FLORIDA POWER CORPORATION

CRYSTAL RIVER - 3

DECAY HEAT PUMP 1-A VIBRATION ANALYSIS

BY

EXTERNAL ACCELEROMETER

J. M. HUZDOVICH
SUPERVISORY ENGINEER
REACTOR DIAGNOSTIC SERVICES
NUCLEAR SERVICE DEPARTMENT

AUGUST 28, 1978

THE BABCOCK AND WILCOX COMPANY

CONTENTS

1.0 References & Attachments

2.0 Introduction

3.0 Data Analysis

4.0 Summary

1.0 REFERENCES & ATTACHMENTS

1.1 Memo: R. V. Green to J. R. Shetler - 8/18/78; File NSS-7/T3.36. "Decay Heat Pump 1-A Disassembly & Visual Inspection.

1.2 Attachment 1 - Frequency Identification & Calculations.

1.3 Attachment 2 - Overall Noise Levels.

1.4 Attachment 3 - Individual Frequency Levels in G-RMS.

1.5 Attachment 4 - Data Comparison Tables - Individual Frequency Levels in G-RMS versus A-Pump, Data Sets 2 & 3 and B-Pump Data Sets 2 and 3.

1.6 Attachment 5 - Selected Frequency Spectra and Comparative Overlays.

1.7 Vibration Tolerances for Industry ASME 67-PEM-14, presented by R. L. Baxter and D. L. Bernhard.

2.0 INTRODUCTION

Frequency Data was obtained by RDS personnel (Reactor Diagnostic Services) on the FPC Decay Heat Pumps (1A & 1B) on several occasions utilizing acclerometers installed externally on the pump, connected piping, and bearing housing. A typical data channel and the data sets acquired are shown on Figure 1. Figure 2 shows the monitoring points on the pump, motor, and base plate.

The acquired data was reviewed for frequency content and noise source identification and then compared to other data sets to identify comparable performance and trends in performance for the 1A Pump. The data sets compared were Pump A, Sets 2 & 3, and Pump B, Sets 2 & 3. These comparative data are presented in Attachment 4.

Raw data reduction consisted of plotting the overall noise levels, tabulating the magnitude versus frequency for selected accelerometer locations, and overlaying Power Spectral Density Plots for direct spectra comparison, which is another type of comparative analysis utilizing visual observation as opposed to numbers comparison. The overlays were done on selected channels and analysis ranges.

The channels ultimately selected for detailed evaluation were 5, 6, 8, 9, and 10. Channels 1, 2, 3, & 4 were associated with the motor and showed no significant levels to explain pump performance other than a contribution at the rotational frequencies which may normally be attributed to this type of pump-drive arrangement. Channel 7 was also deleted from the analysis as this location exhibited a spectrum characteristic of the pump-drive combination with no discernable influence from the mount or foundation.

2.0 INTRODUCTION

(Continued)

Channel 12 was representative of the data from channel 5 and was also judged to lend no further insight to pump performance. Channel 8 was used for the axial pump signature, the data from channel 12 was not used as it was simply redundant with channel 8.

3.0 DATA ANALYSIS

3.1 The total noise level readings were taken by simply measuring the signal RMS voltage level. These data reflect the broadband noise level due to all sources and are useful in demonstrating trends in broadband phenomena such as hydraulic instabilities, rubbing and contact between non-lubricated wear surfaces.

Attachment 2, B-Pump, Data Set 3, shows high background noise level (point 8). This is also seen in Figure 5-1 of Attachment 5. This high level is believed to be due to the fact that the B-DH Pump was on recirc from the BWST. However, the high level is broadband in nature and has little affect on the individual frequency magnitudes. In addition, the rest of the B-Pump Data Set 3 data indicates a normally running pump. Thus, this data set is still used in the comparative analysis. The remaining data sets shown in Attachment 2 are within reasonably expected values and were taken with the respective pump on recirc from the core rather than the BWST. The reduction in noise level at monitoring point 6 (for the A Pump) is of notable significance. Undoubtedly this is due to the approximately 10 to 1 decrease in the magnitude of the signal at 1375 HZ. Valid conclusions regarding the A Pump performance based on comparison of these data are:

1. The A Pump is running at least as good as the B Pump.
2. The overall noise level on the A Pump Casing (Position 6) is decreasing significantly.

3.2 Attachment 3, Individual Frequency Levels in G-RMS shows an expected decrease in noise level as the A Pump accumulated run-in time. Set 2 was taken within four hours after bearing replacement and reassembly. Set 3 was taken after approximately seventy-five (75) hours of operation. The levels recorded after the run-in period indicate a very favorable pump operating condition per industry standards (Ref.-1.7)

3.0 DATA ANALYSIS

3.2 (Continued)
and compared to B-Pump performance.
The dramatic decrease in the level at 1375 HZ between Data Sets 2 and 3 for the A Pump is of interest. This is believed to be indicative of either the shaft assembly (a new carbon runner on a metal contact surface) seating itself (see Attachment 5, Figure 5-8, overlay at this frequency for Position 6) or a reduced influence from flow induced vibrations in the piping system. On close scrutiny, this frequency is also evident on the B-Pump data set, which was taken after several thousand hours of operation. This particular noise will be examined in more detail when baseline data is established for both pumps.

3.3 Attachment 4 comprises the basic comparison between the A and B Pumps. In addition the data is tabulated so that the A Pump is compared against itself after approximately 75 hours of run time. Excluded in this comparison are the bearing frequencies listed in Attachment 1. The frequencies of interest here are the dominant rotational, pumping, and shaft seal frequencies. Except for channel 5, A Pump, Set 3 compared to A Pump, Set 2, the trend in the A Pump readings is favorable as compared to the B Pump data. Particularly on an A Pump, Set 2, to A Pump Set 3 comparison, the A Pump appears to show improvement with run time and by industry standards is not unusually noisy after 75 hours of runtime. Based on this data, a reasonable conclusion is that there is no non-lubricated metal-to-metal rub as indicated by the extremely low noise levels at the various frequencies, no high frequency (1-2KHZ) spiking and low broad-band noise levels.

3.0 DATA ANALYSIS

3.3 (Continued)

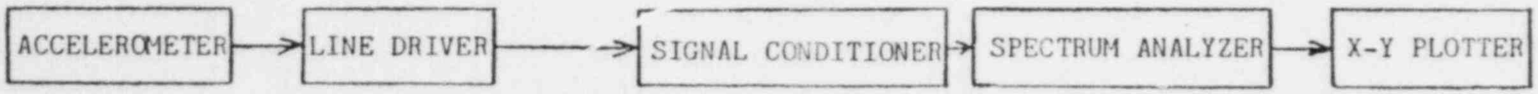
These low levels are characteristic of a smooth running machine by industry standards. In addition, Reference 1.1 summarizes a disassembly and visual inspection of the A Pump after the post impeller repair run-in period. This inspection showed no metal wear on any rotating members.

3.4 Attachment 5, Fig.-5-2&5-5, depicts the reason for the increase in noise levels monitoring position 5. The overlays show a "spiking" (circled peaks) at frequencies previously calculated for the radial and thrust bearings. Although these new peaks do not add significantly to the overall noise level, they can influence the rotational and pumping frequency peaks and certainly, as shown on the overlays, have individual characters of their own. Significantly, several of these bearing frequencies have increased, or appeared, 6-db above their previous level. This represents a quadrupling of power for a PSD measurement and is reason for concern. Based on this observation, a recommendation was made by RDS personnel that the bearings be replaced on the A Pump. Corroborating evidence regarding the bearing condition was obtained by taking shock pulse measurements (SPM) on the bearing housing. These measurements showed the SPM to be high for a pump with newly replaced bearings, thus strengthening the recommendation for replacing the A Pump bearings.

4.0 SUMMARY

The data acquired by external accelerometers* indicate faulty operation of the bearing assembly and prompted the recommendation that the bearings be replaced. The lack of significant unidentified frequency peaks, the acceptable noise levels both broadband and at individual peaks, and the visual inspection which showed no metal-to-metal contact in the pump assembly, indicate that the "A" Pump is running with sufficient clearances to preclude the type of failure experienced twice before.

*(For the A Pump)



The signal channel was calibrated by attaching the Accelerometers to an NBS traceable Unholtz-Dickie portable shaker and inserting 1 G Rms through the chain and checking the 1 volt RMS out of the charge amp. This was done on all channels prior to data acquisition.

DATA SETS:

PUMP - 1A

6-26-78-SET 2

0-100 HZ
0-500 HZ
0-2 KHZ

8-3-78-SET 3

0-100 HZ
0-500 HZ
0-2 KHZ

PUMP - 1B

6-26-78-SET 2

0-100 HZ
0-500 HZ
0-2 KHZ

8-3-78-SET 3

0-100 HZ
0-500 HZ
0-2 KHZ

NOTE: SET 1 was taken only on the B-Pump on 6-6-78. This set established the basis for subsequent measurements and was considered as preliminary data only. The final two data sets were then taken and these are the only sets considered in the analysis.

FIGURE 1

JSS
8/28/78

LOCATION OF ACCELEROMETERS

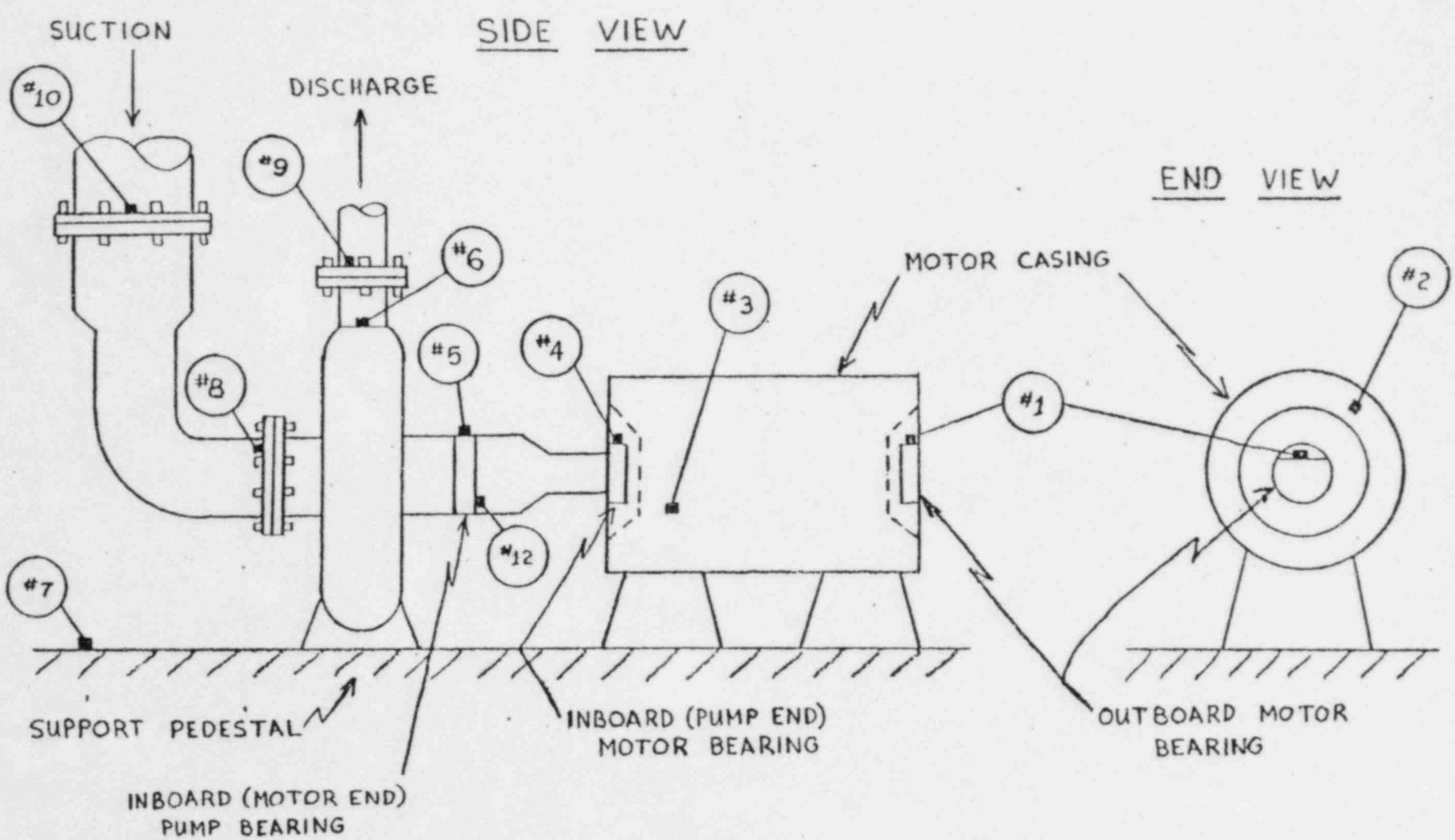


FIGURE - 2

Attachment 1

Frequency Identification & Calculations

Table `-1

Frequency Identification

Fundamental Rotational Frequency	- f_f	29.6HZ
	X2	59.2HZ
	X3	88.8HZ
Pumping Frequencies	- f_f x 5 vanes	148HZ
	X2	296HZ
	X3	444HZ
	X4	592HZ

Motor Frequencies
No significant participation in the pump signature.

Bearing Frequencies - attached. Calculated per the formulas on the attached sheet.

Table 1-2

Bearing Frequencies

Radial	5214C3	10 Balls
Thrust	7313B	12 Balls

Radial Bearing - 5214C3

$B = 2.76$
$D = 4.92$
$E = 1/2\ (B + D) = 3.84$
$d = 11/16 = .688$
$N = 10$
$\alpha = 35°$
$f_f = 29.6$

$$f_{EO} = \frac{f_f}{2}\left(1 - \frac{d}{E}\cos\alpha\right) = \frac{29.6}{2}\left(1 - \frac{.688}{3.84}\cos 35°\right) = 14.8\ (1 - .147)$$

$f_{EO} = 12.62$ HZ

$$f_{EI} = \frac{f_f}{2}\left(1 + \frac{d}{E}\cos\alpha\right) = 14.8\ (1.147)$$

$f_{EI} = 16.98$ HZ

$$f_B = \frac{E}{d}\frac{f_f}{2}\left(1 - \frac{d^2}{E^2}\cos^2\alpha\right) = 82.60\ (1 - .022)$$

$f_B = 80.78$ HZ

$f_{BO} = Nf_{EO}$ $\qquad$ $f_{BO} = 126.2$HZ

$f_{BI} = Nf_{EI}$ $\qquad$ $f_{BI} = 169.8$HZ

Thrust Bearing - 7313B

$B = 2.56$
$D = 5.51$
$E = 4.04$
$d = 15/16 = .938$
$N = 12$
$\alpha = 40°$
$f_f = 29.6$

$f_{EO} = 14.8\left(1 - \frac{d}{E}\cos\alpha\right) = 14.8\,(1 - .178)$ $\qquad f_{EO} = 12.17HZ$

$f_{EI} = 14.8\left(1 + \frac{d}{E}\cos\alpha\right)$ $\qquad f_{EI} = 17.43\ HZ$

$f_B = 14.8\left(\frac{E}{d}\right)\left(1 - \frac{d^2}{E^2}\cos^2\alpha\right) = 14.8\,(4.31)\,(1 - .032)$ $\qquad f_B = 61.75HZ$

$f_{BO} = Nf_{EO}$ $\qquad f_{BO} = 146HZ$

$f_{BI} = N\,f_{EI}$ $\qquad f_{BI} = 209HZ$

7313B THRUST HARMONICS

1	2	3	4	5	6	7	8	9
12.17	24.34	36.51	48.68	60.85	73.02	85.19	97.36	109.53
17.43	34.86	52.29	69.72	87.15	104.58	122.01	139.44	156.87
61.75	123.5	185	247	308	370	432	494	555
146	292	438	584	730	876	1022	1168	1314
209	418	627	836	1045	1254	1463	1672	1881
5214C3 RAD								
12.62	25.24	37.86	50.48	63.1	75.72	88.34	100.96	113.58
16.98	33.96	50.94	67.92	84.9	101.88	118.86	135.84	152.82
80.78	161	242	323	403	484	565	646	727
126.2	252	378	504	631	757	883	1009	1135
169.8	340	509	679	849	1018	1188	1358	1528

Bearing Frequency Calculations

Nomenclature:

B = Bore, inside bearing diameter (inches)
D = Outside bearing diameter (inches)
E = Pitch diameter = 1/2 (B+D) (inches)
d = Ball diameter (inches)
N = Number of balls
α = Contact angle (degrees)
f_f = Fundamental rotational frequency (RPM/60) (HZ)

Formulas

Frequency (HZ)	Approximate	Contact Angle	Remarks
Cage to outer ring frequency (f_{EO})	$\frac{f_f}{2}(1-d/E)$	$\frac{f_f}{2}(1-\frac{d}{E}\cos\alpha)$	Fundamental cage (train) frequency when the inner ring is rotating and the outer ring is stationary.
Cage to inner ring frequency (f_{EI})	$\frac{f_f}{2}(1+d/E)$	$\frac{f_f}{2}(1+d/E\cos\alpha)$	Fundamental cage (train) frequency when the inner ring is stationary and the outer ring is rotating.
Ball frequency (f_B)	$\frac{Ef_f}{2d}(1-d^2/E^2)$	$\frac{Ef_f}{2d}(1-\frac{d^2}{E^2}\cos^2\alpha)$	Spin frequency of a rolling element. A rough spot or indentation produces twice this frequency.
Outer ballpass (f_{BO})	Nf_{EO}	Nf_{EO}	Frequencies generated due to an irregularity on the stationary raceway.
Inner ballpass (f_{BI})	Nf_{EI}	Nf_{EI}	Frequencies generated due to an irregularity on the stationary raceway.
Cage to rotating ring (f_{ER})	f_f-f_{EI} or f_f-f_{EO}	f_f-f_{EI} or f_f-f_{EO}	Frequency due to the relative rotation between the cage and the rotating ring. For an irregularity in the ring, a frequency of (f_{ER}) will be generated.

Note: In the case of many irregularities, the harmonics of the above frequencies will be evident in the noise spectrum.

Attachment 2

Overall Noise Levels

Table 2-1

Overall Noise Levels
MVRMS

A-Set 2	B-Set 2
5 - 1020	5 - 1245
6 - 1600	6 - 765
8 - 1395	8 - 1750
9 - 510	9 - 495
10 - 1100	10 - 1400
12 -	

A-Set 3	B-Set 3
5 - 875	5 - 1125
6 - 1035	6 - 625
8 - 1590	8 - 2925
9 - 1170	9 - 930
10 - 1080	10 - 2400
12 - 850	12 - 650

Attachment 3

Individual Frequency Levels in G-RMS

Table 3-1

Frequency Levels in G-RMS

Pump A Set 2

	Channel				
Frequency	5	6	8	9	10
Rotational					
29.6	<.003	.005	.017	.0061	.032
59.2	.027	.045	.29	.017	.14
88.8	.026	.028	.019	.0043	.063
Pumping					
148	.19	.63	.073	.18	.44
296	.027	.41	.037	.064	.73
444	.017	.19	.033	.05	.44
592	.021	.32	.012	.034	.57
Seal & Piping					
1375	.15	4.1	.55	.2	2.2

Other

Table 3-2

Frequency Levels in G-RMS

Pump A Set 3

Frequency	Channel 5	6	8	9	10
Rotational					
29.6	.002	<.003	.003	<.003	<.003
59.2	.066	.012	.042	.018	.009
88.8	.032	.012	.0078	.02	.018
Pumping					
148	.23	.099	.12	.18	.051
296	.04	.065	.039	.042	.069
444	.012	.013	.039	.021	.03
592	.043	.054	.18	.017	.21
Seal & Piping					
1375	.28	.39	.28	.25	.345
Other					

Table 3-3

Frequency Levels in G-RMS

Pump B Set 2

Frequency	Channel 5	6	8	9	10
Rotational					
29.6	.10	.017	.033	.026	.035
59.2	.042	.11	.64	.12	.35
88.8	.11	.045	.095	.042	.061
Pumping					
148	.37	1.33*	1.4*	.48	1.93*
296	.023	.24	.63	.69	.82
444	.012	.19	.44	1.0	.27
592	.011	.22	.51	.15	.7
Seal & Piping					
1375	.016	.19	.2	.069	.15
Other					

*Note: Noise levels indicate pump in cavitation.

Table 3-4

Frequency Levels in G-RMS

Pump B Set 3

	Channel				
Frequency	5	6	8	9	10
Rotational					
29.6	.009	.0057	<.003	<.003	.0036
59.2	.024	.04	.087	.035	.054
88.8	.02	.0062	.0084	.0042	.0035
Pumping					
148	.23	.22	.27	.25	.35
296	.024	.007	.18	.081	.17
444	.014	.03	.066	.096	.015
592	.C39	.03	.036	.09	.09
Seal & Piping					
1375	.019	.012	.054	.03	.066
Other					

Attachment 4

Data Comparison Tables

Table 4-1

CHANNEL 5 Level in G-RMS

f	A Pump Set 2	A Pump Set 3	B Pump Set 2	B Pump Set 3
29.6	<.003	.002	.10	.009
59.2	.027	.066	.042	.024
88.8	.026	.032	.11	.02
148	.19	.23	.37	.23
296	.027	.04	.023	.024
444	.017	.012	.012	.014
592	.021	.043	.011	.039
1375	.15	.28	.016	.019

Table 4-2

CHANNEL 6 Level in G-RMS

f	A Pump Set 2	A Pump Set 3	B Pump Set 2	B Pump Set 3
29.6	.005	<.003	.017	.0057
59.2	.045	.012	.11	.04
88.8	.028	.012	.045	.0062
148	.63	.099	1.33	.22
296	.41	.065	.24	.007
444	.19	.013	.19	.03
592	.32	.054	.22	.03
1375	4.1	.39	.19	.012

Table 4-3

CHANNEL 8 Level in G-RMS

f	A Pump Set 2	A Pump Set 3	B Pump Set 2	B Pump Set 3
29.6	.017	.003	.033	<.003
59.2	.29	.042	.64	.087
88.8	.019	.0078	.095	.0084
148	.073	.12	1.4	.27
296	.037	.039	.63	.18
444	.033	.039	.44	.066
592	.012	.18	.51	.036
1375	.55	.28	.2	.054

Table 4-4

CHANNEL 9 Level in G-RMS

f	A Pump Set 2	A Pump Set 3	B Pump Set 2	B Pump Set 3
29.6	.0061	.003	.026	<.003
59.2	.017	.018	.12	.035
88.8	.0043	.02	.042	.0042
148	.18	.18	.48	.25
296	.064	.042	.69	.081
444	.05	.021	1.0	.096
592	.034	.017	.15	.09
1375	.2	.25	.069	.03

Table 4-5

CHANNEL 10 Level in G-RMS

f	A Pump Set 2	A Pump Set 3	B Pump Set 2	B Pump Set 3
29.6	.032	<.003	.035	.0036
59.2	.14	.009	.35	.054
88.8	.063	.018	.061	.0035
148	.44	.051	1.93	.35
296	.73	.069	.82	.17
444	.44	.03	.27	.015
592	.57	.21	.7	.09
1375	2.2	.345	.15	.066

Attachment 5

Selected Frequency Spectra
And Comparative Overlays

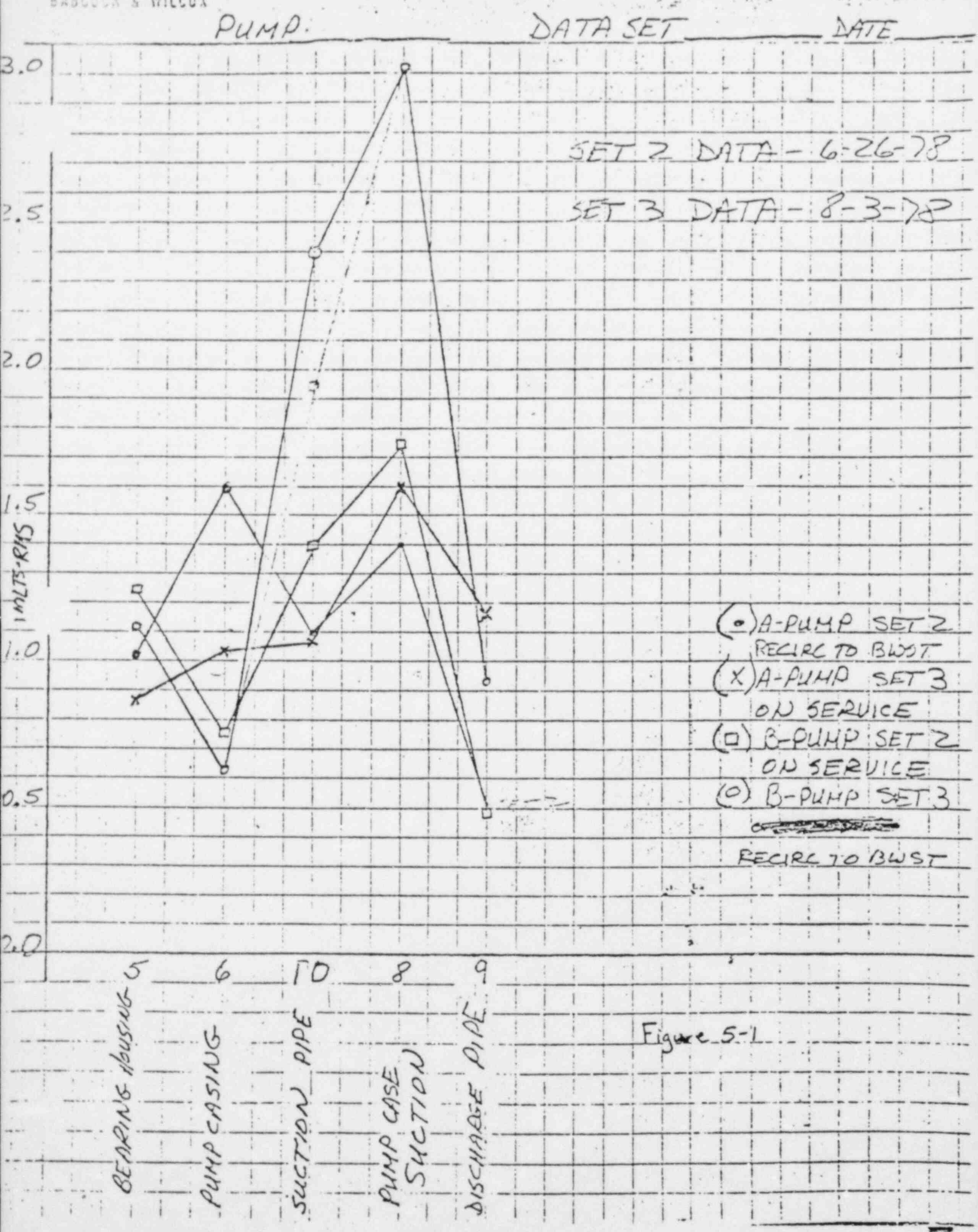
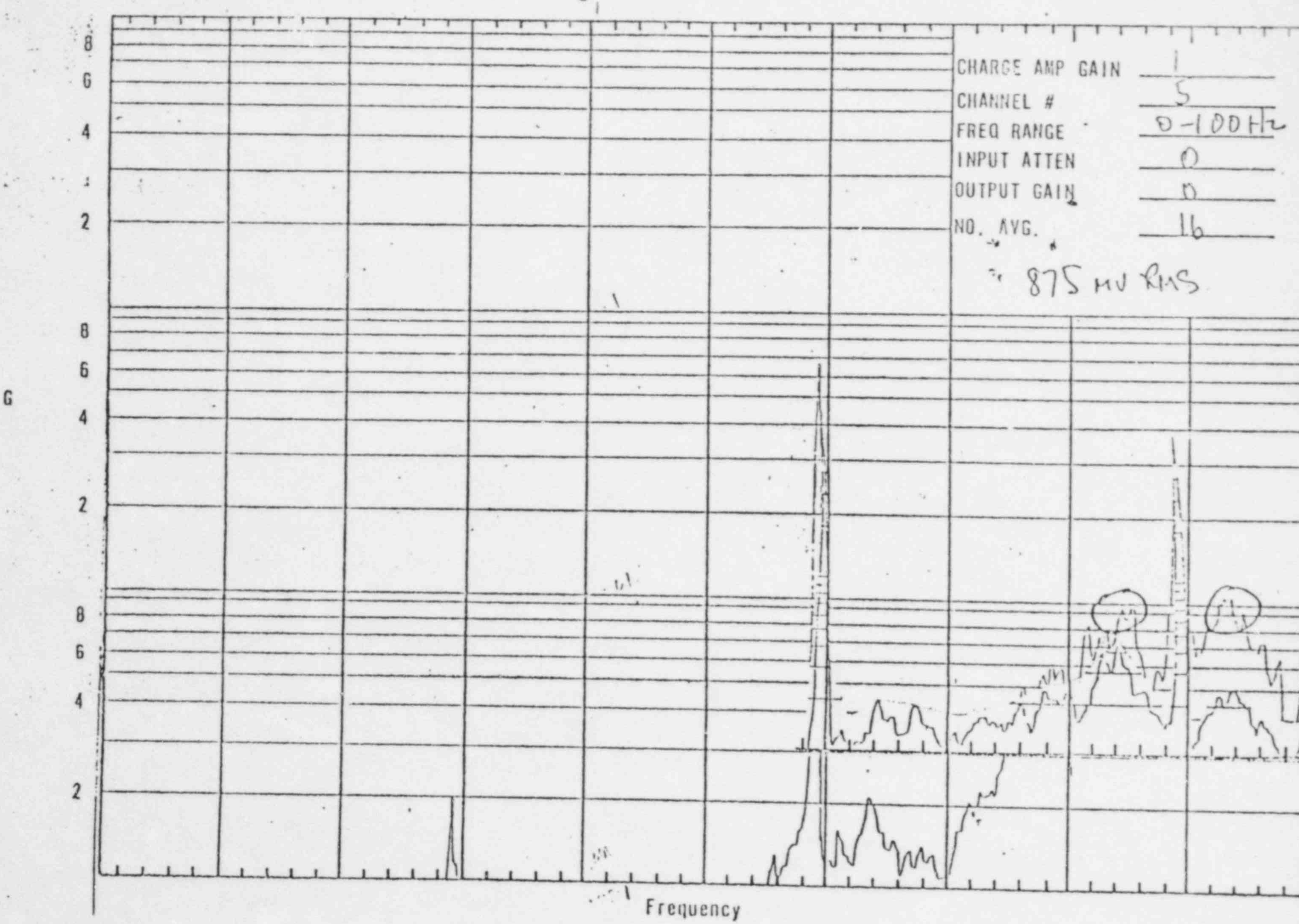

PUMP
DATA SET
DATE
SET 2 DATA - 6-26-78
SET 3 DATA - 8-3-78
3.0
2.5
2.0
1.5
1.0
0.5
MLTS-RMS
(•) A-PUMP SET 2
RECIRC TO BWST
(X) A-PUMP SET 3
ON SERVICE
(□) B-PUMP SET 2
ON SERVICE
(○) B-PUMP SET 3
RECIRC TO BWST
5
6
TO
8
9
BEARING HOUSING
PUMP CASING
SUCTION PIPE
PUMP CASE SUCTION
DISCHARGE PIPE

Figure 5-1

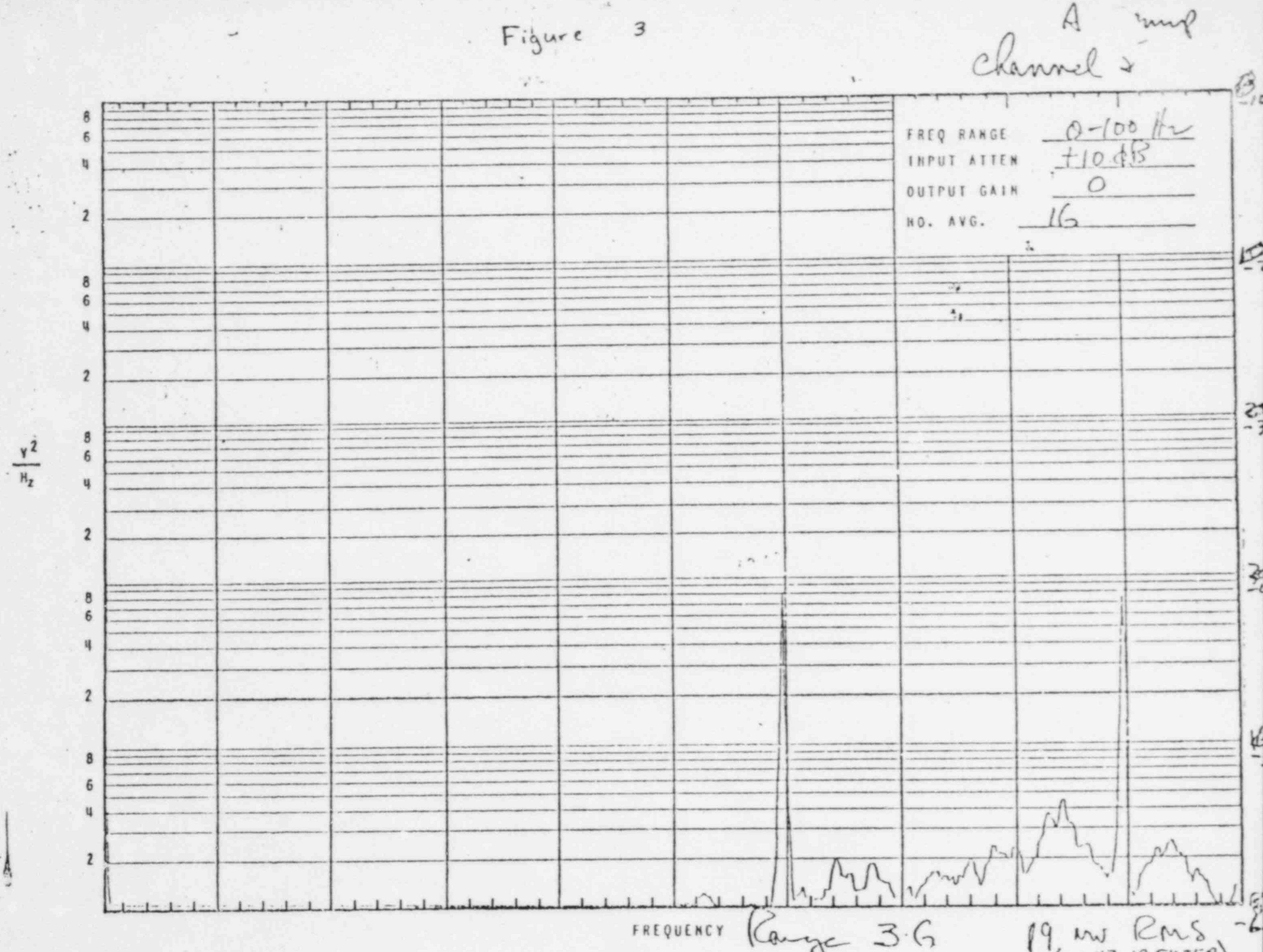
A PUMP SET 2 0-100 HZ OVERLAY ON A PUMP SET 3 0-100 HZ

Fig 5-2



PLANT ——— DATE/TIME ——— PWR LVL ——— TAPE NO. ——— SENSOR I.D. ———

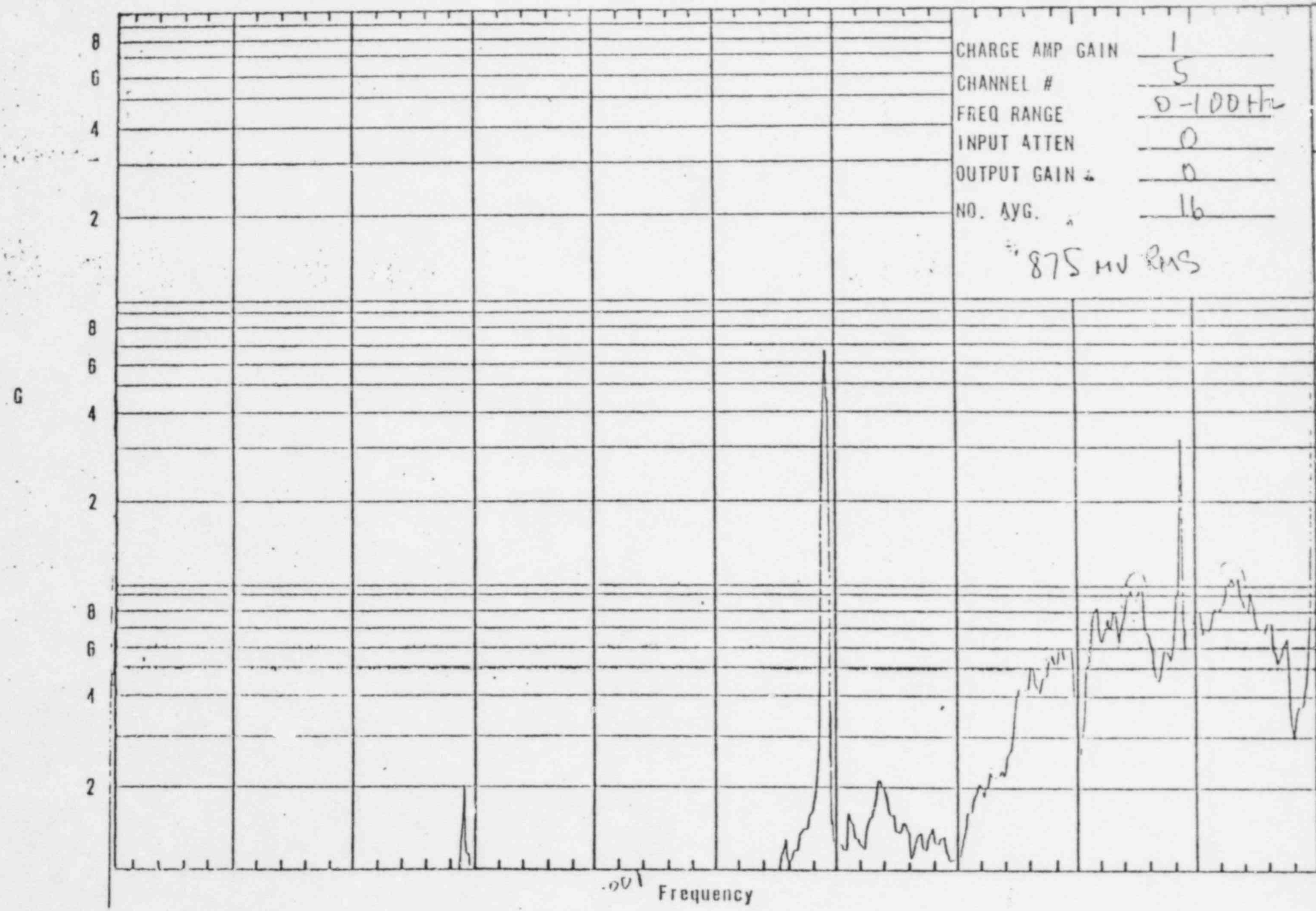
Figure 3



PLANT ______ DATE/TIME ______ PWR LVL ______ TAPE NO. ______ SENSOR I.D. ______

Figu. 5-4

A mp

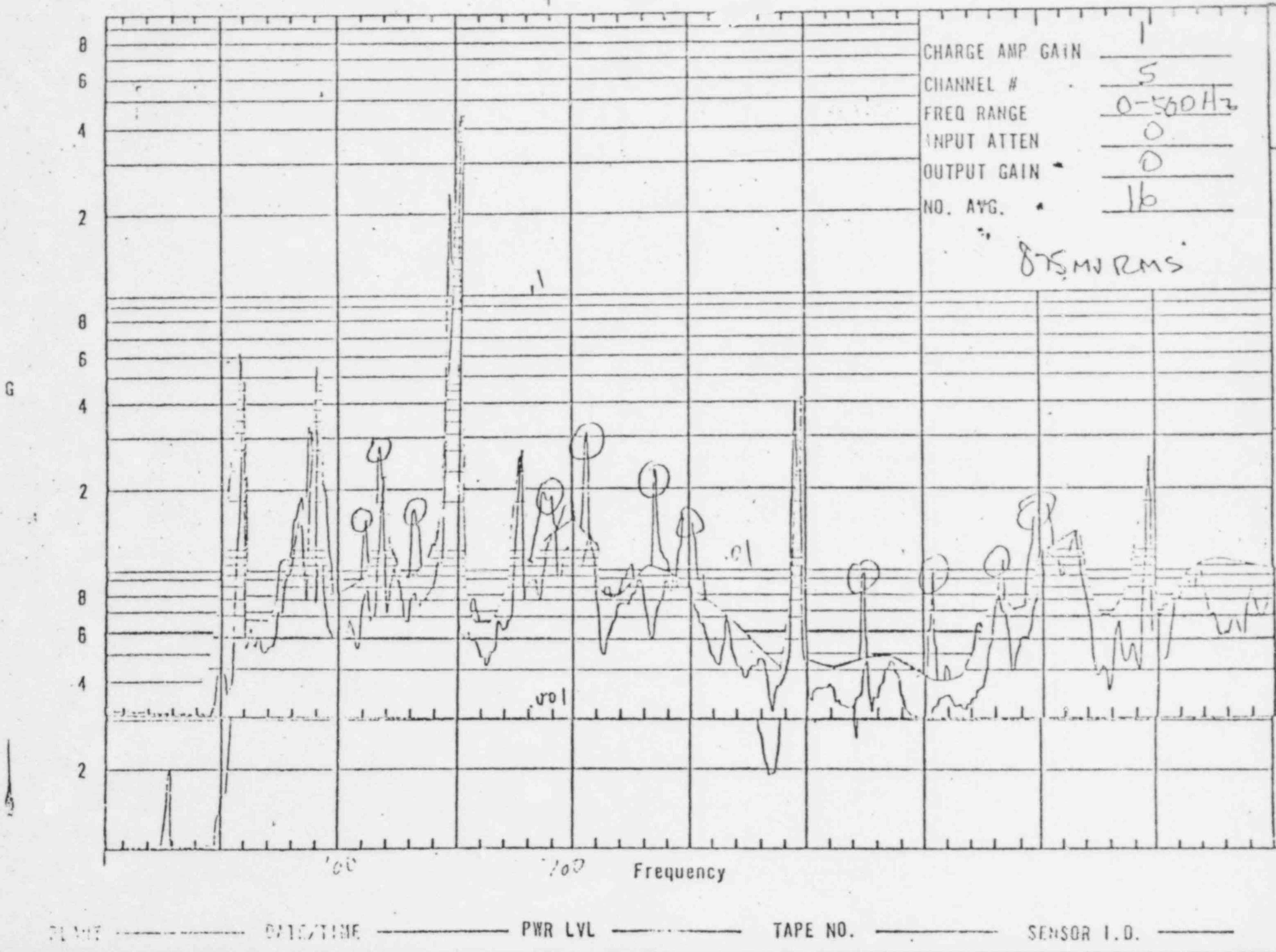


PLANT ——— DATE/TIME ——— PWR LVL ——— TAPE NO. ——— SENSOR I.D. ———

A PUMP SET 2 0-500 Hz OVERLAY ON A PUMP SET 3 0-500 Hz

Figure -5

A P



Figur :-6

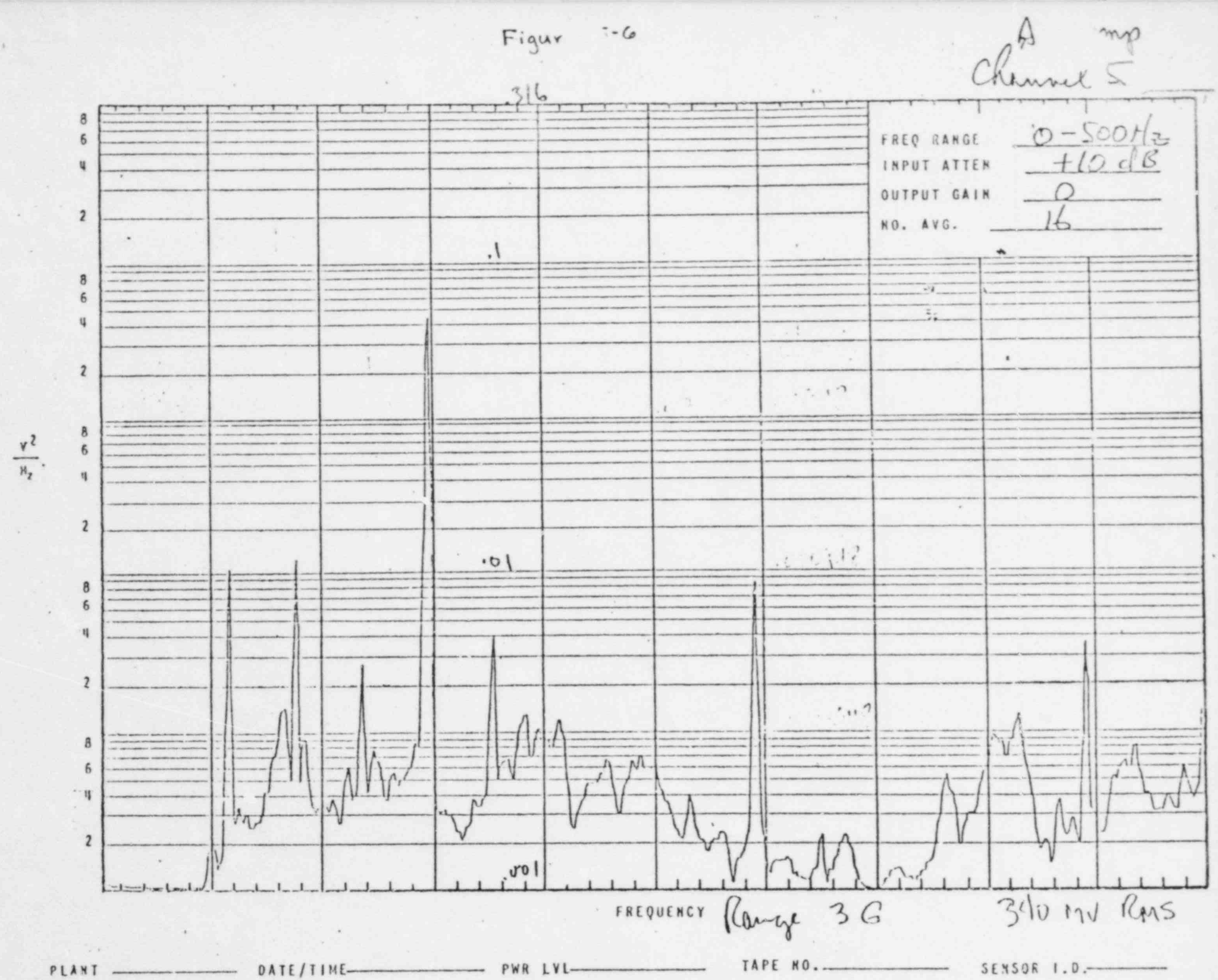
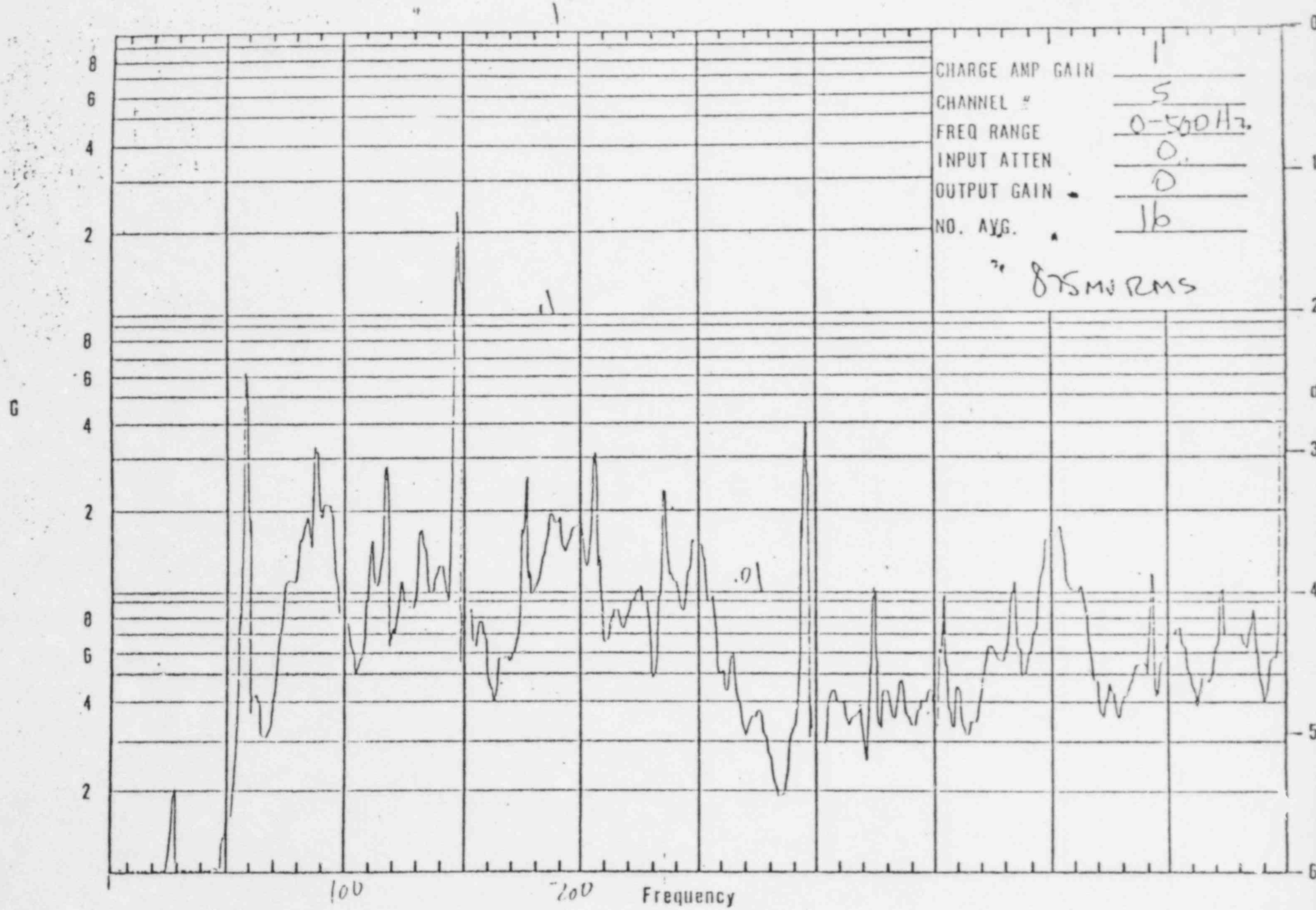

A mp
Channel 5
316
FREQ RANGE 0-500Hz
INPUT ATTEN +10 dB
OUTPUT GAIN 0
NO. AVG. 16
.1
.01
.001
8
6
4
2
V²/Hz
FREQUENCY
Range 3G
340 mV RMS
PLANT
DATE/TIME
PWR LVL
TAPE NO.
SENSOR I.D.

Figure 7

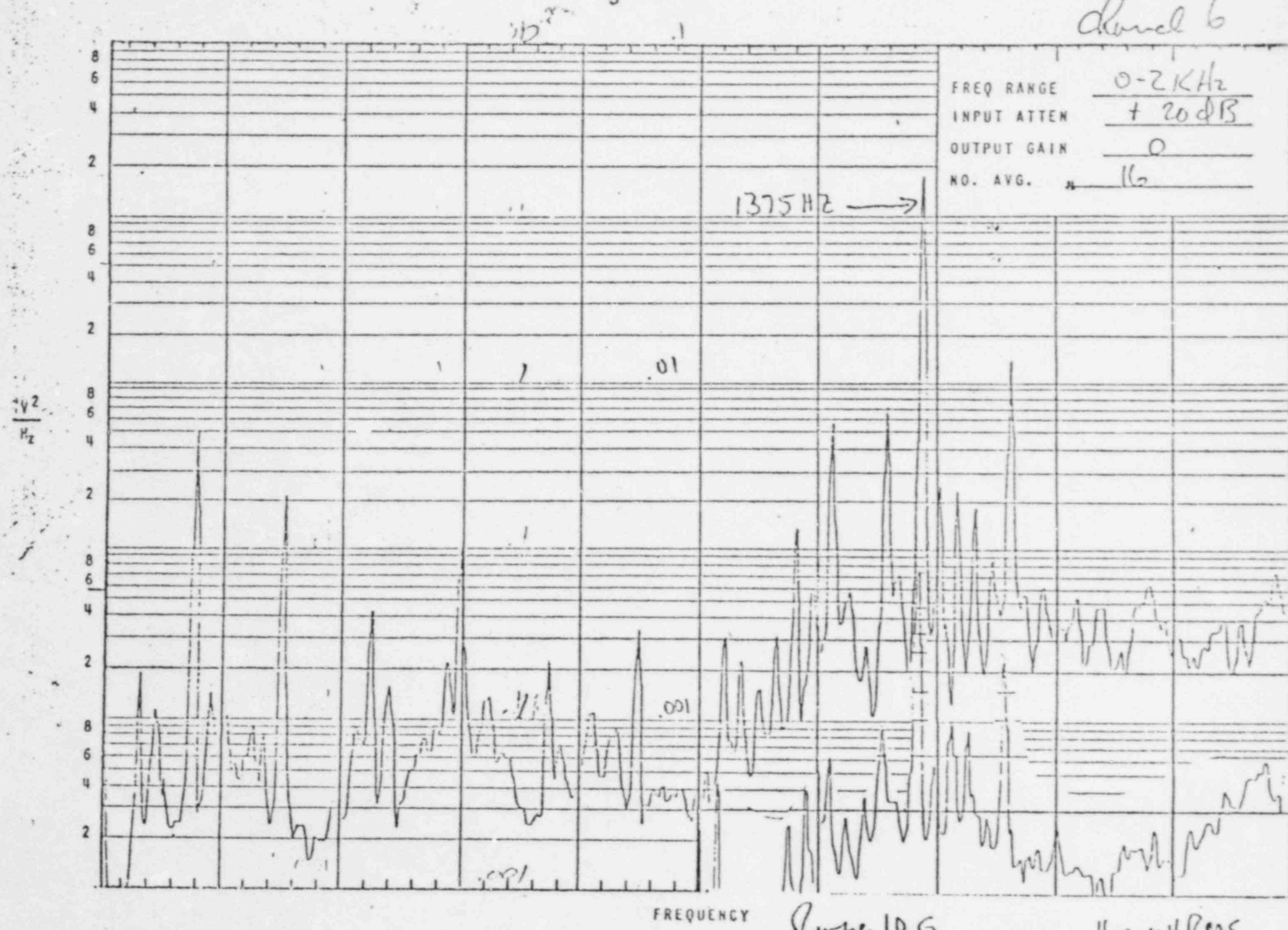
A Pv.



PLANT ——— DATE/TIME ——— PWR LVL ——— TAPE NO. ——— SENSOR I.D. ———

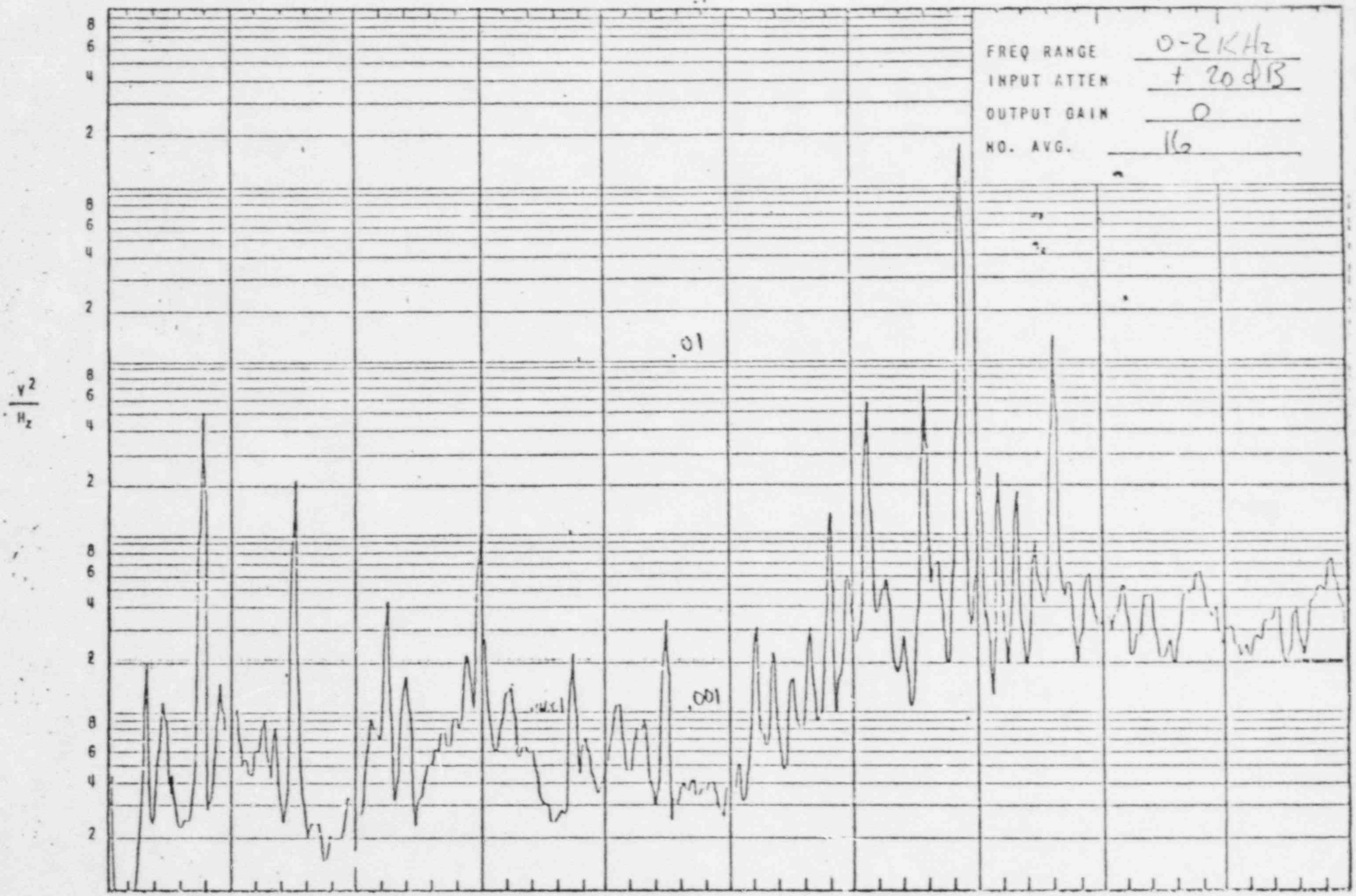
1MP SET 3 0-2KHZ OVERLAY ON A 4P SET 2 0-2KHZ

Figure 5-8



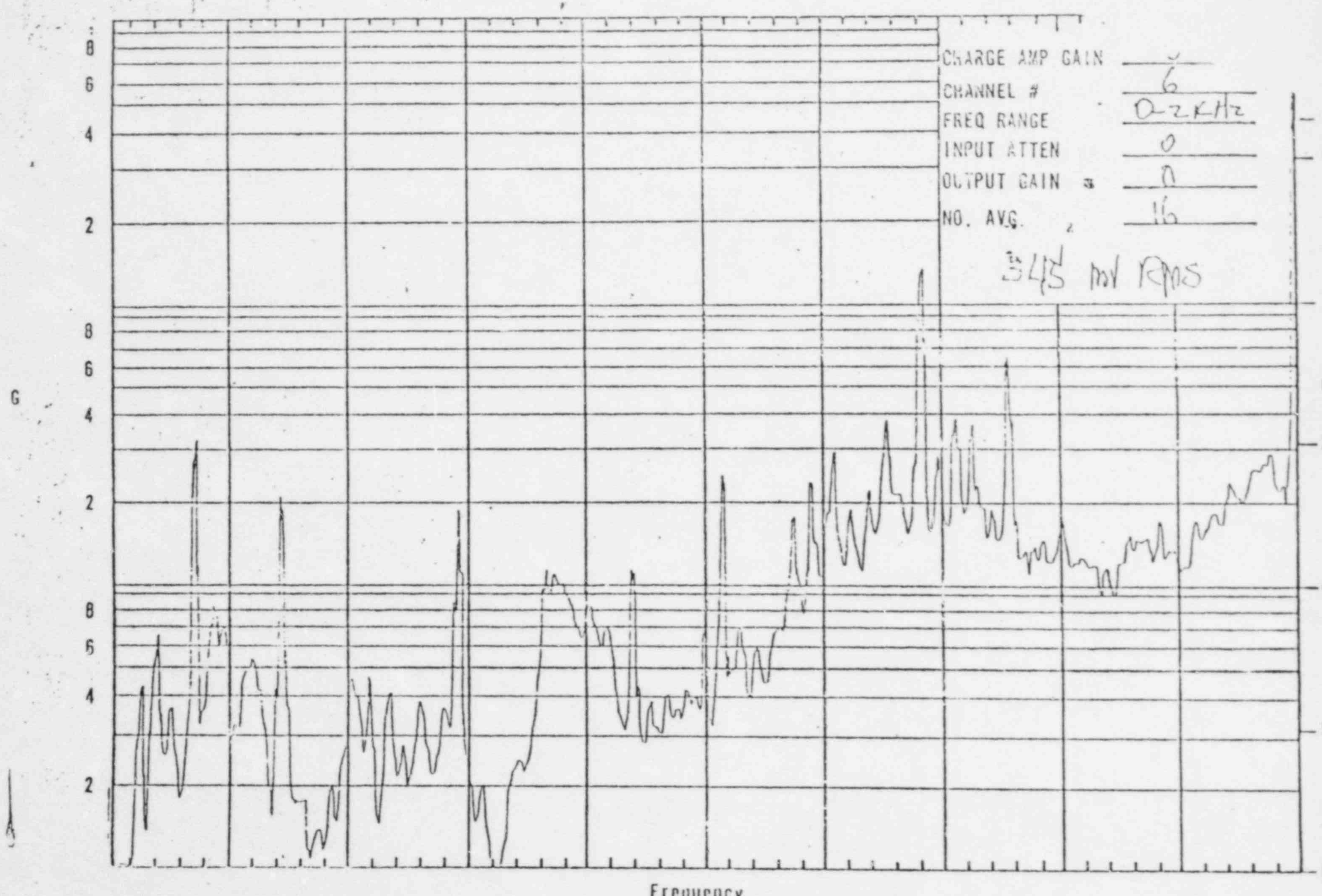
PLANT ______

Fig. 5-9



PLANT ______ DATE/TIME ______ PWR LVL ______ TAPE NO. ______ SENSOR I.D. ______

Figure 9



PLANT —— DATE/TIME —— PWR LVL —— TAPE NO. —— SENSOR I.D. ——