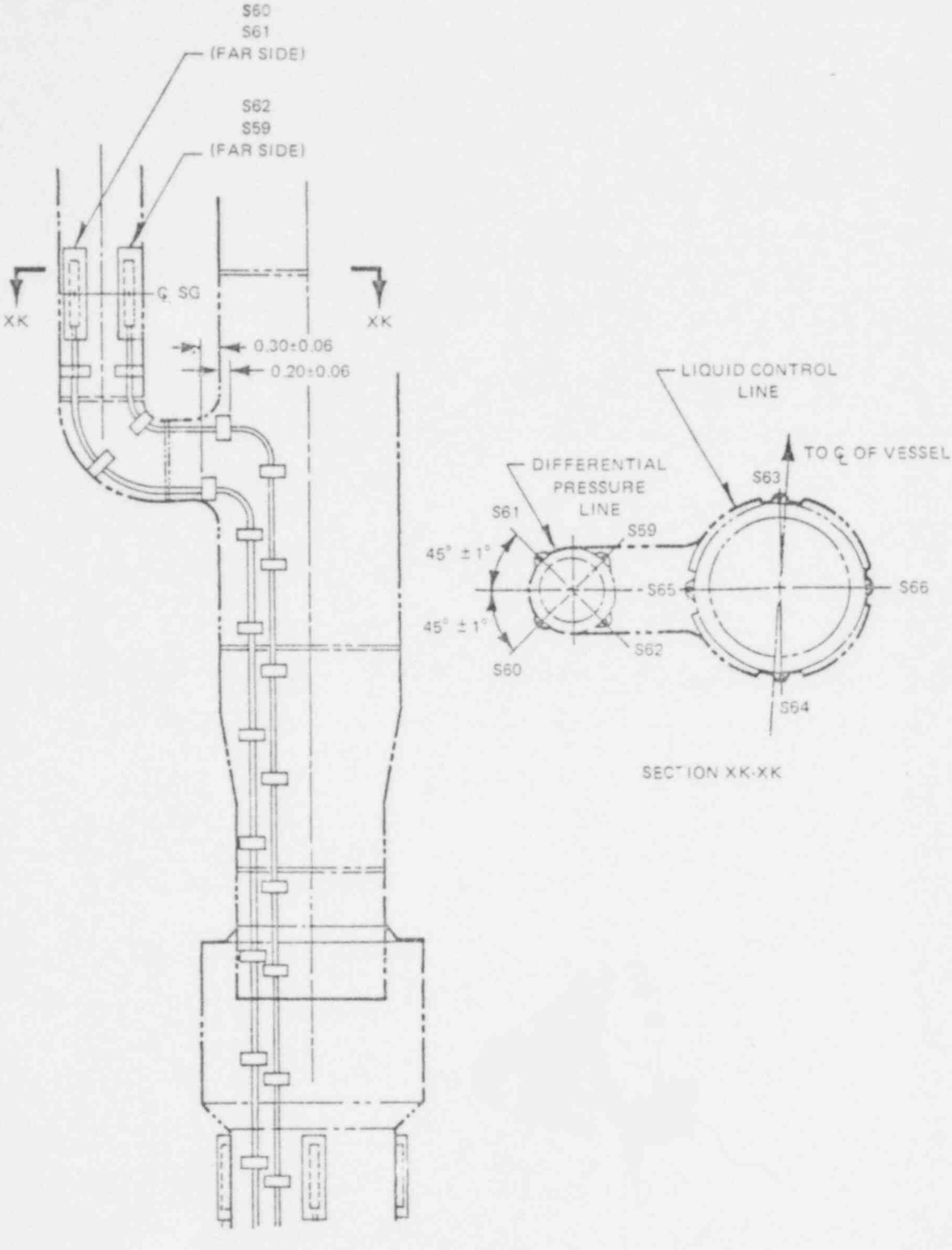

NOTE: Sxx DENOTES STRAIN GAGE LOCATIONS.

Figure 4-4. Strain Gage Locations on Core ΔP Liquid Control Line

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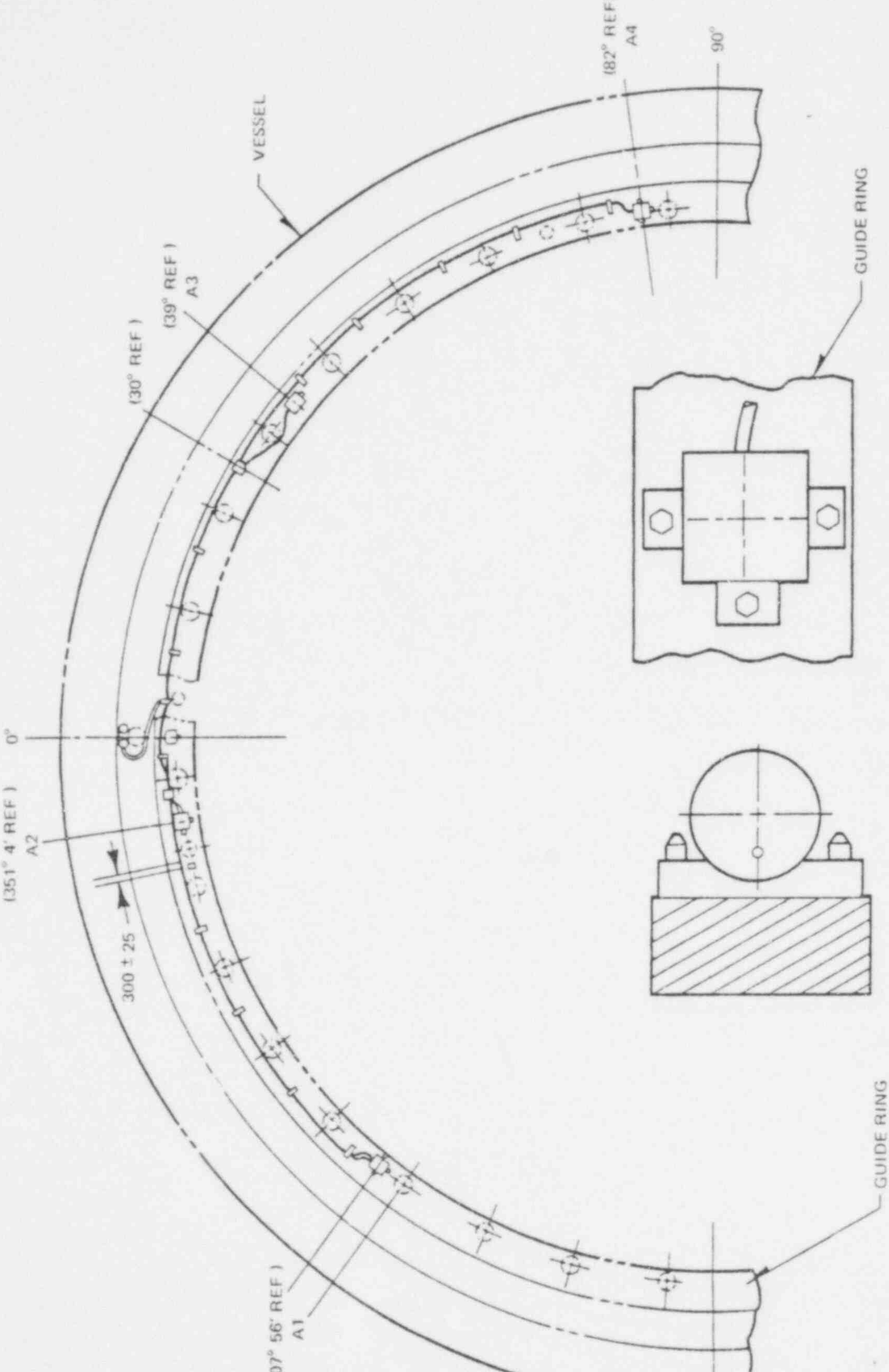

NOTE: Ax DENOTES ACCELEROMETER LOCATION.

Figure 4-5. Accelerometer Locations on Upper Bolt Guide Ring

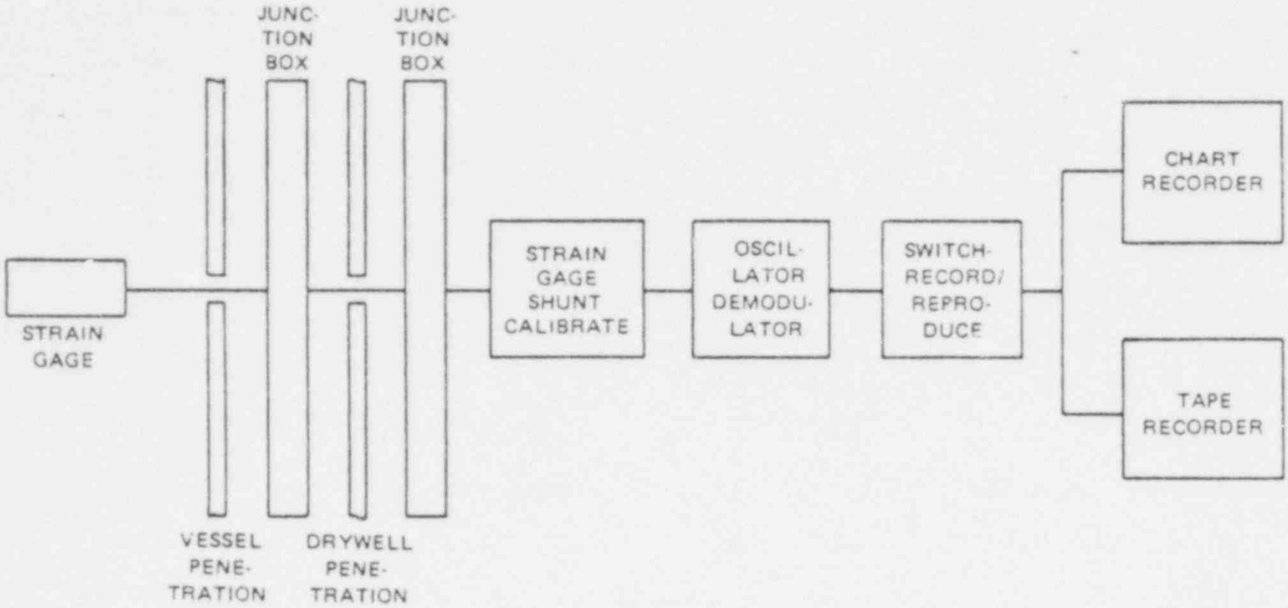

Figure 4-6. Block Diagram of Strain Gage Instrumentation

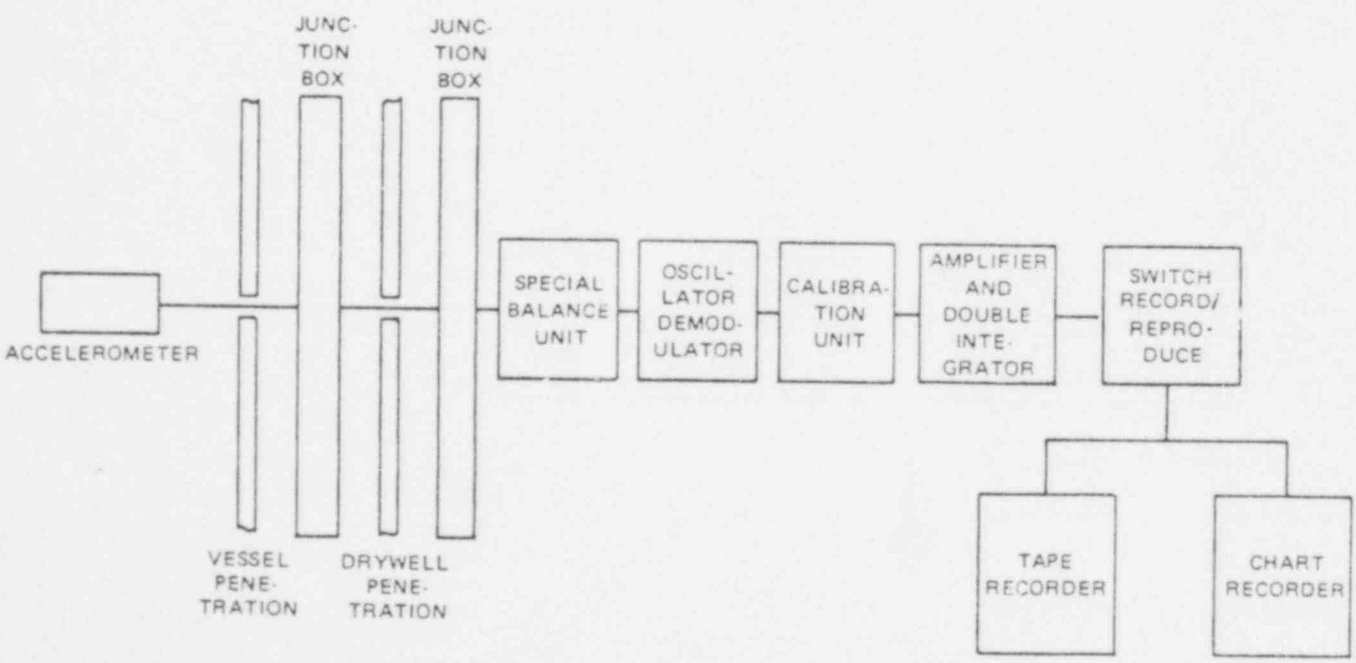

Figure 4-7. Block Diagram of Accelerometer Instrumentation

5. RESULTS OF VIBRATION MEASUREMENTS

The following subsections give the results of vibration test measurements taken at Tokai-2 during preoperational and startup testing. Since preoperational testing and precritical testing are for assessing the vibration adequacy of the internals and their proper installation, only the maximum flow test condition is reported, although all the test conditions are analyzed. No transient amplitudes are reported, since none exceeded balanced or single pump operation.

5.1 SHROUD AND SHROUD HEAD MOTION

During preoperational and precritical testing, rotational motion of the water flowing through the steam separators excites the upper bolt guide ring to which the accelerometers are attached. The excitation results in a lateral and torsional motion to the separator assembly proportional to flow. The allowable amplitude is calculated assuming shroud and separator lateral motion only. Thus, the comparison of shroud motion during preoperational and precritical testing is not valid. The allowable displacement for the torsional mode of a similar separator was calculated to be ___*___. For the observed motion the more conservative lateral motion criterion was used.

The significant results of the shroud-separator assembly motion are given in Tables 5-1 to 5-4. The shroud motion reached a maximum of ___ of the allowable during preoperational testing, and ___ during power operation.

5.2 JET PUMP ASSEMBLY MOTION

Jet pump motion measured by sensors on riser pipe braces indicated vibration in three modes at frequencies of ________________________________. The strain levels reached a maximum of ___ of criteria _____________ during pre-operational testing. During 75% load line testing, a maximum of ___ of criteria was reached __________________. ________ of criteria _____ __________________ was measured during 100% load line power testing.

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*General Electric Company proprietary information has been deleted.

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The Tokai-2 jet pump motion at low flow averaged higher than a similar sized BWR/4 plant. However, at maximum flow the percents of allowable were comparable. The sensors on the riser brace show frequencies higher than ______, and are covered in Section 5.3.

Tables 5-1 through 5-4 give the most significant vibration strain measurements for the jet pump sensors.

Strain gages were mounted on jet pump nozzle vanes to measure jet pump motion. Very low amplitudes were measured. During overall testing, a maximum amplitude of _____ was observed at the recirculation pump vane passing frequency.

5.3 JET PUMP RISER BRACE LEAF MOTION

Strain gages are mounted on the jet pump riser braces primarily to measure the motion of the jet pump assembly, but they also measure the motion of the jet pump riser brace leaf. The riser brace leaf frequencies range from ______ for the first mode to ______ for the third mode. The riser brace leaf also responds significantly to those recirculation pump vane passing frequencies corresponding to 5, 10 and 15 times the pump speeds. The brace responds readily to the first vane passing frequency (five times pump speed or _______ and reached ___ of the allowable strain amplitude during 100% load line testing.

Tables 5-1 through 5-4 give the maximum observed amplitudes with frequency and percent of the criteria for the jet pump leaves.

5.4 FEEDWATER SPARGER VIBRATION MOTION (S41-S58)

The feedwater sparger showed very little motion. The maximum strain measured was _______________ (first vane passing frequency). This is less than __ of the criteria.

5.5 CORE ΔP/LIQUID CONTROL LINE VIBRATION MOTION (S59-S66)

The maximum vibration measurement observed on the ΔP/liquid control line was

____

Table 5-1

RESULTS OF PREOPERATIONAL TESTING

(General Electric Company Proprietary)

Table 5-1 (Continued)

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Table 5-2

RESULTS OF PRECRITICAL TESTING

(General Electric Company Proprietary)

Table 5-2 (Continued)

Table 5-3

RESULTS OF 75% LOAD LINE TESTING

(General Electric Company Proprietary)

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Table 5-4
RESULTS OF 100% LOAD LINE TESTING
(General Electric Company Proprietary)

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6. ANALYSIS

6.1 TEST ACCEPTANCE CRITERIA

The test acceptance criteria for Tokai-2 is the same as used for BWR/4 plants. This is as described in Section 6.1 of NEDE-24057-P.

6.2 DATA ANALYSIS METHODS

Vibration amplitudes are determined by direct measurement from chart records. Frequency spectra are used to determine the test condition at which the maximum amplitude for each mode occurs. The chart record is then analyzed to find the maximum peak-to-peak amplitudes, which are then compared to the criteria. This analysis method is conservative in that the criteria are based on the assumption of vibration at a constant sustained amplitude, whereas actual vibration amplitudes are generally random and seldom reach the maximum recorded values.

7. DISCUSSION

7.1 BWR/5 VIBRATION MEASUREMENTS

BWR/5 vibration measurement tests, in addition to Tokai-2 (a 251-in. size BWR/5), are planned for Zimmer (a 218-in. size BWR/5) and the first 201-in. size BWR/5 to start up. These tests will consist primarily of jet pump instrumentation with other sensors used to provide information for modal identification. The test conditions will be the same as performed at Tokai-2 and will include a preoperational flow test and inspection, preoperational vibration measurements, precritical vibration measurements, and startup vibration measurements.

Due to a difference in jet pump adaptor design, LaSalle-1 (a 251-in. size BWR/5) will have an instrumented jet pump vibration program. The test conditions are summarized in Table 4-1.

7.2 BWR/5 CONFIRMATORY TESTS

Hanford-2 (a 251-in. size BWR/5) will have a minimum instrumented confirmatory vibration test during startup and will not have a preoperational flow test and inspection. Two jet pump riser braces and the shroud head upper guide ring will be instrumented.

A preoperational flow test and inspection will be performed in LaSalle-2 and Nine Mile Point-2 in accordance with provisions of Regulatory Guide 1.20 for nonprototype, Category 1 plants. Test conditions and inspection procedures will be as described in Subsection 7.2.2 and 7.4 of NEDE-24057-P.

8. CONCLUSIONS

Test results show that vibration amplitudes of the jet pump and shroud head assembly are within acceptable limits and showed vibration characteristics similar to those observed in other boiling water reactor (BWR) plants. The maximum amplitude of jet pump vibration reached ___ of the allowable during power operation. The riser pipe brace leaf vibrated at ___ of the criteria during normal operation.

During power testing, the shroud and shroud head assembly vibration amplitudes did not exceed ___ of the criteria and performed as expected.

The jet pump vane sensors, feedwater sparger and core ΔP/liquid control line vibration sensors did not show significant vibration amplitudes. This indicates that the design of these structures is sufficient to withstand flow induced vibrations.

The test results demonstrate the adequacy of the BWR/5 251-in. vessel size internals with respect to vibration.

9. REFERENCES

1. *Assessment of Reactor Internals Vibration in BWR/4 and BWR/5 Plants*, General Electric Company, NEDE-24057-P (Company Proprietary), November 1977.

2. *Tokai-2 Reactor Internals Vibration Measurements*, General Electric Company, NEDE-25091 (Company Proprietary), December 1978.

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