MONTICELLO VIBRATION

TEST SUMMARY REPORT

June 12, 1972

Vibration measurements were made on the reactor internals at Monticello starting 12/22/70 with cold flow tests and being completed 7/6/71 with the turbine trip test from 100% power, 100% coolant flow. This is a summary report of the measurements, listing the measured amplitudes, criteria and with a discussion and evaluation of the significance of the results.

The results of these measurements and tests indicate that vibration amplitudes are all within acceptable limits for normal operation up to 100% power and 100% flow. The highest levels of vibration occurred on the jet pump riser pipes during transient and unbalanced flow conditions. Jet pumps were cavitating during the cold recirculation pump trip tests. Automatic interlocks normally prevent operation above 20% pump speed in the cold condition; the pump trip tests were done from 65% pump speed and therefore resulted in vibration levels significantly higher than expected during normal operation. Even though vibration levels were less than the acceptance criteria for unbalanced flow conditions, procedural controls have been established to further reduce these levels.

The "Results - Summary and Discussion", Section I, covers in detail the maximum vibrations measured in each section of the reactor listing the maximum amplitudes both in terms of inches peak to peak motion and the percent this amplitude is of the criterion. The detailed tabulation of the criteria and the measurements is given in Section II, "Criteria and Measurements". Sections III and IV are a tabulation of raw data included in the complete test record; these sections are not included as part of the summary report. Section V, "Vibration Instrumentation", discusses the type and location of sensors and associated instrumentation.

I. Results - Summa[illegible] and Discussion

1. Shroud-Separator Assembly Vibration Measurements

The maximum vibration motions of the shroud-separator assembly for all steady operating conditions, with both balanced and unbalanced flow, were 0.001" peak to peak at 6. to 7. Hz and .0006" peak to peak at 14.8 Hz. These represent 1.8% and 3.2% of the respective criterion.

The highest vibration amplitudes are related to the opening of a pressure relief valve and to scram when operating at and above 50% power. This vibration was very transient in nature, never lasting more than 1. to 1.5 seconds. The maximum transient amplitudes measured were as follows:

	Amplitude Peak to Peak	Vibration Frequency	% Criteria
2 Pump Trip	.0012"	5.5 Hz	2.2%
	.0025	15.	13.1
Turbine Trip	.005	5.6	9.1
	.0065	15	34

2. Jet Pump Riser Pipe Vibration Motion (Tangential)

	Vibration Amplitude	Vibration Frequency	% of Steady State Criteria
Constant Flow, Cold			
Balanced Flow	.004" p.p.	25 Hz	50%
Unbalanced Flow	.0066	25	83 (1) (4)
Constant Flow, Hot			
Balanced Flow	.002	25 Hz	25
Unbalanced Flow	.008	23.5	91 (1)
Transient Flow			
"A" Pump Trip, Cold	.009	26	112 (2) (4)
Hot	.008	24.8	100 (2) (3)
"B" Pump Trip, Cold	.012	25	150 (2) (4)
Hot	.0035	31.5	25
Turbine Trip	.004	26.8	53 (2)

(1) Procedural limitation will forbid operation with the unbalanced flow established for these test points.

(2) The amplitudes measured occurred for less than 1.5 seconds.

(3) This reading occurred during "A" pump coastdown when unbalanced flow passed through critical region (see Note 1).

(4) The jet pumps cavitated under these conditions and this mode is not permitted during plant operation.

3. Jet Pump Vibration Motion (Radial, at the Top)

	Vibration Amplitude	Vibration Frequency	% Criteria
Constant Flow, Cold			
Balanced Flow	.004" p.p.	36 Hz	30%
Unbalanced Flow	.003	24	17
Constant Flow, Hot			
Balanced Flow	.0015	24.8	6
Unbalanced Flow	.005	24.8	20
Transient Flow			
"A" Pump Trip, Cold	.012	32	47
Turbine Trip	.005	36	37

For each main heading in the above table, the readings listed represent the maximum amplitudes observed. The cold readings also represent operation during initial cavitation which is normally avoided.

The amplitudes listed for transient conditions last only 1. to 2. seconds.

4. In-Core Guide Tube Housing Vibration Motion

The maximum vibtation amplitudes of the in-core guide tube housing occurred during the cold unbalanced flow test. This amplitude was 0.0098" peak to peak at 45 Hz which is 19% of the criterion. During the hot flow tests, the amplitude never exceeded 6.6% of the criterion.

5. Control Rod Guide Tubes

The maximum vibration strain amplitude occurred during unbalanced cold flow operation. The amplitude was 69. micro strain peak to peak at 19 Hz which is 9% of the criterion. All readings during the hot flow tests were below 1% of the criterion.

II. Criteria and Measurements

The vibration criteria and the measurements for each of the five sections or components in the reactor are both tabulated in tables with the following five headings:

Table 1 - Shroud and Separator Assembly Vibration Amplitudes
Table 2 - Jet Pump Riser Pipe Tangential Vibration Motion
Table 3 - Jet Pump (Top) Vibration Motion (Radial)
Table 4 - Incore Guide Tube Housing Vibration Motion
Table 5 - Control Rod Guide Tube Vibration Motion

Each table is composed of two parts, with the first part titled "A-CRITERIA", and the second part, "B-MEASURED VIBRATION AMPLITUDES". The source and the significance of the information given in each part is discussed in the following paragraphs:

A-CRITERIA

The criteria listed in the following tables represents the vibration amplitude at the sensor location for a limiting stress at the point of maximum stress in the reactor internals structure.

In order to provide assurance that the limiting stress criteria which are established as an acceptance basis for the vibration tests are conservative, the ASME Code design values for endurance limit are used as a guide. The 1968 edition of the ASME Nuclear Vessel Code establishes the endurance limit as "two times the S_a value at 10^6 cycles in the applicable fatigue curve." For austenitic materials, such as the stainless steel and inconel from which BWR internals are constructed, the design S_a value at 10^6 cycles is 26,000 psi. Therefore, the code would permit a vibration stress of $\pm$ 26,000 psi which corresponds to a design endurance limit of 52,000 psi.

The procedures and criteria applied in evaluating the acceptability of vibration of BWR reactor internals are based on engineering judgment where more specific information is lacking, and are more conservative than requirements of the ASME Code for Nuclear Vessels. The criteria used in the General Electric BWRs is to limit the alternating peak stress intensity, including all stress concentration factors, to a value of $\pm$ 10,000 psi. This is assumed to be a conservative criterion and represents an additional margin of safety compared to the value permitted by ASME Codes.

The relationship between the vibration amplitude at the sensor location and the stress at the point of maximum stress is determined analytically for normal mode response amplitudes and stresses. Where a more detailed analysis is needed, the normal mode responses are combined to take into account non-model force inputs (i. e., input forces at one and two coordinate locations only).

The normal mode calculations, in general, involve the following steps: When computer programs are used, the steps are often combined in the program so that only the problem statement steps 1 and 2 require detailed effort.

(1) Express the reactor internals structure as a mathematical model in terms of lumped masses and inertias, and lumped springs with coordinate identifications assigned to each.

(2) Calculate the stiffness and the mass matrices. The mass matrix should include the effect of the water in the vessel which will add hydrodynamic masses to many coordinates and will add off diagonal mass terms to the matrix.

(3) Calculate the natural frequencies (eigen values) and the corresponding normal modes (eigen vectors).

(4) For each normal mode determine the location of the limiting stress.

(5) From the normal mode and limiting stress calculations, determine the limiting vibration amplitude at the sensor locations.

B-MEASUREMENTS

The data for the vibration measurements were recorded on three 6-channel chart recorders and a 14-channel tape recorder. Detailed characteristics of the instrumentation are given in Section V.

The measured values reported in the following five tables were taken from the chart recordings using a purely manual procedure aided by a Gerber Variable Scale. In general, when the vibration amplitudes were fairly low (i. e., less than 10% of the criterion), both the amplitude and the frequency tended to be random. When the amplitudes were higher single frequency, components tended to predominate. The vibration amplitudes listed represent the largest peak to peak value observed during the recording period (usually for twenty seconds or more), and the frequency (H_z) for each amplitude reading.

Table 1 - Shroud and Separator Assembly Vibration Amplitudes

A. CRITERIA

Vibration Frequency	Limiting Vibration Amplitude (inches peak to peak)		Critical Stress Location
	Sensors D-1,2,3,4	Sensors V-1,2,3,4	
4.1	0.055"	0.103"	Shroud legs
6.6	0.055	0.110	Shroud legs
7.9	0.062	0.029	Shroud legs
13.6	0.019	0.209	Shroud legs
17.4	0.0024	0.048	Fuel
19.7	0.0072	0.082	Standpipes
20.8	0.013	0.074	Standpipes
23.1	0.024	0.012	Shroud legs
35.8	0.006	0.0062	Fuel
40.3	0.024	0.031	Standpipes
43.2	0.062	0.038	Standpipes

B. MEASURED VIBRATION AMPLITUDES

Power	% Pump Speeds A	% Pump Speeds B	Maximum Vibration Amplitudes (inches peak to peak) Elevation 387" (D-1, 2, 3, 4) A	f	Elevation 532" (V-1, 2, 3, 4) A	f
Balanced Flow Operation						
Cold	65%	65%	.001"	4.8 Hz	.001" .001	24 Hz 29.8
50% Power	81	83	.0007	4.7-6.5	< .0001	-
75% Power	86	87	.0008	6.6	< .0001	-
	53.5	53	.0003	6.0	< .0001	
			.0003	16.0		
	24.5	22.5	.0005	5.5	< .0001	
100% Power	92	91	.001	6.2	< .0001	-
			.0006	14.8		
Unbalanced Flow Operation						
Cold	20	50	.001	5	.0005	25
	9	65	.001	5	.001	25
	60	40	.0005	25	.001	25
50% Power	0	83	.0005	5.75	< .0001	-
	81	0	.0005	5.75	< .0001	-
75% Power	0	93	.001	6.-7.	< .0001	-
100% Power	28	94	.0005	6.2	< .0001	-
			.0002	15.5		
	91	24./27.	.0004/ .0006	6	< .0001	-
			.0005	15		
Equalizer Valves Open						
Cold	60	0	.0003	5	< .0001	
50% Power	79	0	.0003	6		
	0	87	.0003	6		
100% Power	86	0	.0005	6		
			.0002	15		

Table 1 (cont'd)

A - Pump Trip and B - Pump Trip

Cold 50% Power 75 100	Vibration amplitudes changed gradually from those for two pump operation to those for single pump operation.				
Two Pump Trip					
50% Power	33	36	.0008	5.6	< .0001
	11	15	.0025	15.2	
75	-	-	.0012*	5.5	
			.006*	15.5	
100	91	94	.0008	6	
			.0008	15	
	10	16	.0007	6	
	0	0	.001	6	
Turbine Trip					
50% Power			.0064**	15	-
75			.005	5.6	
			.0065	15	
100			.005*	4.6	
			.0035**	5.8	

*When reactor control rods scrammed.

**Main pressure relief valve was operated.

Table 2 - Jet Pump Riser Pipe Tangential Vibration Motion

A. CRITERIA

Vibration Frequency	Limitating Vibration Amplitude (inches peak to peak) Sensors D-5, D-6
24	0.0088"
26	0.008
28	0.0075
29	0.0084
30	0.0116
31	0.0142
32	0.0132
34	0.0116
36	0.0113
40	0.0108

Table 2 (cont'd)

B. MEASURED VIBRATION AMPLITUDES

Power	% Pump Speeds A	% Pump Speeds B	Maximum Vibration Amplitudes (inches peak to peak) Riser at 30° (Sensor D-5) A	f	Riser at 330° (Sensor D-6) A	f
Balanced Flow Operation						
Cold	40	40	.0004	27	.0001	62.5
	65	65	.0001	25	.004*	21
			.004	25	.004*	30
50% Power	52	52	.0015	29.5	.0006	29
	62	62	.001	31	.0008	27
	70	70	.001	30	.001	26
	75	75	.0008	-	.0012	-
	81	83	.001	31	.0012	25
	90	90	.0008	31	.002	24.5
75% Power	88	89	.0005	31	.002	25.2
	53	54	.0008	31	.0005	28.5
	20	20			.0003	30.5
100% Power	92	91	.0012	31.5	.002	25
	74	76.5	.001	31	.0005	27
Unbalanced Flow Operation						
Cold	65	50	.002	25-29	.005*	25
	65	40	.002	25-29	.0074*	25
	60	40	.002	26	.0066*	25
	0	40	.0005	25	.0005	25
50% Power	82	22	.002	30	.0015	28
	25	87	.0018	31	.006	25
75% Power	0	89	.001	31	.002	24
	0	93	.002	31	.0022	[illegible]
100% Power	50	94	.0006	26	.0005	26
	40	94	.001	26	.002	26
			.0007	31		
	32	94	.0007	31	.005	25.7
	28	94	.001	32.5	.007	24.5
	25	94	.0008	31	.008	23.5
	23	94	.0006	30.2	.003	25.5
	91	42	.001	32	.002	25
	91	37	.002	32	.002	25
	91	30	.0035	31.5	.002	25.5
	91	27	.004	30	.0025	25
	91	24	.0022	31	.0016	25.2
	87	0	.001	30.5	.0015	28

Equalizer Valves Open						
Cold	70	0	.0008	25	.001	25
50% Power	80	0	.0004	31	.0004	29
	0	82	.0004	31	.0004	29
100% Power	84	0	.0006	30.6	.0005	28
A - Pump Trip Maximum Readings						
Cold*	9	65	.009	26	.004	30
50% Power	87	87	.0015	31	.0065	25
75% Power	26	89	.0008	30	.005	24
	14.6	88.5	.0015	31	.0005	24
100% Power	92.5	96	.001	30.5	.0015	24.7
	30	95	.001	31.6	.008**	24.8
	0	94	.0013	29	.002	27.5
B - Pump Trip Maximum Readings						
Cold*	65	0	.003	30	.012	25
50% Power	87	87	.0025	31	.001	26
75% Power	***	***	.003	***	.0025	***
100% Power	92	94	.0014	31	.0021	26.5
	91	28	.0035	31.5	.0013	26
	91	23	.001	31	.002	25.5
	91	16	.0005	-	.0024	25.5
Two Pump Trip Maximum Readings						
50% Power	87	87.	.0018	32.5	.002	26
75% Power	****	****	.001	33	.0008	33
100% Power			Gradual Reduction in Amplitudes			
Turbine Trip Maximum Vibration Readings						
50% Power	87	87	.0018	32.5	.002	26
75% Power	87.4	87.4	.0035	33	.004	26.8
	44.5	44.0	.001	33	.0015	26.8
	12.4	13.1	.001	33	.001	26.8
100% Power	92	96	.001	28.3	.0015	25.1
	91.5	94.5	.004***	30.5	.003***	25.2
	57.0	59.5	.0006	29.5	.001	29.5
	25.0	28.0	.0001	-	.0002	-

Generator Trip Maximum Vibration Readings

50% Power	81	83	.001	30.5	.0015	25

Cavitation Search at 100% Flow

As power was reduced to 20%, no increase in riser pipe vibration amplitude was noted.

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*Jet pumps were cavitating during these measurements.

**Maximum during "A" pump coastdown due to unbalanced flow. Occurred for approximately one second.

***The recorder chart speed was too slow to define the frequencies.

****These readings were obtained when the control rods scrammed.

Table 3 - Jet Pump (Top) Vibration Motion (Radial)

A - CRITERIA

Vibration Frequency	Limiting Vibration Amplitude (inches peak to peak) (Sensors D-7, D-8)
28	.0248"
30	.0262
32	.0256
34	.0232
36	.0134
38	.0076
40	.0062
42	.0092
43	.0156

B - MEASURED VIBRATION AMPLITUDES

Power	% Pump Speed A	% Pump Speed B	Maximum Vibration Amplitudes (inches peak to peak) JP-1 (21°) (Sensor D-7) A	f	JP-2 (39°) (Sensor D-8) A	f
Balanced Flow Operation						
Cold	65%	65%	.004	36	.004	36
50% Power	90	90	.001	-	.0015	28
	81	83	.0003	31	.0005	31
	70	70	.0006	28	.0008	28
	62	62	.0006	34	.0008	34
	52	52	.0004	29.5	.0004	31.5
	30	30	.0001	27.5	.0001	27.5
75% Power	89	89	.0005	-	.0005	-
	53	54	.0005	28.5	.0007	28.5
	20	20	.0001	29	.0001	29
100% Power	92	91	.001	30	.001	30
	74	76.5	.0004	29	.0005	29
Unbalanced Flow Operation						
Cold	65	50	.0008	31.4	.001	31.5
	65	40	.003	29.4	.004	25-31.2
	60	40	.0026	30	.003	30
	0	40	.0005	25	.0005	25
50% Power	82	22	.005	28	.004	28
	25.4	87	.001	28	.0015	28
75% Power	0	89	.002	28.8	.0025	28.8
	0	93	.0015	29.4	.005	29.4
100% Power	40	94	.001	29	.001	29
	34.1	94	.001	29	.001	29
	29.4	94	.0015	29	.002	29
	25	94	.0015	29	.0015	29
	23	94	.002	29	.0025	29
	91	51	.0005	29	.0006	29
	91	40	.001	29	.0015	29
	91	35	.003	28.5	.004	28.5
			.001	40	.001	40
	91	30	.004	28.7	.0055	28.7
			.0025	38.5	.0035	38.5
	91	26	.005	28	.005	28
	91	24.5	.003	29	.004	29
	91	22	.001	29	.0008	29

Equalizer Valves Open

Cold	[illegible]	[illegible]	.00025	25	.0005	25
	[illegible]	[illegible]	.0005	22	.00075	22
50% Power	[illegible]	[illegible]	.0004	29	.0005	29
	[illegible]	[illegible]	.0004	29	.0005	29
100% Power	[illegible]	0	.0003	29	.0005	29

A - Pump Trip Maximum Readings

Cold	9	65	.010	32	.0126	32
50% Power	82	86	.0025	28	.003	28
75% Power	0	89	.002	28.8	.0025	28.8
100% Power	92.5	96	.0015	28.8	.0015	28.8
	30	95	.0015	29	.0015	29
	0	94	.0015	27.7	.002	27.7

B - Pump Trip Maximum Readings

Cold	65	65	.0022	31	.001	28
	65	0	.0025	34	.003	32
50% Power	82	86	.0025	28.5	.003	28.5
75% Power	*	*	.0045	*	.006	*
100% Power	92	94.5	.0015	29	.0015	29
	91	28	.0045	29	.0055	29
	91	23	.0005	29	.0007	29
	91	16	.0005	29	.0007	29

Two Pump Trip Maximum Vibration Readings

50% Power	82	86	.0015	28	.0015	28
75% Power	*	*	.0025*	35	.0025*	35
100% Power	Gradual Reduction in Vibration Amplitudes					

Turbine Trip Maximum Vibration Readings

50% Power			.0035**	40	.0035**	40
75% Power	88	91	.0045	46	.003	46
	56.0	61	.0015	46	.002	46
	12	14	.001	46	.001	46
100% Power	91.5	94.5	.005	36	.004	36
	57	59.5	.001	30	.002	30
	25	28	.0002	-	.0002	-

Table 3 (cont'd)

Generator Trip Maximum Vibration Readings

50% Power	81	83	.0005	29	.0006	29

Cavitation Search at 100% Flow

As power was reduced to 20%, no increase in jet pump vibration amplitude was noted.

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*Chart speed too slow to define the frequency.
**When control rods scrammed.

Table 4 - In-Core Guide Tube Housing Vibration

A - CRITERIA

Vibration Frequency	Limiting Vibration Amplitude (inches peak to peak) Sensors A-1,2,3,4	Support at Center or Grid Location
6.5	0.164	No
19.5	0.081	Yes
21.1	0.101	No
38.5	0.054	No
43.8	0.053	Yes
59	0.010	No
72.4	0.022	Yes

Table 4 (cont'd)

B - MEASURED VIBRATION AMPLITUDES

Conditions	% Pump Speed A	% Pump Speed B	Maximum Vibration Amplitudes (inches peak to peak), Location 44, 13 and (20, 05)*: Sensor A3 A	Sensor A3 f	Sensor A4 A	Sensor A4 F
Balanced Flow Operation						
Cold	65	65	(.009)	(27.6)*	(.0035)	(45.8)
			(.0065)	(48.3)	(.0085)	(48.3)
			.002	49	.007	44.5
50% Power	90	90	.003	9	.003	9
			.0005	49.5	.0006	49.5
	81	83	.0018	9	.0015	9
			.0004	49	.0005	49
	70	70	.0015	9	.001	9
			.0004	49	.0004	49
	62	62	.0015	9	.0008	9
	52	52	.0012	9	.0005	9
	30	30	.001	9	.009	9
75% Power	88	89	.0005	48	.0005	48
	53	54	.001	17	.0005	17
	20	20	.001	9	-	-
100% Power	92	94	.0006	45.9	.0003	45.9
	74	76.5	.0001	45	.0001	45
Unbalanced Flow Operation						
Cold	65	50	(.008)	(27.4)		
			(.0054)	(49.)	(.008)	(49.)
			.001	45	.006	45
			(.0185)	(27.-34.)	(.004)	(45.)
	60	40	.0019	45	.0098	45
	65	40	(.009)	(28.2)	(.004)	(49)
			.0006	44	.004	44
			.0005	49	.003	49
50% Power	82	25	.002	8.25	.0025	8.25
			.001	17.3	.001	17.3
			.0002	41	.0005	41
	82	30	.0002	8.25	.0005	8.25
			.0002	41	.0001	41
75% Power	0	89	.0025	44	.001	44
	0	93	.0035	44	.0015	44

100% Power	52	94	.0007	45	.0002	45
	40	94	.0015	45	.0002	45
	38.5	94	.0023	45	.0003	45
	32	94	.0017	45	.0003	45
	29.5	94	.0015	45	.0003	45
	28	94	.001	45	.0003	45
	23	94	.0021	45	.0005	45
	91	51	.0005	9		
			.0001	45	.0005	45
	91	34	.0015	9	.0006	9
			.0001	45	.0001	45
	92	28	.00015	9	.0003	9
			.0001	45	.0001	45
	91	24.5	.0003	45	.0003	45

Equalizer Valves Open

Cold	70	0	(.00098)	(37)	(.00073)	(38)
					(.00073)	(45)
					.00049	30
50% Power	77	0	All amplitudes were less than for one pump			
	0	82	operation with valves closed.			
100% Power	86	0	.0002	9		
			.0001	45	.0001	45

A - Pump Trip Maximum Vibration Readings

Cold	No data available					
50% Power	83	87	.002	47	.0015	47
75% Power	86.5	89	.0005	44	.0013	44
	18	89	.0023	44	.0012	44
	0	89	.0025	44	.001	44
100% Power	93	96	.0006	45.9	.0003	45.9
	42	96	.0018	45.9	.0005	45.9
	25	96	.002	45.9	.0008	45.9

B - Pump Trip Maximum Vibration Readings

Cold	65	65	.007	48	.002	45
	65	0			.007	18
50% Power	87	87	.002	8.6	.002	8.6
			.0003	46	.0008	46
75% Power	No data available					
100% Power	92	94.5	.0006	45	.0003	45
	91	28	.0007	9	.0001	9
			.0001	45	.0001	45
	91	23	.0006	9	.0001	9
			.0002	45	.0002	45
	91	16.5	.0015	9	.0002	9
			.0002	45	.0002	45

Table 4 (cont'd)

Two Pump Trip Maximum Vibration Readings

50% Power	83	88	.0005	49	.0005	49
	80	83	.0002	49	.0002	49
	51	53.5	.0001	49	.0001	49
75% Power	88	90	.0004	49	.0003	49
	75	76	.0002	49	.0002	49
	48	52.5	.0001	49	.0001	49
	0	4	.0002**	49	.0004**	49
100% Power	91	94	.0005	9	.0005	9
			.0002	45	.0001	45
	0	0	.0003	9	.0002	9

Turbine Trip Maximum Vibration Readings

50% Power	82.5	83	.0015	9	.001	9
			.0007	45	.0005	45
	31	33	.001	9	.0005	9
			< .0001	45	< .0001	45
75% Power	86	86	.0017	9	.0015	9
			.0004	45	.0002	45
	58	61	.0001	45	.0002	22.5
					.0001	45
	0	0	< .0001	9.-45.	< .0001	9.-45.
100% Power	93.5	97	.0003	25	< .0001	25
			.0002	45	< .0001	45
	91	88	.0006	9	.0003	9
			.0002	45	< .0001	45
	40	43	.0005	9	.0003	9
			.0003	45	< .0001	45

Generator Trip Maximum Vibration Readings

50% Power	85	86	.002	9	.002	9
			.0005	45	.0007	29

The vibration amplitudes did not change with the trip since the pump speed stayed constant.

---

*All data within (   ) were obtained from sensors A-1 and A-2. These sensors failed before any hot data were obtained.

**These readings were obtained during scram.

Table 5 - Control Rod Guide Tubes

A - CRITERIA

Vibration Frequency	Limiting Vibration Strain (micro-strain peak to peak) Strain Gages S-1, 2, 3, 4	Critical Stress Location
13.6	100	Shroud legs
19.8	110	Standpipes
20.8	190	Standpipes
23.1	468	Shroud legs
20.0*	780	Center of guide tube

*This mode is for case where guide tubes only vibrate in which case sensors D-1, 2, 3, 4 and V-1, 2, 3, 4 would indicate very low readings. Other frequencies listed are for the case where all tubes vibrate together.

Table 5 (cont'd)

B - MEASURED VIBRATION AMPLITUDES

Condition	% Pump Speeds		Maximum Vibration Strain Amplitudes (micro-strain peak to peak)							
			Location 10, 43				Location 02, 23			
			SG-1		SG-2		SG-3		SG-4	
	A	B	$\mu\epsilon$	f Hz	$\mu\epsilon$	f Hz	$\mu\epsilon$	f Hz	$\mu\epsilon$	f Hz
Cold Flow Operation										
Balanced	65%	65%	9.2	21	7.5	21	3.0	20	5.0	20
			9.2	21	14.0	21	9.2	18.5	34.2	18.5
Unbalanced	65	40	6.0	28	10	25	-	-	-	-
	65	0	14.0	20	20	21	6	19	68.8	19
	9	65	6.0	22	16.0	22	-	-	17.2	-
A - Pump Trip			Amplitudes changed gradually from the balanced to unbalanced above.							
B - Pump Trip										

Power Operation

For all operating conditions at 50%, 75% and 100% operation, the recorded strain amplitudes were all less than $3\mu\epsilon$ and the predominant frequencies were above 60 Hz. No signals in the frequency range 20 $\longrightarrow$ 30 Hz were observed.

Section III and Section IV are not included in the summary report.

These sections are a tabulation of the raw test data summarized earlier.

SECTION V

INTRODUCTION

All of the vibration measuring systems used were composed of a vibration transducer, a signal conditioning unit, a magnetic tape recorder and a chart recorder for monitoring readout. As usually employed, this system had an overall sensitivity of 0.0005" for 1.0 mm (smallest division) on the chart recorder and .010" for one volt into the tape recorder. The strain gage readout had a sensitivity of 5 ue per division (1.0 mm). The overall sensitivity of each system could be increased by a factor of from 2 to 10 depending upon the electrical background noise.

Table V-1 and drawings 761E260 (sheets 1 and 2) indicate the location and measurement direction of each of the vibration transducers or sensors used. The following sections give a detailed description of the four measurement systems and their components.

A-1 DISPLACEMENT TRANSDUCER

The sensing element in the displacement transducer is a linear variable differential transformer (LVDT). The LVDT consists of a three-coil assembly with the coils wound side by side on a hollow spool. The center coil or primary winding is energized by a 5-volt 3KHz power supply to provide a continuous A-C magnetic field. The two outside or secondary windings are connected in opposing series so that the voltage induced in one coil tends to cancel that from the other. A magnetic armature is guided in the hollow spool, and its position relative to the three coils determines the voltages in the two outside coils. When the armature position is such that equal voltage are generated in the outside coils, the net output voltage is zero, and the armature is located at the electro-mechanical null position. See Fig. V-1 for a schematic diagram of the LVDT. The armature of the LVDT is connected to a spring loaded probe follower. As the probe is moved with respect to the case, the net output is proportional to the probe position (displacement). Fig. V-1 shows a cross-sectional sketch of the displacement transducer.

This transducer is a relative motion sensing unit and usually mounted so the probe is against a relatively non-vibrating structure, and the coil assembly is mounted on the vibrating structure (e.g., vessel wall to shroud). The probe tip is initially set so the LVDT is in its electro-mechanical null position. The LVDT is designed so the probe can move 0.20" in either direction from the null position and remain in the linear range of the transformer.

Although the LVDT is adjusted to its null position when mounted, by the time it is to be used, temperature changes have caused expansions and contractions which change the relative position of the vibrating and non-vibrating surfaces. The inaccessibility of the LVDT makes a mechanical adjustment of the electro-mechanical null position impossible; thus it is necessary to have an external method of "nulling" the LVDT electrical output so that the signal conditioning and readout equipment will remain on scale. This null adjustment of the LVDT electrical output is handled by a specially-built unit called the "balance box", the output of which becomes the input to the demodulator. For a block diagram of the complete signal conditioning system, see Fig. V-2. The balance box can be switched so as to apply a calibration signal to the demodulator.

The demodulator unit is Validyne Engineering Corp. Model CD-19, which is plugged into a module case containing an oscillator that produces the 3KHz carrier excitation signal for the LVDT and the DC power for the CD-19. The demodulator converts the modulated 3KHz signal from the LVDT into a voltage proportional to the armature position, and at the modulation frequency.

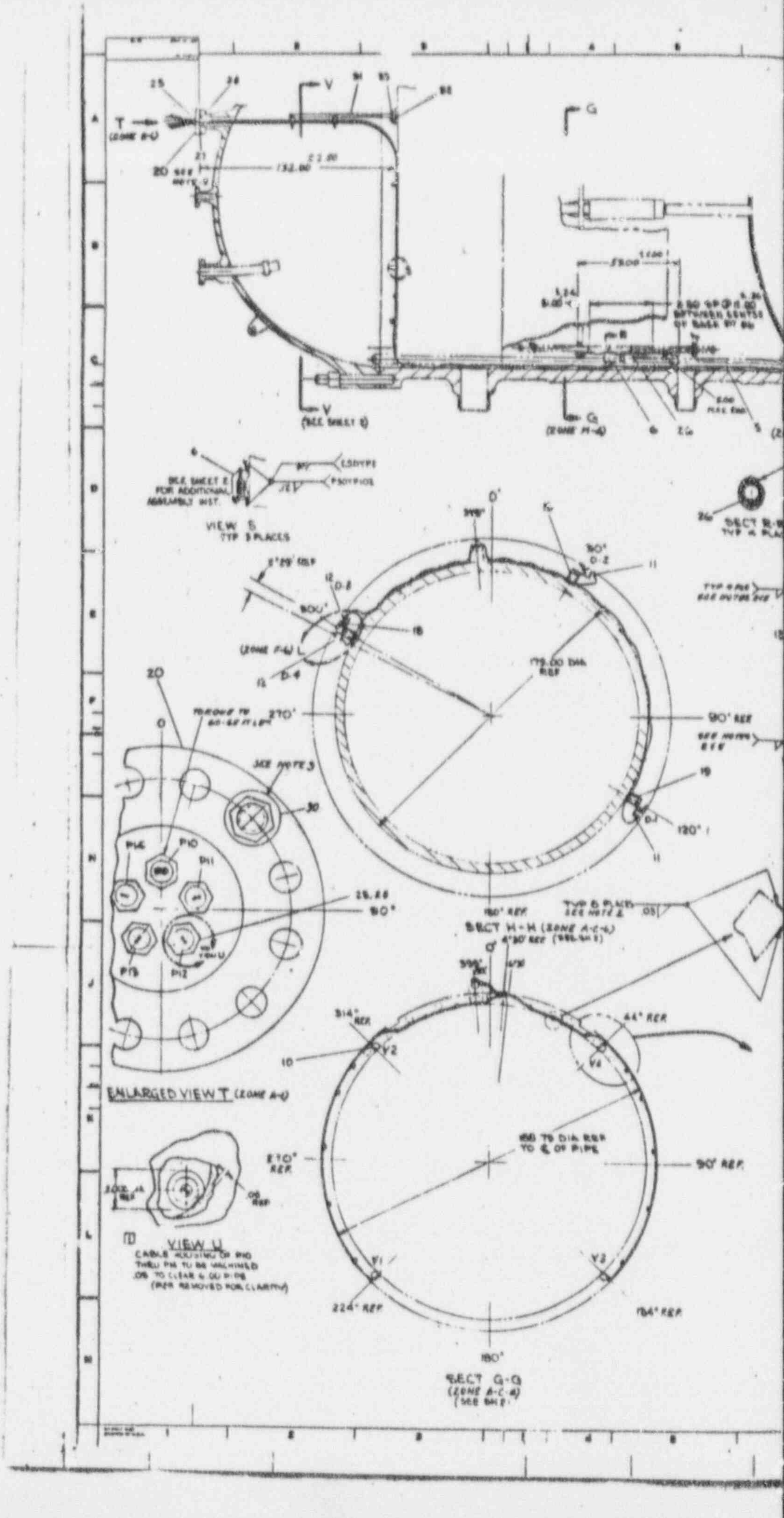
The CD-19 output goes through a specially-built switching unit to the tape recorder and the chart recorder. The switching unit makes it possible to play the tape recorder back to the chart recorder.

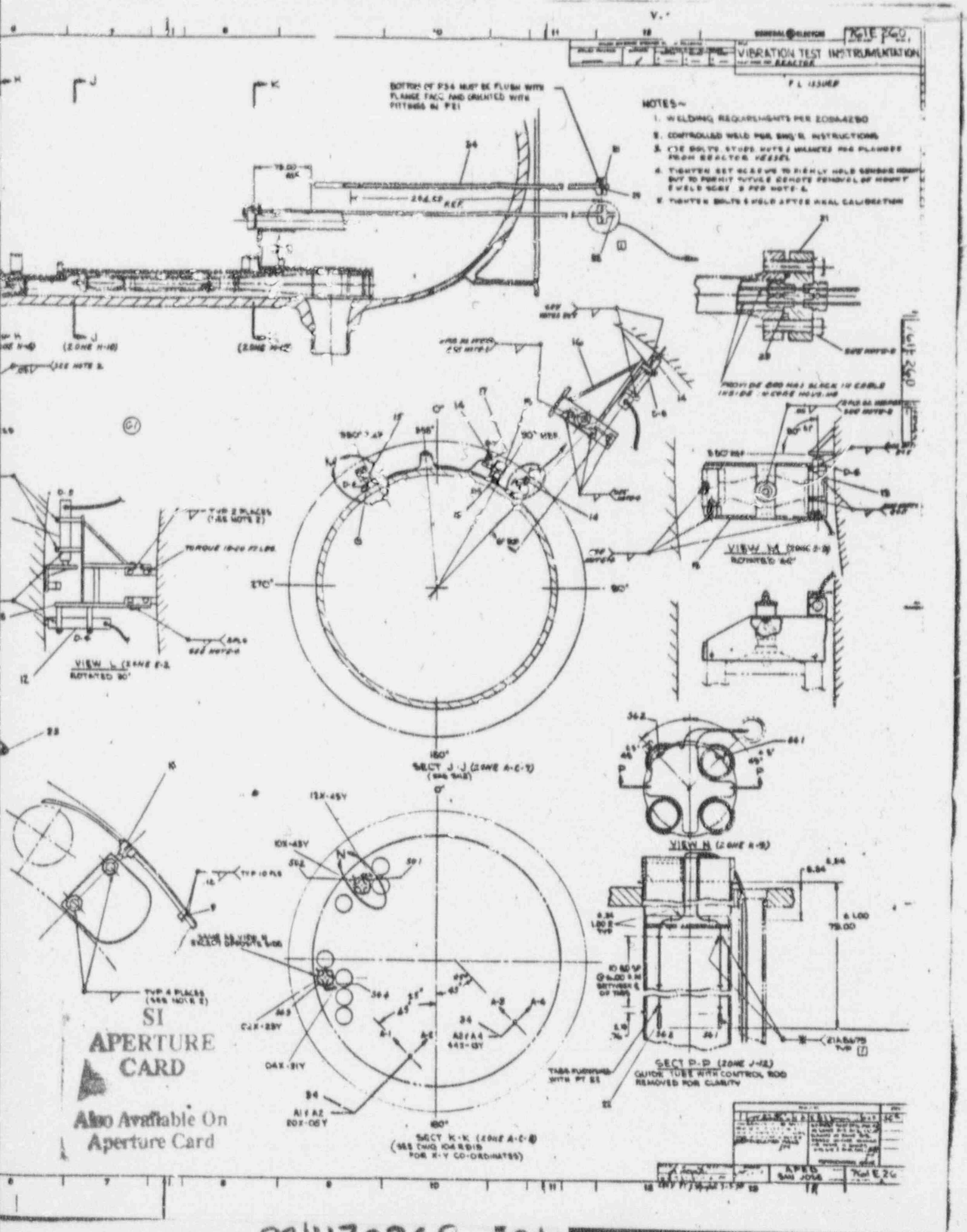
The overall response characteristics of each component in the displacement measuring system is listed in Table V-2 for each of the components indicated by the block diagram in Fig. V-2.

TABLE V-1

Sensor Locations and Orientation

Sensor	Location	Orientation	Elevation	Azimuth
D1	Shroud to vessel	Tangential	386.50	120°
D2	Shroud to vessel	Tangential	386.50	30°
D3	Shroud to vessel	Tangential	386.50	300°
D4	Shroud to Vessel	Radial	386.50	297° 30'
D5	JP riser top to shroud	Tangential	339.25	30° (JP1,2)
D6	JP riser top to shroud	Tangential	339.25	330° (JP19,20)
D7	JP1 elbow to vessel	Radial	334.00	21°
D8	JP2 elbow to vessel	Radial	334.00	39°
V1	Upper bolt guide ring	Tangential	531.83	224°
V2	Upper bolt guide ring	Tangential	531.83	314°
V3	Upper bolt guide ring	Tangential	531.83	134°
V4	Upper bolt guide ring	Tangential	531.83	44°
SG1	CRD guide tube	X10-Y43	122.00	45° within tube
SG2	CRD guide tube	X10-Y43	122.00	315° within tube
SG3	CRD guide tube	X02-Y23	122.00	225° within tube
SG4	CRD guide tube	X02-Y23	122.00	135° within tube
A1	In-core guide tube	X20-Y05 Tan.	70.00	315° within tube
A2	In-core guide tube	X20-Y05 Rad.	70.00	45° within tube
A3	In-core guide tube	X44-Y13 Rad.	70.00	315° within tube
A4	In-core guide tube	X44-Y13 Tan.	70.00	45° within tube


VIEW S
TYP 3 PLACES
SECT H-H (ZONE A-C-4)
ENLARGED VIEW T (ZONE A-1)
VIEW U
CABLE HOUSING OF P10 THRU P16 TO BE MACHINED .05 TO CLEAR & OD PIPE
(P16 REMOVED FOR CLARITY)
SECT G-G
(ZONE A-C-4)
270° REF
90° REF
180°
224° REF
314° REF
44° REF



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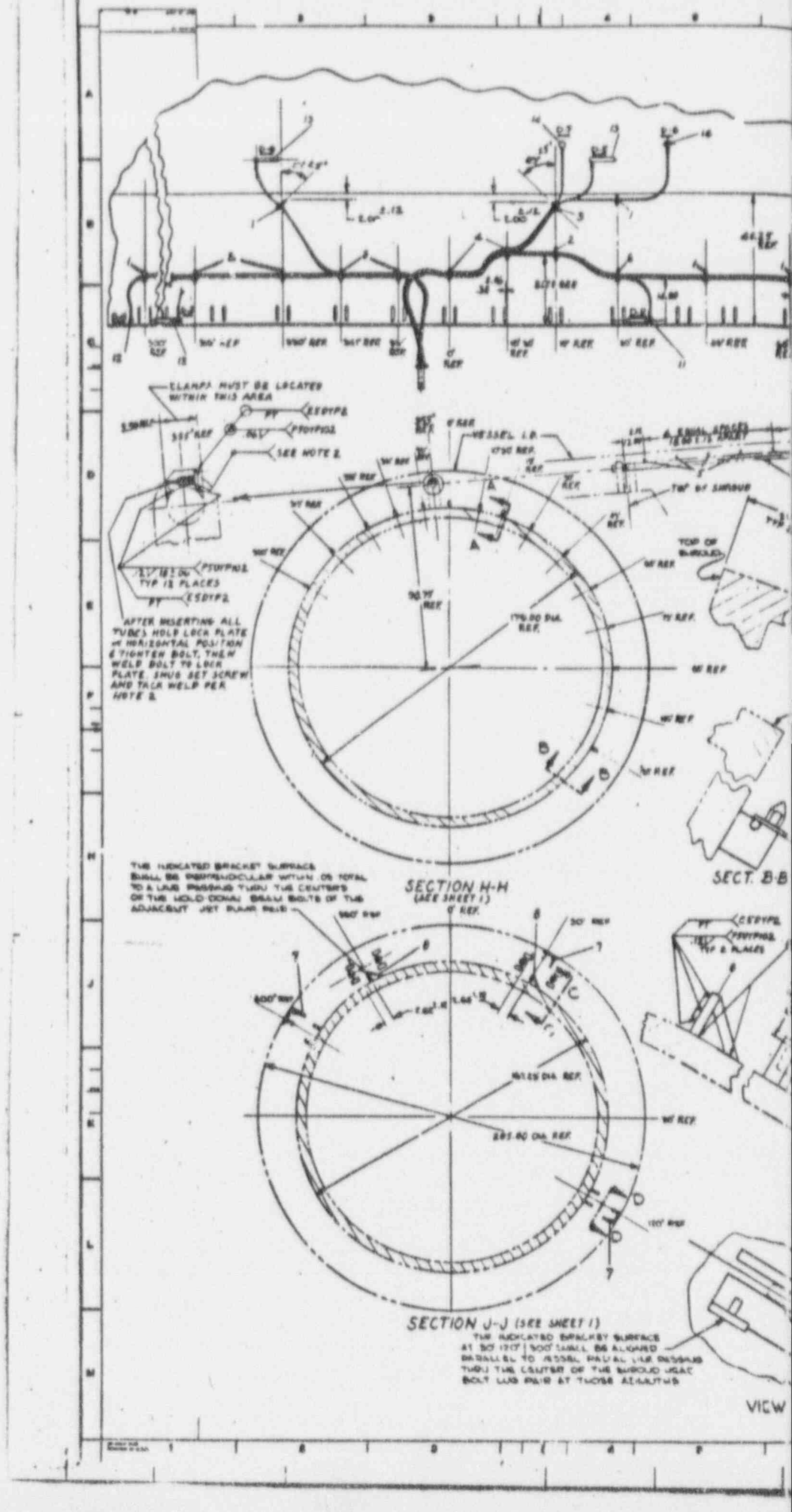
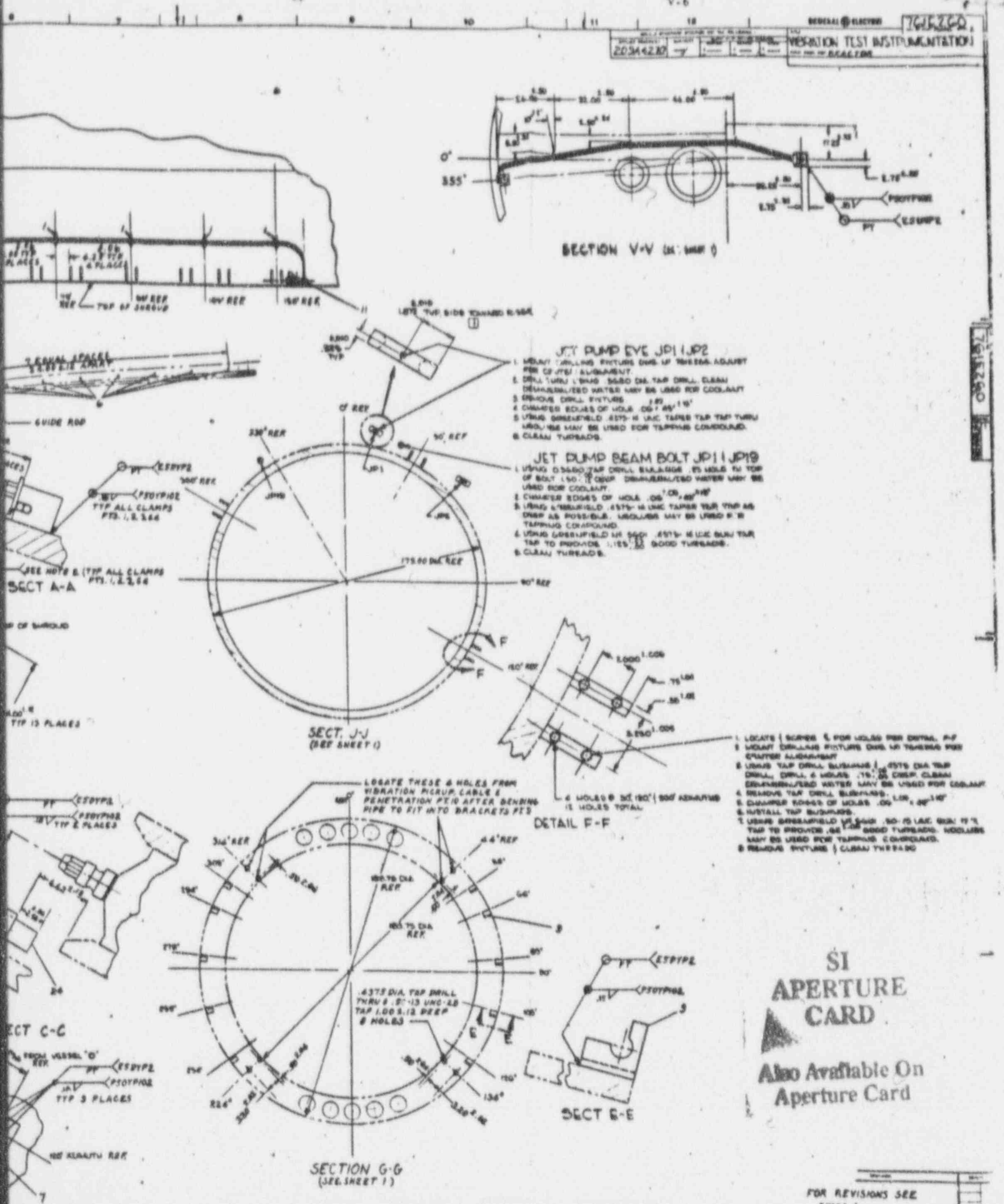


CLAMPS MUST BE LOCATED WITHIN THIS AREA
SEE NOTE 2
VESSEL I.D.
TOP OF SHROUD
TYP 12 PLACES
AFTER INSERTING ALL TUBES HOLD LOCK PLATE IN HORIZONTAL POSITION & TIGHTEN BOLT, THEN WELD BOLT TO LOCK PLATE. SNUG SET SCREW AND TACK WELD PER NOTE 2.
THE INDICATED BRACKET SURFACE SHALL BE PERPENDICULAR WITHIN .05 TOTAL TO A LINE PASSING THRU THE CENTERS OF THE HOLD-DOWN BEAM BOLTS OF THE ADJACENT JET PUMP PAIR
SECTION H-H (SEE SHEET 1)
SECT. B-B
SECTION J-J (SEE SHEET 1)
THE INDICATED BRACKET SURFACE SHALL BE ALIGNED PARALLEL TO VESSEL RADIAL LINE PASSING THRU THE CENTER OF THE SHROUD HEAD BOLT LUG PAIR AT THOSE AZIMUTHS
VIEW



SI APERTURE CARD

Also Available On Aperture Card

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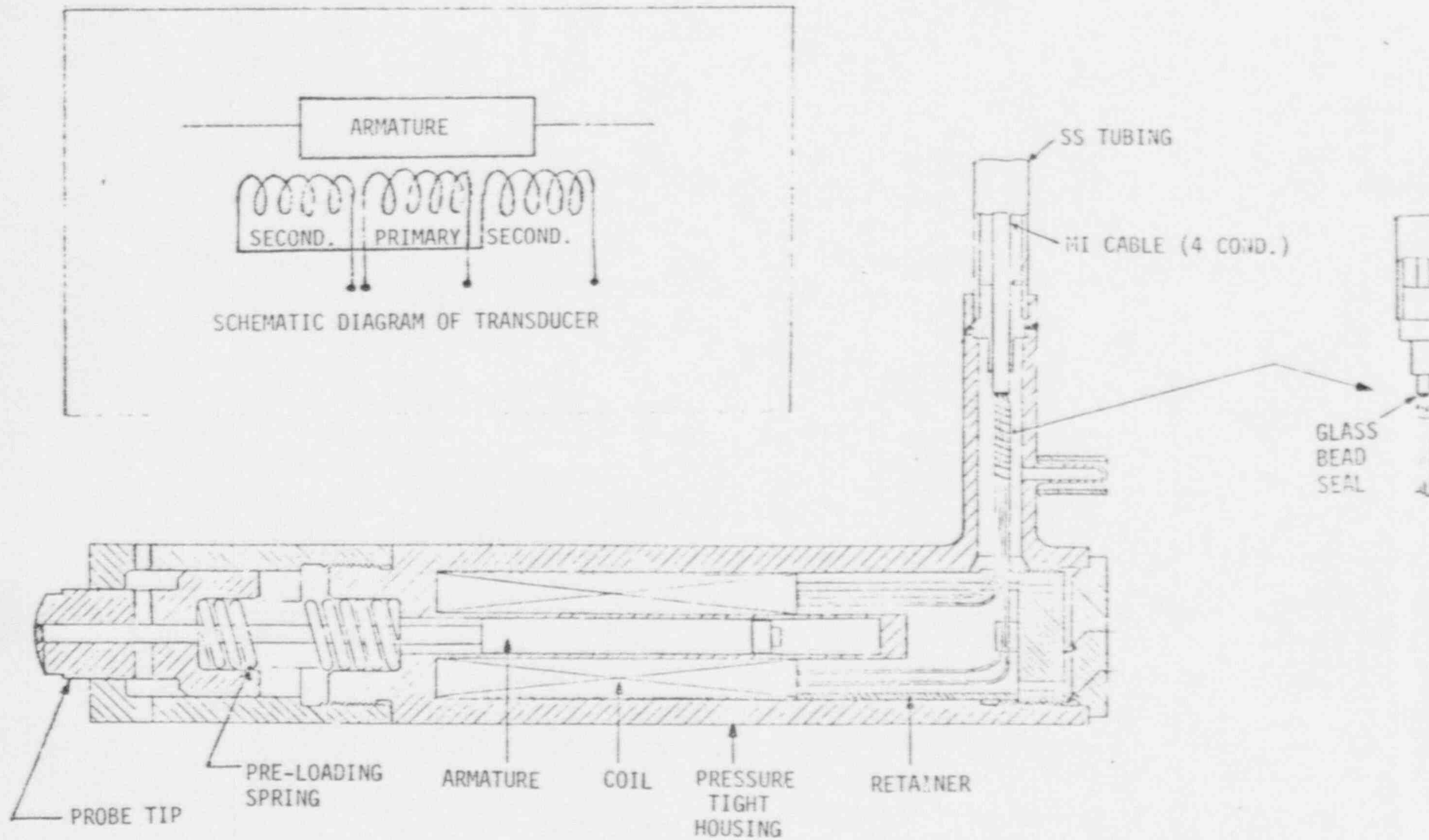
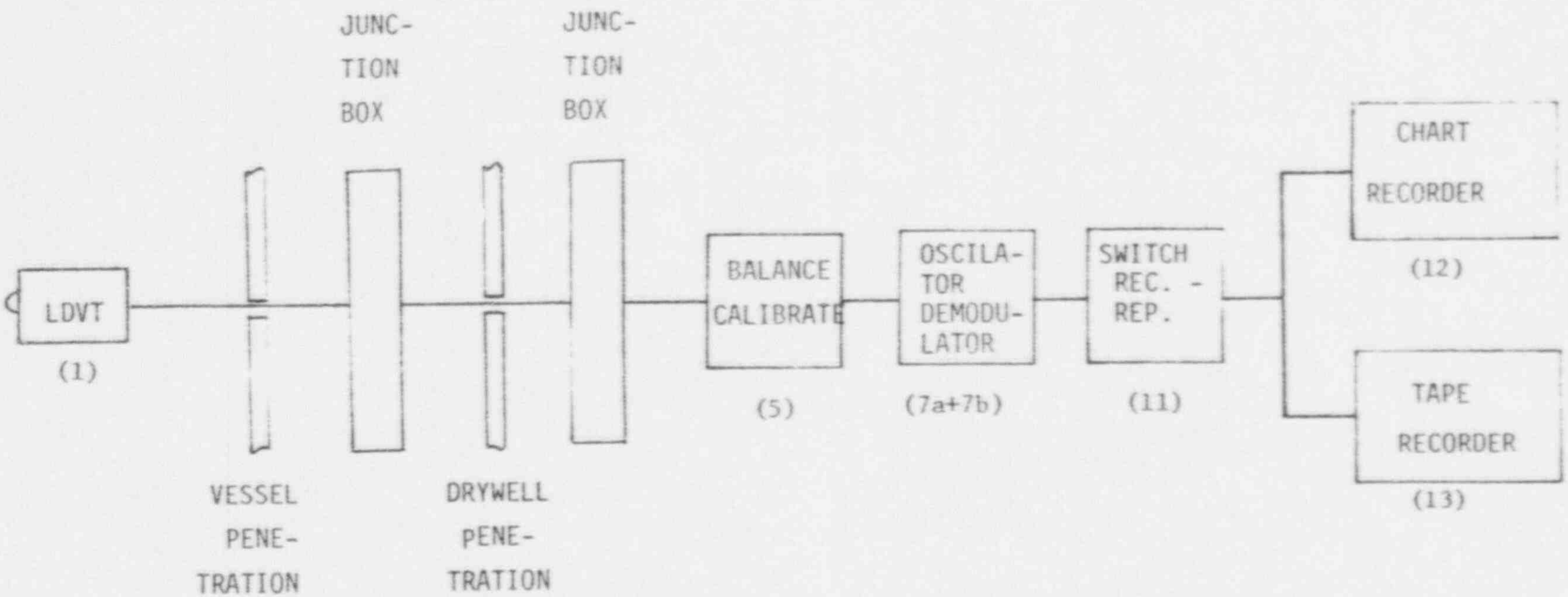


FIG. V-1 DISPLACEMENT TRANSDUCER

(DIFFERENTIAL TRANSFORMER TYPE)



Note: Refer to table V-2 for the
description of each block.

FIG. V-2 BLOCK DIAGRAM OF THE LVDT VIBRATION INSTRUMENTATION

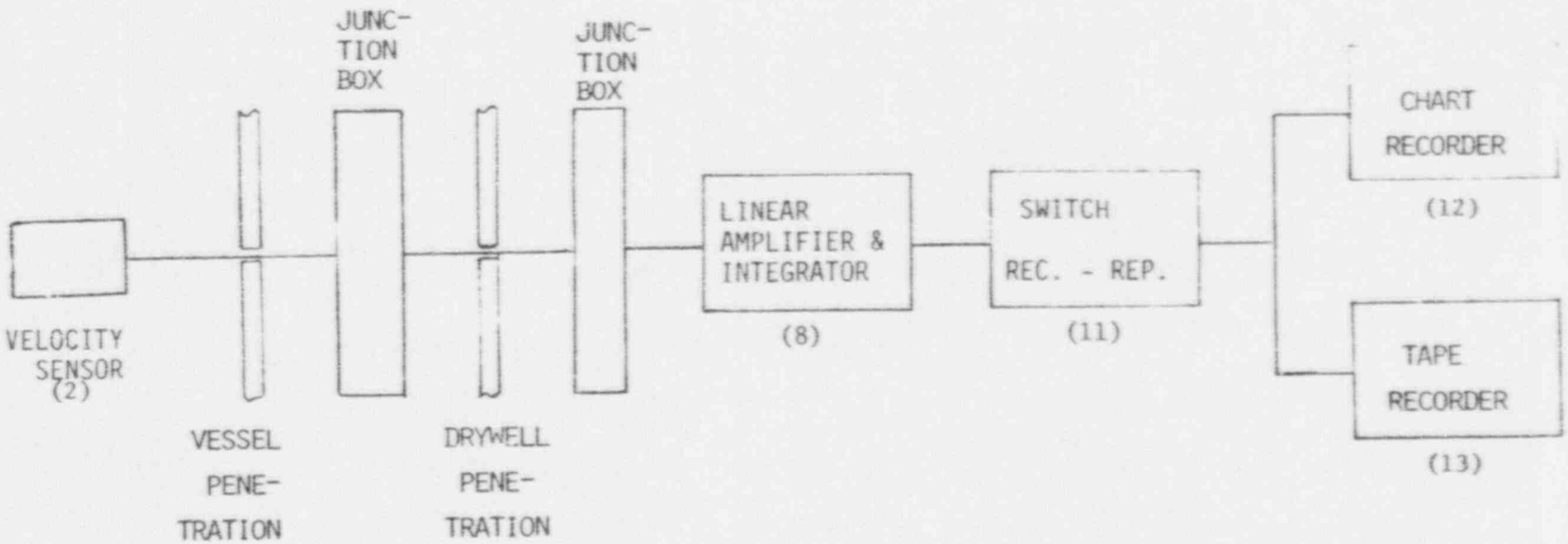
A-2 VELOCITY SENSOR

The velocity-type vibration sensor used was a seismic self-generating unit whose output voltage was proportional to the linear velocity of the surface upon which it was mounted.

This sensor is basically a coil of wire that vibrates in a magnetic field in a direction that is at right angles to the magnetic flux lines. The coil of wire is mounted on a weighted spring-supported arm, which is free to vibrate around a pivot at the opposite end. When the frequency of vibration is higher than the natural resonance of the suspended system (spring, arm and coil), the suspended system essentially remains in an undistrubed position. Thus, relative motion (velocity) between the stationary coil and the moving magnetic field causes a voltage to be generated in the coil.

The output voltage from the sensor is amplified and integrated by a Validyne linear amplifier and integrator (Model AM-49), which makes the output proportional to displacement as shown in the block diagram in Figure V-3. This integrated signal goes through a specially-designed switching circuit to a magnetic tape recorder and a pen-type chart recorder.

The overall response characteristics of each component in this velocity-to-displacement measuring system is listed in Table V-2 for each of the components indicated by the block diagram in Fig. V-3.



Note: Refer to table V-2 for the description of each block.

FIG. V-3 BLOCK DIAGRAM OF VELOCITY SENSOR INSTRUMENTION

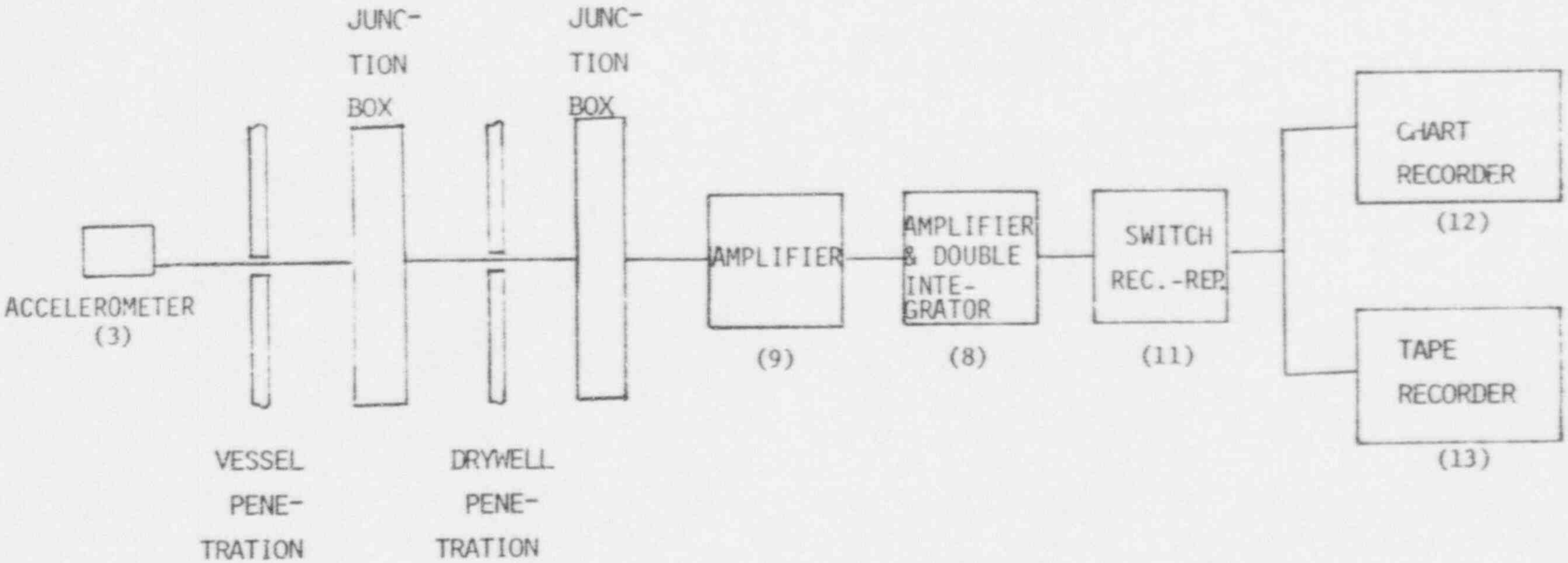
A-3 ACCELEROMETER

The acceleration-type sensor used was a seismic self-generating unit whose output voltage was proportional to the linear acceleration of the surface upon which it was mounted. The sensing element in the accelerometer was a special ceramic-type piezoelectric material that generates an electrical charge proportional to its mechanical distortion. This ceramic-type material was used to support a mass such that when the system was accelerated along its sensitive axis, the acceleration forces at the mass would distort the piezoelectric ceramic generating an electric charge. (The resultant voltage sensitivity would depend on the total capacitance of the piezoelectric, leads, etc.)

The accelerometer was used with an Unholtz-Dickie voltage amplifier as shown in the block diagram in Fig. V-4. The output from the amplifier was integrated twice by the linear amplifier and two-stage integrator. This double integration gave an output which was proportional to the displacement.

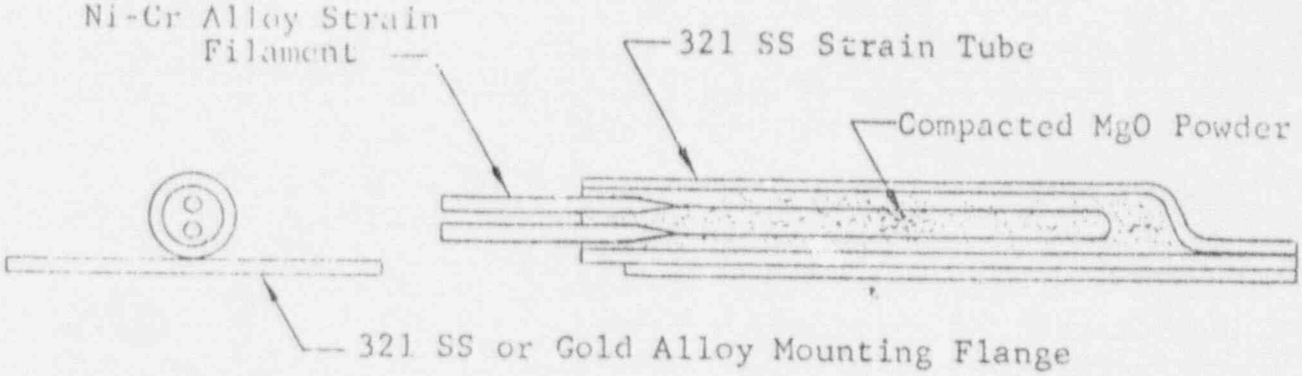
The displacement signal goes through a switching system to a tape recorder and a 6-pen chart recorder. The switching unit also allows the tape recorder to play back to the chart recorder.

The overall response characteristic of each component in this acceleration to displacement measuring system is listed in Table V-2 for each of the components indicated by the block diagram in Fig. V-4.

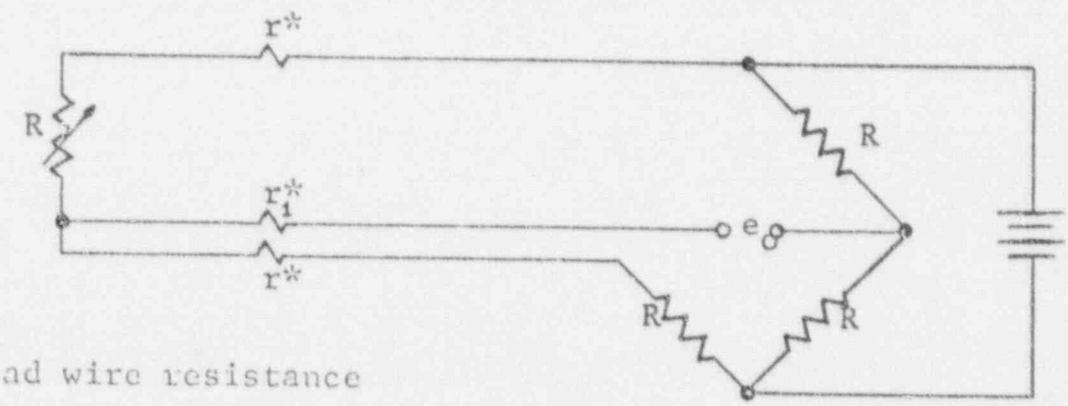


Note: Refer to table V-2 for the description of each block.

FIG. V-4 BLOCK DIAGRAM OF ACCELEROMETER INSTRUMENTATION



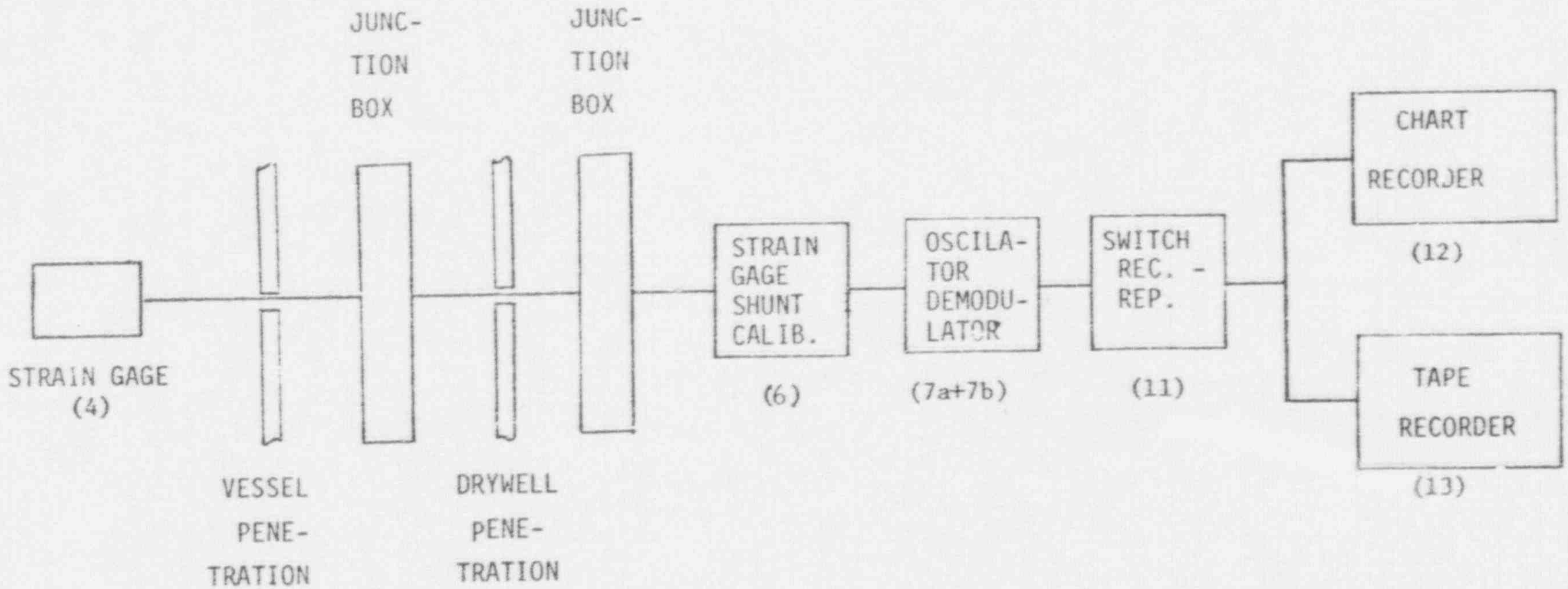
Single Active Gage Construction



*lead wire resistance

Three-Wire Circuit For Quarter-Bridge Strain Gage

FIG. V-5



Note: Refer to table V-2 for the description of each block.

FIG. V-6 BLOCK DIAGRAM OF THE STRAIN GAGE INSTRUMENTATION

A-5 RECIRCULATION PUMP SPEED INSTRUMENTATION

The rotational speed of the recirculation pumps was determined by counting the number of once-per-rev. spikes recorded on the chart recorder. The sensing system used was a photocell and lamp assembly that saw changes in light caused by different width black marks painted on the pump-motor coupling. The changes in light caused a change in resistance of the photocell which is in series with a power source and a variable load resistor.

The pulses across the load resistor are sent through a switching circuit to a magnetic tape recorder and a 6-pen chart recorder.

The switching circuit allowed the tape recorder to play back to the chart recorder.

The relative position of the large and small pulse from the different width strips on the coupler determine the direction of the pump rotation.

TABLE V-2

SPECIFICATIONS AND RESPONSE CHARACTERISTICS OF VIBRATION INSTRUMENTATION COMPONENTS

(1) LVDT

Case - Manufacturer - G. E.

Model - Drwg. 761E392

Specifications: Operates underwater at ~ 1200 psi and from 70-550° F in a radiation field of $10^{10} n/cm^2$ sec fast neutrons (above 1.0 Mev) and 10^{13} Mev/cm^2 sec gamma.

Excitation - 5v - 3KHz from Validyne module case

Linearity - within ± 2% over range or ± 0.20"about null position

Sensitivity -

Linear Variable Transformer - Manufacturer - Columbia Research Lab., Inc.

Model - modified Cat. No. SL-200-S3R

Range- ± .200

Freq. - optimum: 60 cps

Null voltage: 2.00 millivolts

Output voltage: 1.08

Sensitivity: 0.86 MV/.001"/Volt input

Linearity 0 = .25%

(2) Velocity Sensor

Manufacturer: MB Electronics

Model: 122(S). (S) denotes modified for high temperature

Specifications: Natural Frequency - 4.75 Hz

Damping - .65

Open circuit sensitivity - 963 mv(rms/in/sec(rms)

Suspension - Jewel bearing

Temp. Range - to 500° F

Frequency range - 5 to 2000 Hz

(3) Accelerometer

Manufacturer - Columbia Research Laboratories, Inc.

Model - 902

Specifications - Nominal Sensitivity: 15pk-mv/pk-g (± 25% range)

Nominal Charge Sensitivity: 150 coul./g

Freq. Response: w/1000 Megohm load - 1 cps to 6Kc

w/10 Megohm load -

w/o cathode follower -

5 cps to 6 Kc

Resonant Frequency: (1st. minor mode)

32 Kc. (nominal)

Maximum Acceleration: 2,000 g

Minimum acceleration: determine by sig./noise ratio

Aplitude Linearity: ± 1%

(4) Stress Gage

Manufacturer - Microdot Inc. (Instrument Division)
Model - SC 125
Specifications:
Resistance - 120 ohm ± 3.5 ohm
Gage factor - nominal: 1.80
Rated strain level - ± 6000 microinches per inch
Fatigue life - Exceeds 10^6 cycles at ±1000 microinches per inch
Transferse Sensitivity - Negligible
Operable Temp. Range - Static. -452° F to + 650° F
Dynamic. -452° F to + 1500° F
Gage factor change with temperature: G.F. varies inversely with temperature approximately 1% per 100° F.
Nuclear radiation - Negligible
Material - Stainless steel (type 321)

(5) Balance Unit - Manufacturer - Validyne
Model - CD-19-529 (specially built for G.E.)

(6) Strain Gage Shunt Calibrator

Manufacturer - special unit built by Comp. Design Laboratory
Model - Drwg. 117C460 - ref. K. Miller and B. Tallman, G.E., Component Design.
Specifications: To provide electrical equivalent of mechanical strain by shunting a 1 megohm resistor across the dummy resistor.

This change in bridge balance resistance provides a 101 microstrain equivalent signal for calibrating the chart recorder.

(7b) Module Case - Manufacturer - Validyne

Model - MC1-20
Oscillator: Output voltage - 5v RMS, center tapped adjustable
Frequency: 3000 Hz ± 1%
Power supply: Output - 7.5, 15 volts, 25 watts.

(7a) Demodulator

Manufacturer - Validyne
Model - CD-19 Plug-in carrier demodulator
Specifications -
Power Requirements: 5v, RMS, 3KHz, ± 15 VDC from MC1
Input sensor sensitivity: 1MV/V, 2.5 Mv/V, 10 Mv/V, 25 Mv/V
Selector switch with 0-100% vernier potentiometer.
Output: ±10 VDC @ 10 ma

Non-linearity - ± 0.05% full-scale max.
Frequency Response - 0-10, 0-50, 0-200 and 0-1000 Hz, flat ± 10%

(8) Linear Amplifier and Integrator

Manufacturer: Validyne Engineering Corp.

Model: AM 49

Specifications: Power requirements - ± 15 VDC from MC-1
Output: A - ± VDC @ 10 ma
Gain - 2.5 to 100 times in 6 steps
Attenuation - 0 to 100% adjustable
10 turn calibrated dial
Frequency response - 0 to 5KHz DC
- 2 to 5KHz AC
Filter Switch - selectable low pass; 0 to 50, 0 to 200, 0 to 1000; 0 to 5000 Hz

(9) Amplifier

Manufacturer - Unholtz-Dickie Corp.

Model - 8PXCV (special version of standard CV608RMG DIAL-A-CHARGE. Does not include the indicating meter or galvo circuitry.)

Specifications:

Input mode - Operates with voltage up to 15 volts rms with tranducers in the sensitivity range of 1 to 100 pk mv/pkg.
Gain ranges - 1, 3, 10, 30, 100, 300 and 1000 g ± 1% calibrated variable dial ±10, 10-100 pcmb or mv/g.
Output - ± 2.5 volts peak on any range 1g to 1000 g, with transducer sensitivity 1 to 100 mv/g into a 2.5K ohm load impedence or greater.
Frequency Response - Output flat within ± 1% from 10 hz to 5Khz and within ± 2% from 5hz to 10 Khz.

(11) Switching Circuit

Manufacturer - G. E.

Model - special component designed by J. M. Sager, Comp. Design, G. E. Company.

Specifications - Passive elements (toggle switches and multiposition switches and relays)

(12) Chart Recorder
Manufacturer - Clevite Corporation, Brush Instruments Division
Model - Mark 260 recorder
Specifications -
General - Number of channels: 6 analog, 4 event
Channel width: 40 mm, 50 div. /channel
Writing method: Pressurized fluid
Chart speeds: eight; 1, 5, 25, 125 mm/sec
1, 5, 25, 125 mm/min
Chart speed accuracy: $\pm$ .25%

Electrical - Measurement range: 1 millivolt per chart division to 500 volts D. C. full scale
Maximum signal input: 500 volts D. C. or peak to peak
Frequency response: 50 div. $\pm$ 1 div. to 40 cps.
10 div. $\pm$ 1 div. to 100 cps.
3 db down at 125 cps
Sensitivity: 1mv/div. to 10 volts/div.

(13) Tape Recorder
Manufacturer - Consolidated Electrodynamics Corp. (CEC)
Model - VR3360
Specifications - Tape speed: 15 in. /sec
Center frequency: 27.0 KC
Information frequency: 0-5 KC $\pm$ 0.5 db
Full-scale signal to noise ratio (RMS signal/RMS noise) 43 db
Harmonic distortion: 1.5%
Input level - 0.5 to 10 volts rms adjustable