CONSUMERS POWER COMPANY

NUCLEAR ACTIVITIES DEPARTMENT

Palisades Nuclear Plant

Reactor Internals Noise Monitoring Tests

January 1979

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ABSTRACT

Reactor internals noise monitoring tests are being conducted on the Palisades reactor using the power range excore detectors. The tests are conducted in two phases. Phase one measurements include determining the amplitude probability distribution, the standard deviation, and the root mean square value of the excore detector noise. Phase two measurements require the determination of the auto-power spectral density, coherence, and phase relationships of the detector noise. Action limits of 0.25% rms and 0.48% rms have been imposed on the noise amplitudes.

This report covers the period from April 1978 through October 1978, which is essentially the first six full months of Core 3.

CONTENTS

LIST OF FIGURES

I. INTRODUCTION

Section 4.13 of the Palisades Plant Technical Specifications requires reactor internals vibration analysis to be conducted on the Palisades core. This monitoring program has been required as a result of the core support barrel (CSB) vibration occurring initially in 1972. Two measurement phases are implemented for the analysis. Phase one measurements provide data which allows analysis of the power range excore detector signals for gross amplitude of CSB movement. The analytical method applied is the determination of amplitude probability distribution, standard deviation, and root mean square of measured data. Phase two measurements allow the analysis of various combinations of excore detector pairs with respect to amplitude, frequency, and phase and coherence relationships. The analytical method applied is the determination of auto-power spectral density, choherence functions, and phase relationships.

II. SIGNAL CHOICES

Operating power range excore detectors, NI-05 through NI-10, which are uncompensated ion chambers, comprise the primary source of information used for analyses of the reactor internals. Figures 1 and 2 illustrate the relative locations of these detectors.

III. SIGNAL CONDITIONING

Excore signals are processed through a signal conditioning unit, which when AC-coupled serves as a high pass filter, and when DC-coupled is used as a "bucking circuit", to remove the DC component of the excore signal. Normally the unit is used in the AC-coupled mode so that extremely low-frequency power fluctuations, such as those caused by control rod movement during the data collection period will be filtered out. All signals are then band-pass filtered, typically from 0.024 Hz to 20 Hz, depending upon the analysis requirements. Figure 3 is a schematic representation of the signal conditioning equipment.

IV. PHASE ONE MEASUREMENTS

Representative amplitude probability distributions (APD's) of the excore detectors for this period are plotted in Figures 4, 5, 6 and 7. Corresponding integrals of the APD's (IAPD) are plotted in Figures 8, 9, 10 and 11. Data points from the IAPD's are plotted on probability paper in Figures 12, 13, 14 and 15. The resulting linear relationship is indicative of Gaussian (random) behavior. A non-linear relationship, suggesting periodicity, could mean a restriction in the motion of the core support barrel, such as contact with the CSB snubbers. This is not the case for the Palisades core, as evidenced by the data.

To facilitate the detection of changes in the various regions of the power spectrum, the percent RMS is calculated for the following frequency bands: 0-0.5Hz, 0.5-5 Hz, 0-5 Hz, 5-25 Hz, and 5-50 Hz. The RMS value for a specific frequency band is computed by integrating the measured power spectral density function over the band of interest.

V. PHASE TWO MEASUREMENTS

Power spectral densities (PSD's), normalized with respect to DC voltage, are plotted in Figures 16, 17, 18 and 19 for the frequency band 0.025 Hz to 25 Hz. Resonances of interest and good resolution dictate the choice of this frequency band. PSD's from .025 Hz to 50 Hz are routinely calculated, however, to monitor changes or unexpected phenomena which may occur at higher frequencies.

Coherence and phase relationships for all detector combinations are determined. Figures 20 through 31 are coherence and phase plots representative of the period addressed by this report.

VI. SUMMARY OF FINDINGS AND OBSERVATIONS

A. Amplitude Probability Distribution (APD and IAPD)

All power range excore detectors exhibit Gaussian behavior, as illustrated by the IAPD vs amplitude plots in Figures 7 through 10.

B. Root Mean Square Values (RMS)

The RMS value in the 0.025 to 5 Hz region has been increasing since the beginning of Core 3. This is in contrast to the first six months of Core 2, during which a decrease in the RMS value for this region was observed. The cause of the decrease was attributed to a decrease in magnitude of the 2.3 Hz peak. Continued observation of this peak revealed a period during which the magnitude was stable, followed by an increase in magnitude with core life that persisted to the end of the cycle. Increasing RMS values in the 0.025 to 5 Hz region for Core 3 seem to be due primarily to a continuing increase in the 2.3 Hz magnitude, (not characteristic of Core 2 until later in life) and in the 0.25 Hz peak, which is linear with decreasing critical boron concentration, as expected.[1] The early appearance of the increasing trend of the 2.3 Hz peak has resulted in higher RMS values for Core 3 than for Core 2 at corresponding times in core life. RMS values in the high frequency range, (5 Hz - 25 Hz) have remained essentially stable for the period. A summary of RMS values for the reporting period is presented in Table 1.

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[1] Reference 2, Page 9

TABLE 1 - PERCENT RMS

Frequency Range	Date	Days Critical	NI-05	NI-06	NI-07	NI-08
0-0.5 Hz	May 78	39	.053	.046	.045	.056
	July 78	92	.065	.055	.051	.067
	Oct 78	147	.090	.081	.073	.093
.5-5 Hz	May 78	39	.033	.034	.033	.034
	July 78	92	.039	.038	.034	.040
	Oct 78	147	.052	.052	.047	.053
0-5 Hz	May 78	39	.062	.057	.056	.066
	July 78	92	.076	.067	.062	.078
	Oct 78	147	.104	.096	.087	.107
5-25 Hz	May 78	39	.010	.010	.011	.012
	July 78	92	.009	.010	.011	.011
	Oct 78	147	.008	.013	.012	.014

C. Power Spectral Density (PSD)

1. Low Frequency (< 5Hz)

All four excore detectors display resonances in the 0.25 Hz and 2.25 Hz range, as they did for Core 2. A potentially important difference between Core 3 and Core 2 in the low frequency band is the increasing magnitude of the 2.3 Hz peak[1] from the beginning of the cycle, since this could lead to RMS values which are closer to limits than they were for Core 2 at the end of the cycle. The 0.25 Hz peak is prominent on the PSD plots, and is linearly related to critical boron concentration, as previously stated.

2. High Frequency (> 5Hz)

All four excore detectors display a resonance in the 11.6 Hz region. This peak appears to be increasing slightly with time, as shown in Table 2, and exhibits behavior which is analogous to that observed during Core 2.[1]

TABLE 2

AMPLITUDE OF PSD IN 11.6 Hz REGION (dB)

Date	Days Critical	NI-05	NI-06	NI-07	NI-08
May 78	39	-93.0	-91.0	-91.0	-90.0
July 78	92	-93.0	-92.0	-91.0	-90.0
Oct 78	147	-91.0	-89.5	-89.0	-88.0

(1) Reference 1

TABLE 3

AMPLITUDE OF CSB CANTILEVERED BEAM RESONANCES (dB)

Date	Days Critical	NI-05	NI-06	NI-07	NI-08
		- 12.8 Hz -			
May 78	39	-92.0	-91.0	-89.5	-90.0
July 78	92	-92.0	-92.0	-89.5	-90.5
Oct 78	147	-94.5	-90.0	-90.0	-89.0
		- 18.5 Hz -			
May 78	39	-102.0	-93.5	-99.0	-94.5
July 78	92	-101.0	-95.0	-98.1	-95.5
Oct 78	147	-98.0	-92.0	-95.0	-91.5

Resonances at frequencies that have been identified as the cantilevered beam modes of the CSB (approximately 12.8 Hz and 18.5 Hz) [1] have increased slightly or have remained essentially stable with time, as shown in Table 3. Previous reports [1] have pointed out that the 12.8 Hz resonance was more significant for detectors NI-07 and NI-08, while the 18.5 Hz resonance was more significant for detectors NI-05 and NI-06. Core 3 data indicates that NI-07 and NI-08 are still dominant for 12.8 Hz, but NI-06 and NI-08 seem to be more sensitive with respect to the 18.5 Hz region. The 14.8 Hz resonance, which is considered to be due to an imbalance in one or more of the primary coolant pumps is very pronounced in all excore detector PSD's and remains relatively unchanged, as was the case for cores one and two.

The average amplitude of the 15.3 Hz shell mode seems to be averaging approximately -87 dB as compared to end of Core 2 values of approximately -86 dB [1].

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(1) Reference 2

D. Coherence and Phase

1. Low Frequency (< 5 Hz)

There are three regions of coherence in the 0 to 5 Hz frequency band, with the entire region being in-phase for all detector pairs throughout this reporting period.

All detector pairs show a high in-phase coherence at 0.5 Hz that is decreasing with time, but remaining in-phase. This same effect was observed in Core 2 and the coherence eventually decreased to a negligible value at the end of the cycle.

Detector pairs NI-05/NI-07, NI-05/NI-06, NI-07/NI-08 and NI-06/NI-08 display high, in-phase coherence in regions around 2.1 Hz and 3.3 Hz. The coherence of 2.1 Hz seems to shift to a lower frequency (1.6 ~1.8 Hz) and to diminish in magnitude from the start of the cycle to late in the reporting period. The 2.1 Hz region exhibited an out-of-phase relationship for diagonally across the core detectors for the first six months of Core 2,[(1)] in contrast to Core 3 experience. As shown in Table 4, the diagonally-across-the-core detector pairs (5/6, 7/8) for Core 3 are in-phase until October, when they begin exhibiting out-of-phase behavior, as in Core 2.

TABLE 4 - COHERENCE/PHASE FOR 2.3 Hz REGION

Detector Pair	June 78	Oct 78
NI-05/06	.21/0°	.08/180°
NI-05/07	.28/0°	.03/0°
NI-05/08	.55/0°	.45/0°
NI-06/07	.55/0°	.50/0°
NI-06/08	.40/0°	.09/0°
NI-07/08	.22/0°	.07/180°

(1) Reference 2 Data

2. High Frequency (>5 Hz)

All detector pairs show a relatively sharp-peaked in-phase coherence at approximately 11.3 Hz. The magnitude of the coherence is increasing with time and was present since the beginning of the cycle. This peak was present in Core 2 data also and exhibited the same behavior, but did not become noticeable until approximately six months into the cycle.[1] Because of the in-phase relationship with all detector pairs, this peak is not considered to represent core barrel motion in any horizontal plane.

There is a region of coherence in the 12-14.5 Hz range. This range was noticed to be divided into two regions during Core 2 which centered around 12.8 Hz and 14.5 Hz. Core 3 exhibits similar behavior in that the two regions exist but they do not appear to be as defined as they were for Core 2. The coherence at 14.5 Hz is the more prominent region, as before, and is decreasing in magnitude with time.

The shell mode frequency region,[1,2] 15-16.5 Hz, exhibits an in-phase relationahip for diagonally-across-the-core detectors, while all other combinations are out-of-phase. This same behavior was observed during Core 2. Table 5 shows the coherence and phase relationships for the higher frequency ranges.

VII. MAGNITUDE OF CSB MOTION

The indicated motion in the frequency band around 2.3 Hz appears to be in the direction of the outlet nozzles. Excore detector pairs NI-05/07 and NI-06/08 do not as yet display out-of-phase behavior and therefore the indication of

(1) Reference 1
(2) Reference 3

motion in this direction is not as substantial as during Core 2. Only the diagonally-across-the-core detectors now exhibit an out-of-phase trend. It is expected that the detector pairs across the outlet nozzles will eventually display out-of-phase characteristics during this cycle if there is indeed motion in the proposed frequency band and direction, as there was in Core 2. For purposes of comparison, the motion as expressed in mils (1/1000 inch) is calculated for the 2.3 Hz region for Core 3 using the same method employed in Core 2. (Reference 3).

$$\text{No. Mils RMS} = \frac{100}{.0376}\sqrt{NPSD_A^{\frac{1}{2}}\ NPSD_B^{\frac{1}{2}}\ \Delta f\ \gamma}$$

where: $NPSD_A$ is the amplitude of the NPSD in Δf

γ is the square root of the coherence within Δf

Δf is the frequency band of interest

TABLE 5

HIGH FREQUENCY COHERENCE/PHASE RELATIONSHIPS

15-16.5 Hz

Detector Pair	June 78 Coh/Phase	Oct 78 Coh/Phase
NI-05/06	.02/0°	.035/0°
NI-05/07	.25/180°	.33/180°
NI-05/08	.40/180°	.28/180°
NI-06/07	.24/180°	.22/180°
NI-06/08	.36/180°	.29/180°
NI-07/08	.16/0°	.10/0°

TABLE 5 (Continued)

HIGH FREQUENCY COHERENCE/PHASE RELATIONSHIPS

16.5-20 Hz

Detector Pair	June 78 Coh/Phase	Oct 78 Coh/Phase
NI-05/06	.19/180°	.21/180°
NI-05/07	.10/180°	.26/180°
NI-05/08	.06/0°	.02/0°
NI-06/07	.05/70°	.04/60°
NI-06/08	.08/180°	.14/180°
NI-07/08	.02/180°	.06/180°

TABLE 6

MOTION AT 2.3 Hz

	Core 3[1]	Core 2[2]
In Direction of NI-05/NI-06	.413 Mils	1.33
In Direction of NI-07/NI-08	.378 Mils	1.19
Total Displacement	.560 Mils	1.78

Note that the degree of CSB motion at this point in Core 3 is smaller by over a factor of three than that near the end of Core 2.

(1) Core 3 data is at 147 days critical.

(2) Core 2 data is at 497 days critical.

VIII. CONCLUSION

Analysis of the data collected during the first six months of this cycle reveals that the behavior of Core 2 and Core 3 from a noise standpoint is essentially the same. The most significant difference is the fact that the RMS is increasing with time in the 0-5 Hz region, (presumably due to the increase in the 2.3 Hz peak) in contrast to the initial decrease in this frequency band observed in Core 2. The degree of motion in the low frequency region is smaller than that observed during Core 2, but is still present, therefore the CSB is considered to be well clamped. It is expected that an increase in motion will be observed at around 2.3 Hz, and also that the across-the-core detector pairs will begin to exhibit out-of-phase behavior, as Core 3 progresses. This behavior was noted in Core 1 and Core 2.

IX. REFERENCES

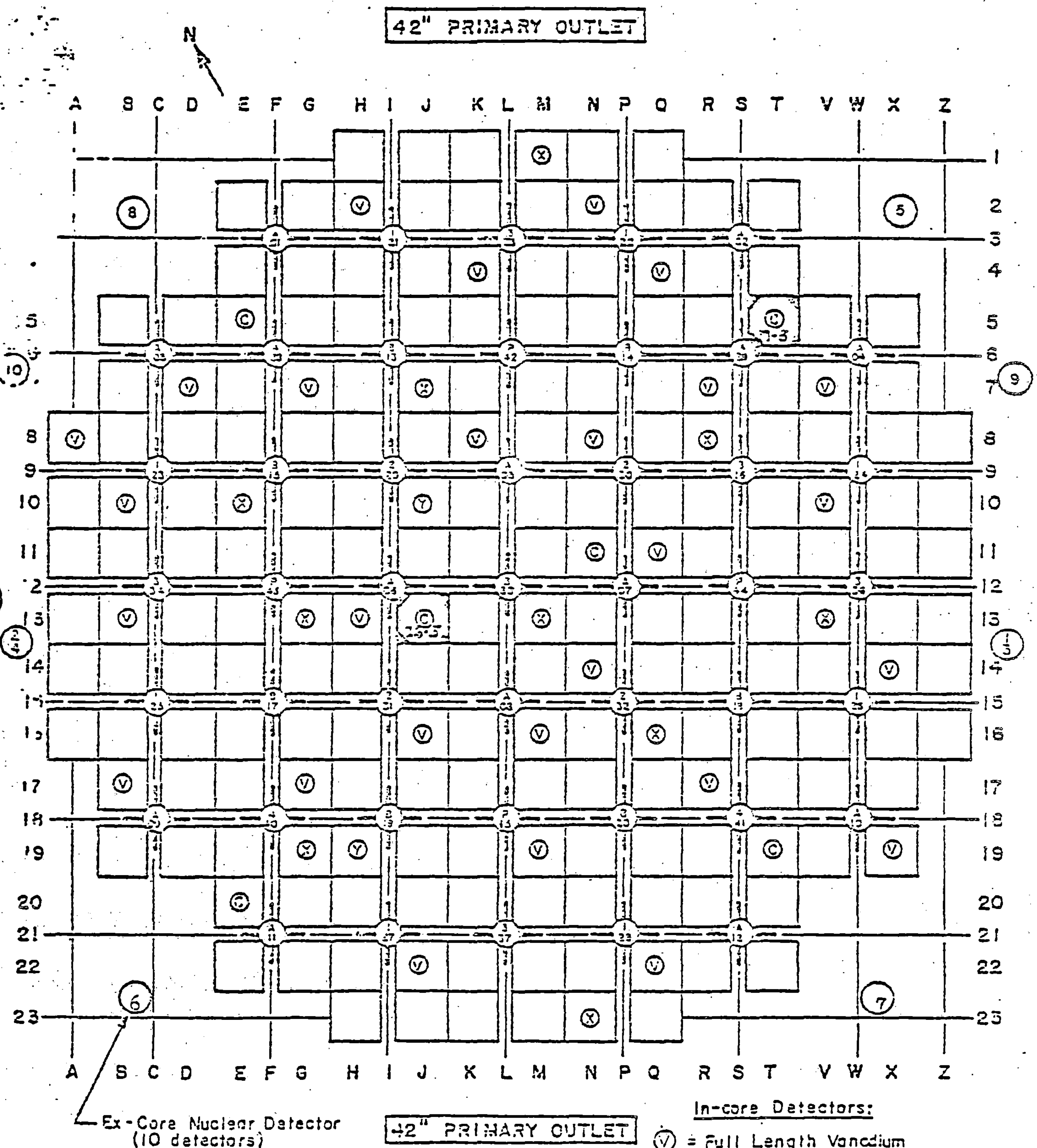
1. Reactor Internals Noise Monitoring Tests, May 1977 (Submitted on June 14, 1977).

2. Reactor Internals Noise Monitoring Tests, January 1978 (Submitted on April 27, 1978).

3. Thie, J.A., Neutron Noise Behavior Near End of Fuel Cycle, prepared for Consumers Power Company, December 19, 1975.

FIGURE 1

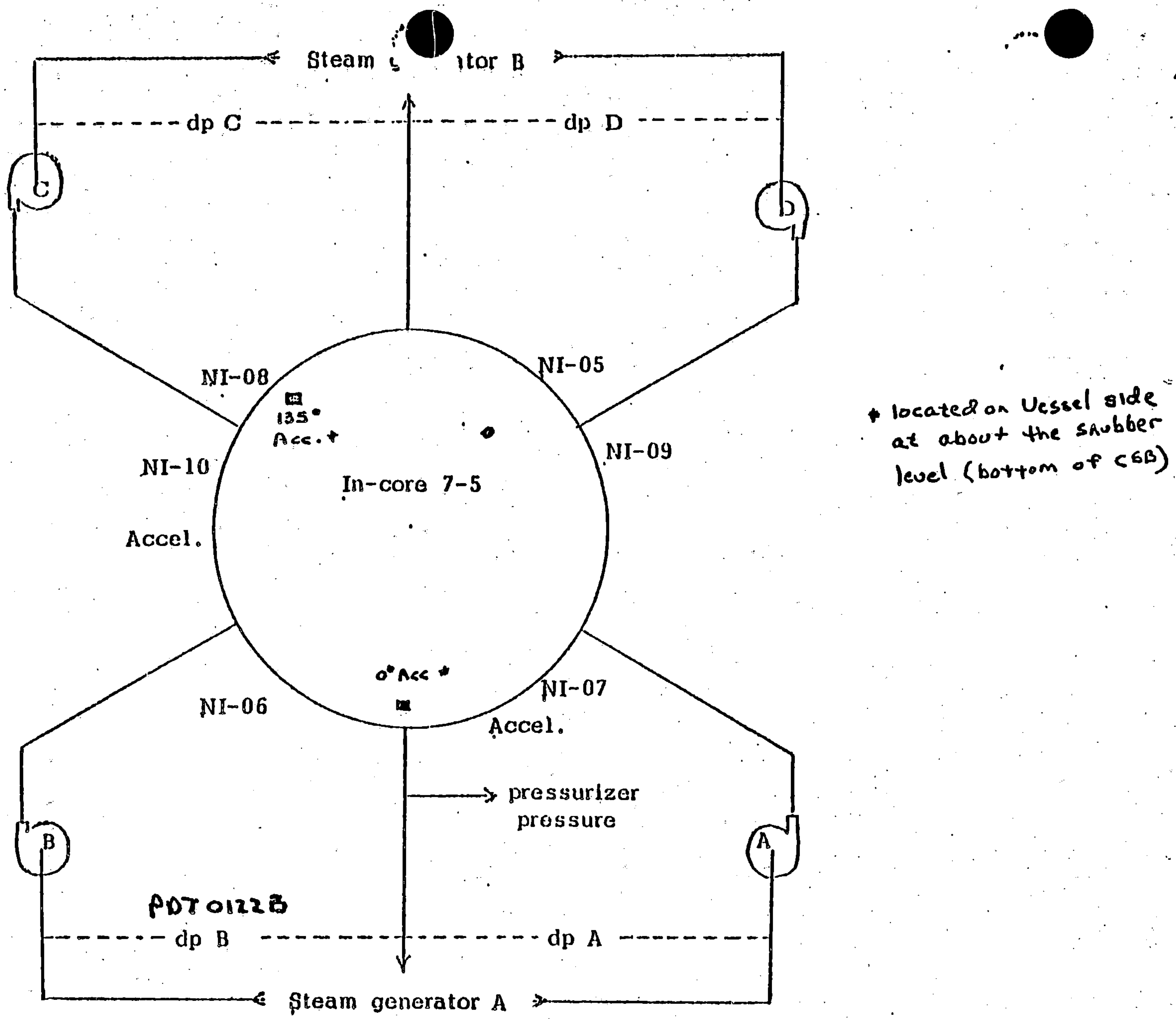
Palisades Plant – Reactor Core Plan



In-core Detectors:

- Ⓥ = Full Length Vanadium
- Ⓒ = Full Length Cobalt
- Ⓧ = Long background
- Ⓨ = Short background

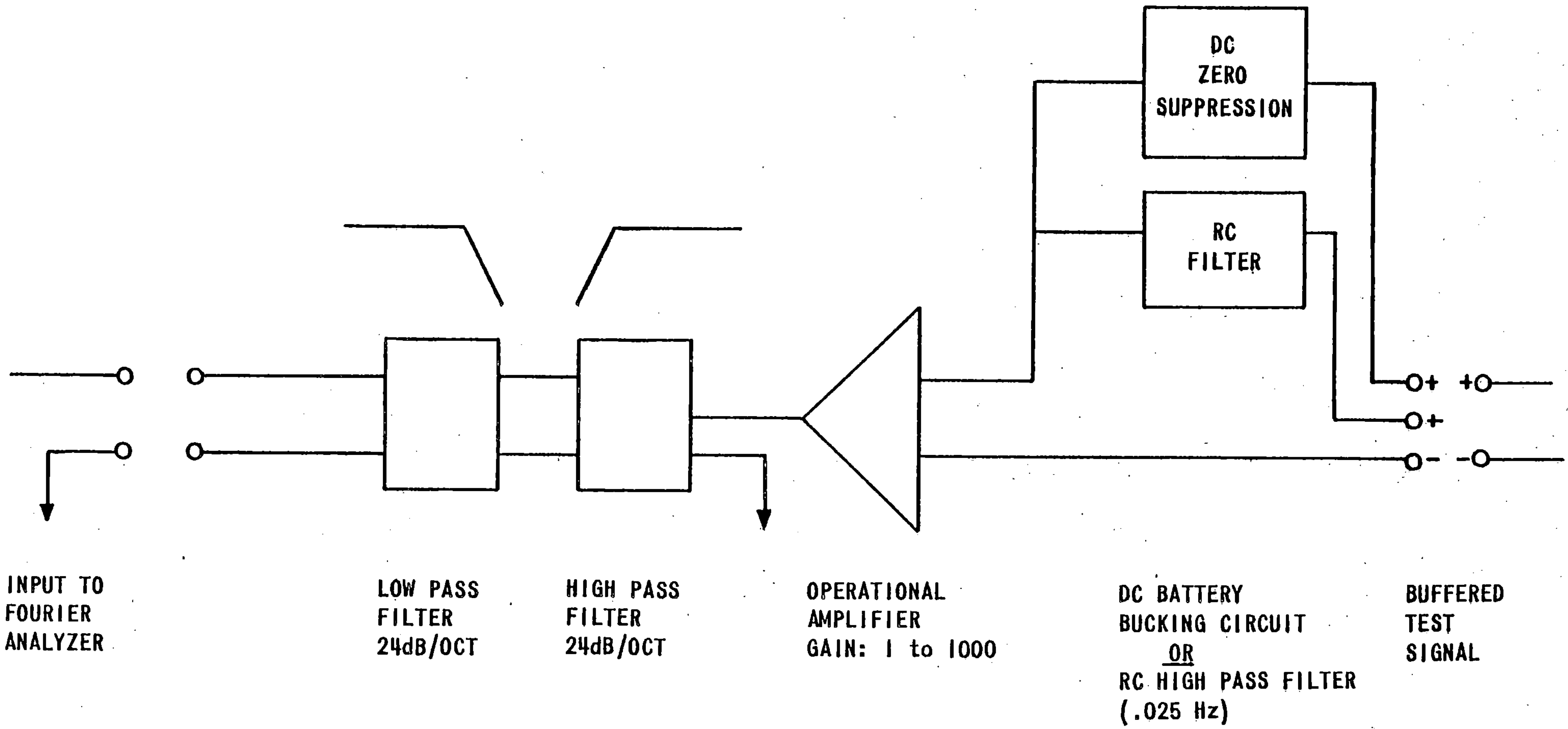
All in-core detectors contain 4 Rhodium detectors and 2 Thermocouples



Instrumentation locations for noise tests

FIGURE 2

FIGURE 3
SIGNAL CONDITIONING FOR NOISE ANALYSIS



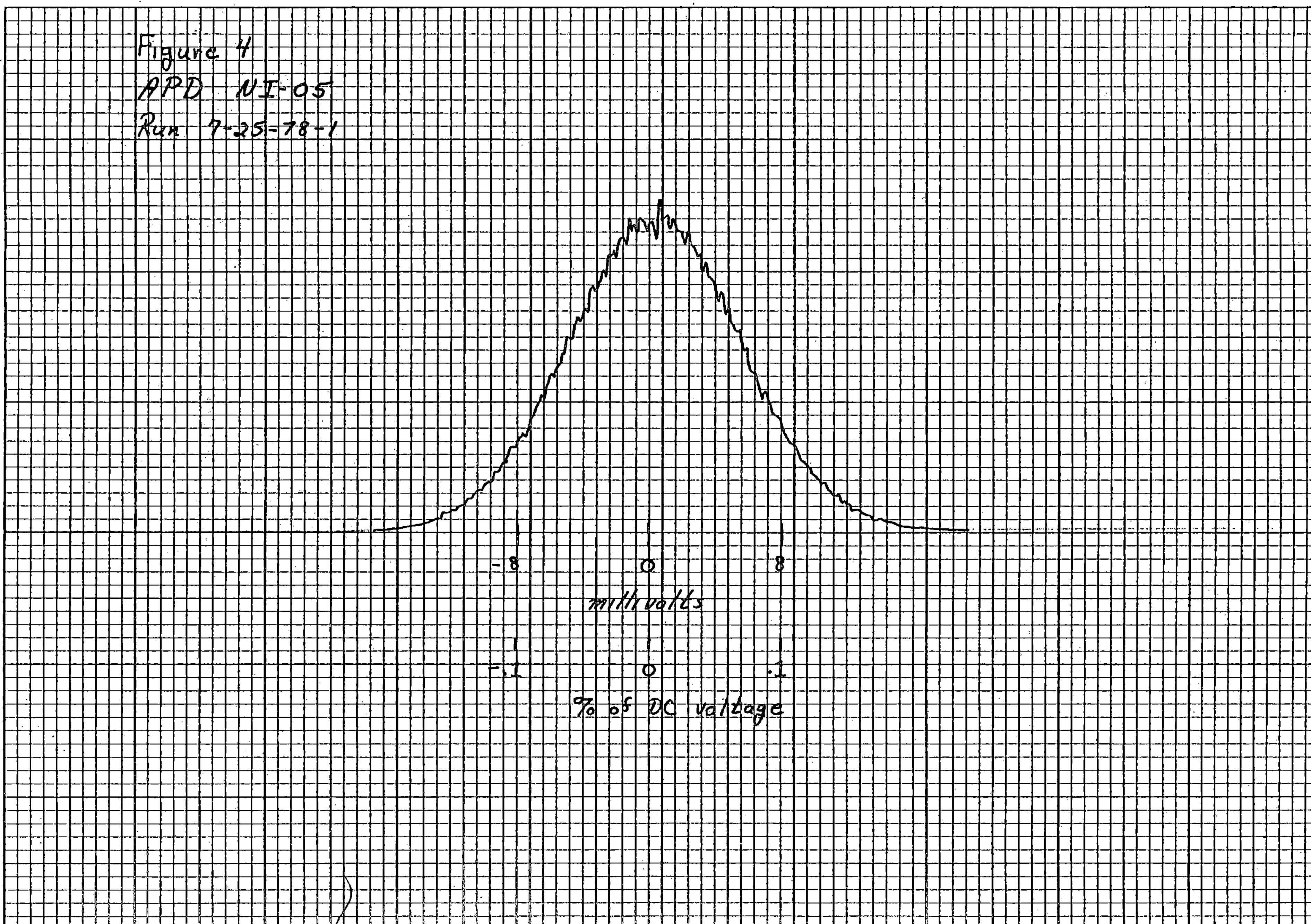


Figure 4
APD NI-05
Run 7-25-78-1
-8
0
8
millivolts
-.1
0
.1
% of DC voltage

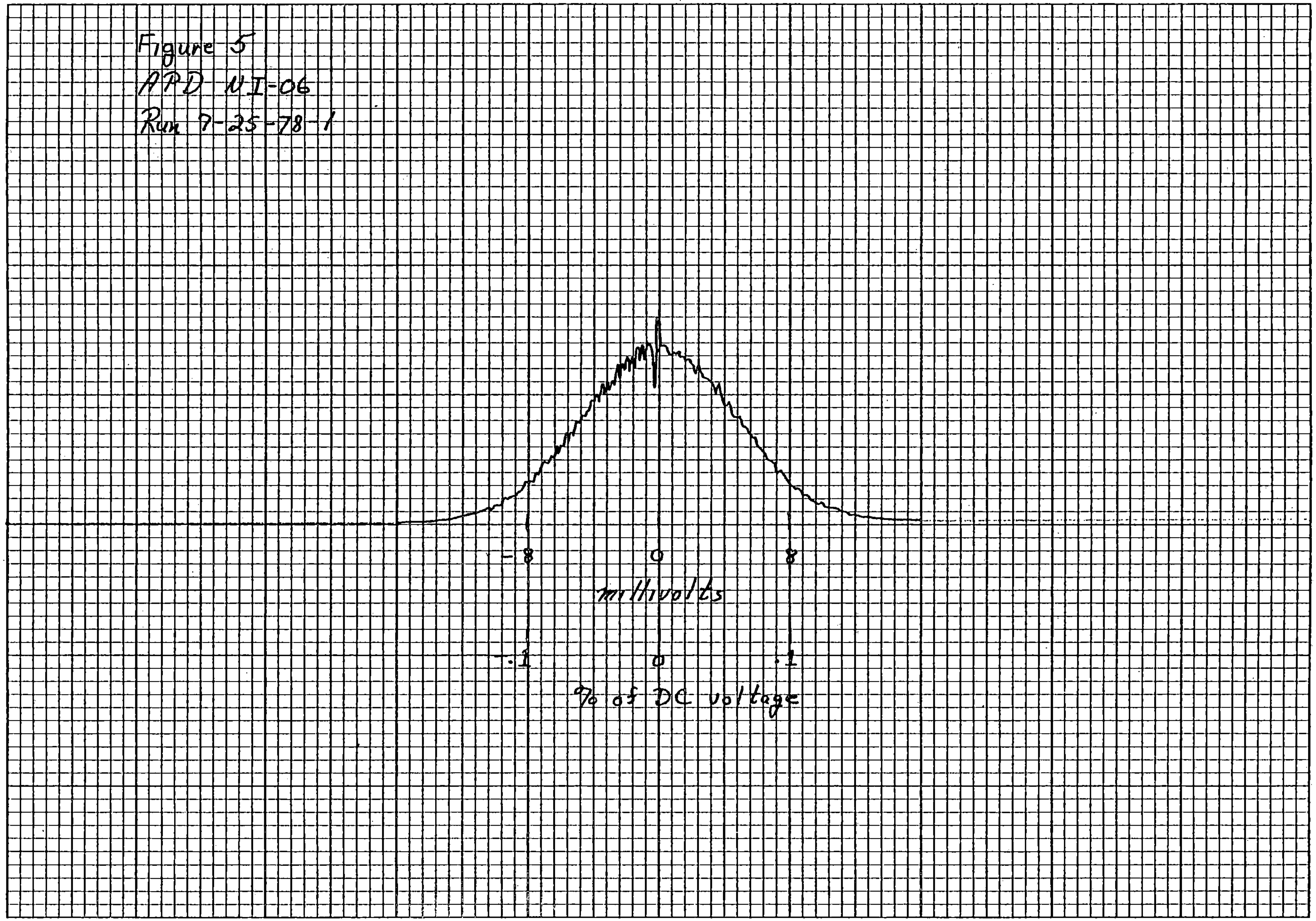


Figure 5
APD NI-06
Run 7-25-78-1

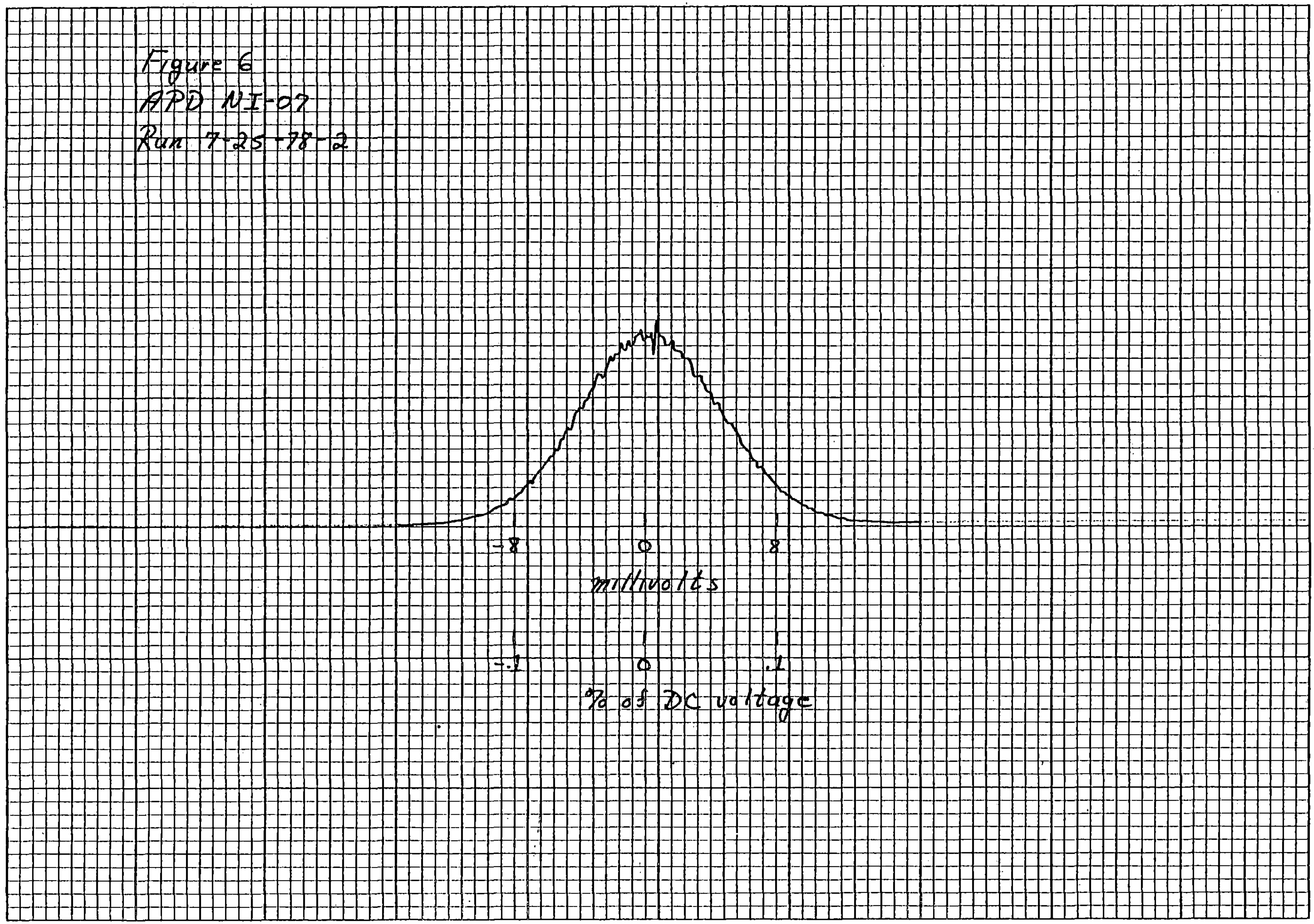


Figure 6
APD NI-07
Run 7-25-78-2
-8
0
8
millivolts
-.1
0
.1
% of DC voltage

46 0782

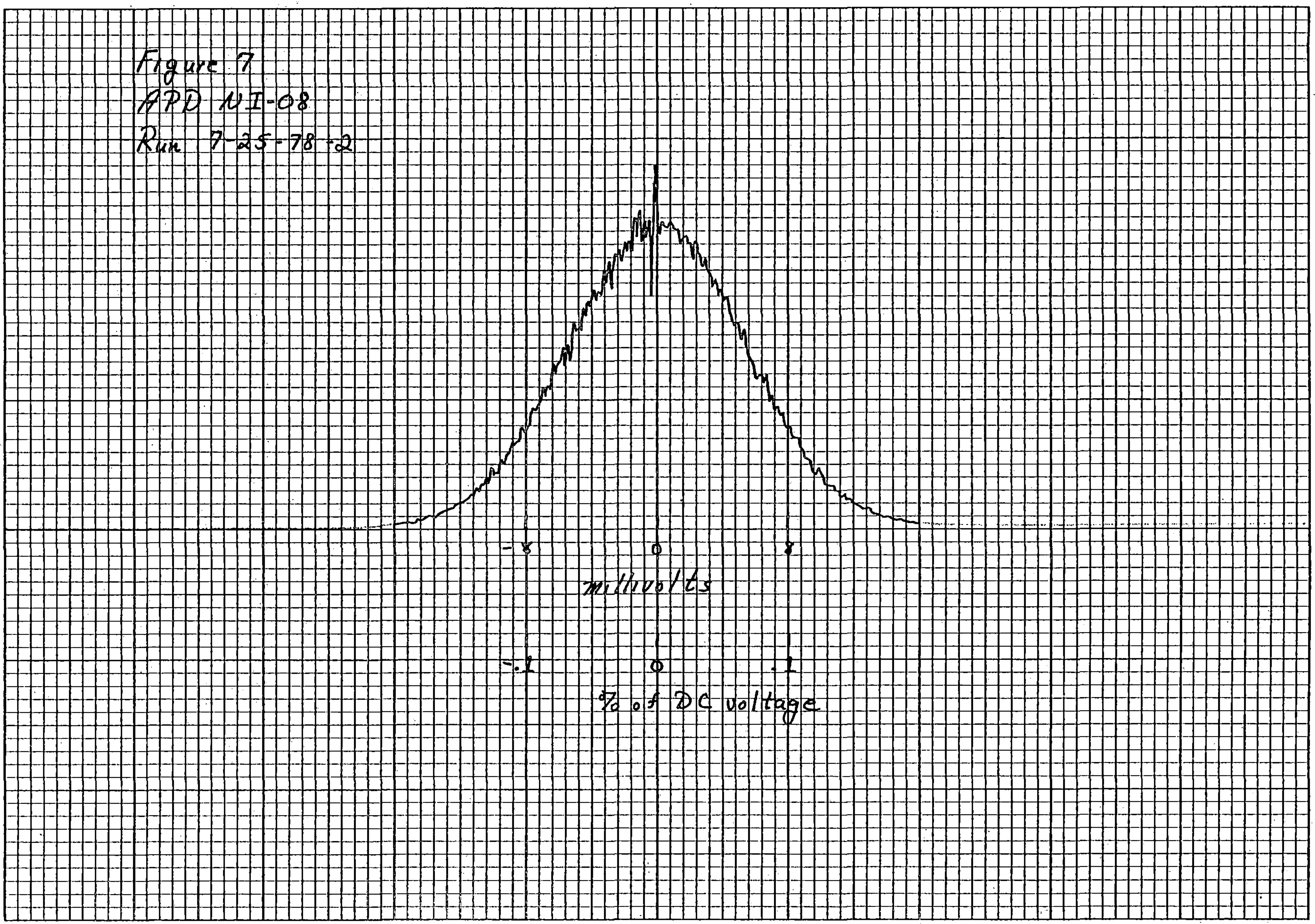


Figure 7
APD NI-08
Run 7-25-78-2

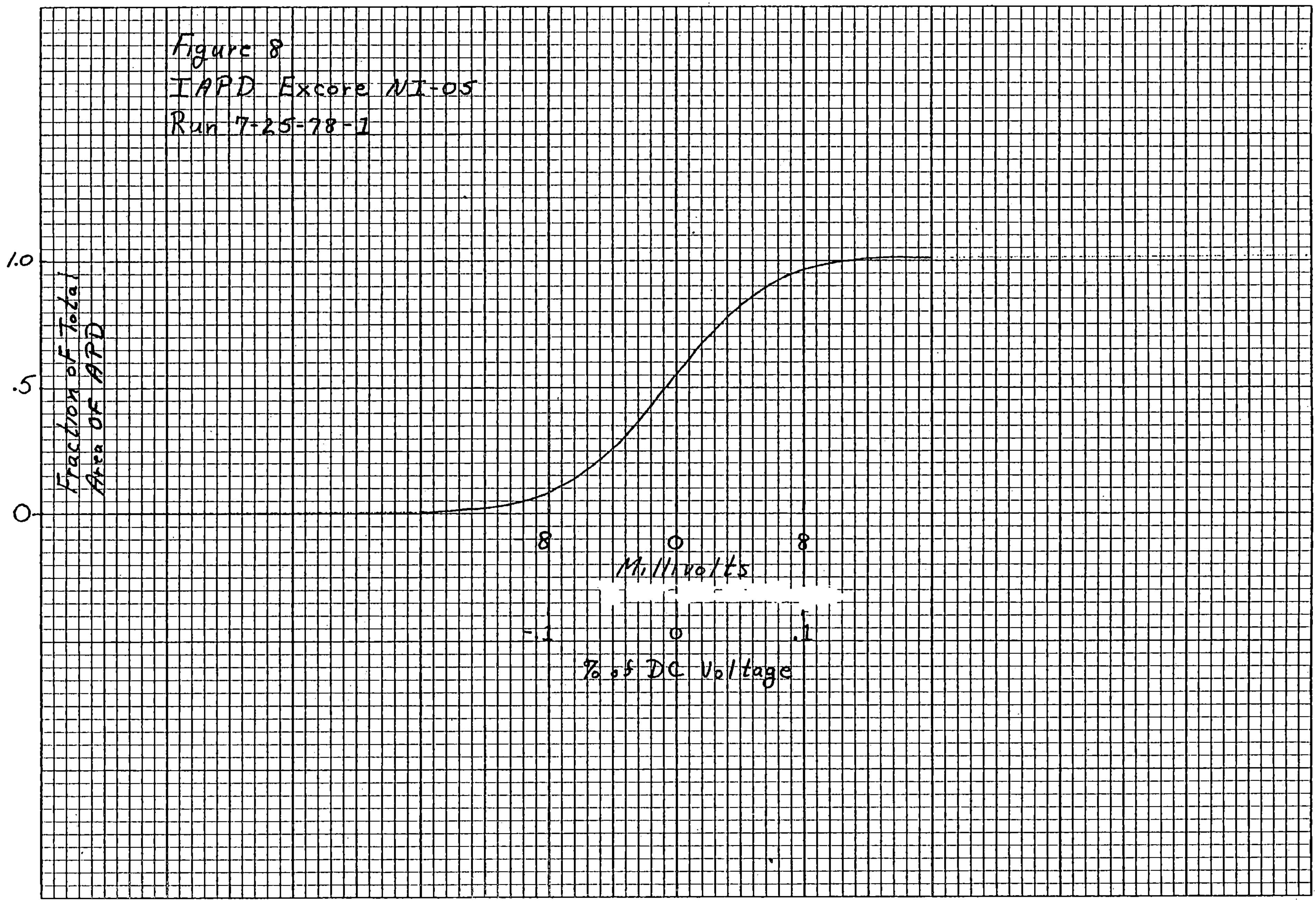


Figure 8
IAPD Excore NI-05
Run 7-25-78-1
1.0
.5
0
Fraction of Total
Area of APD
-8
0
8
Millivolts
-.1
0
.1
% of DC Voltage

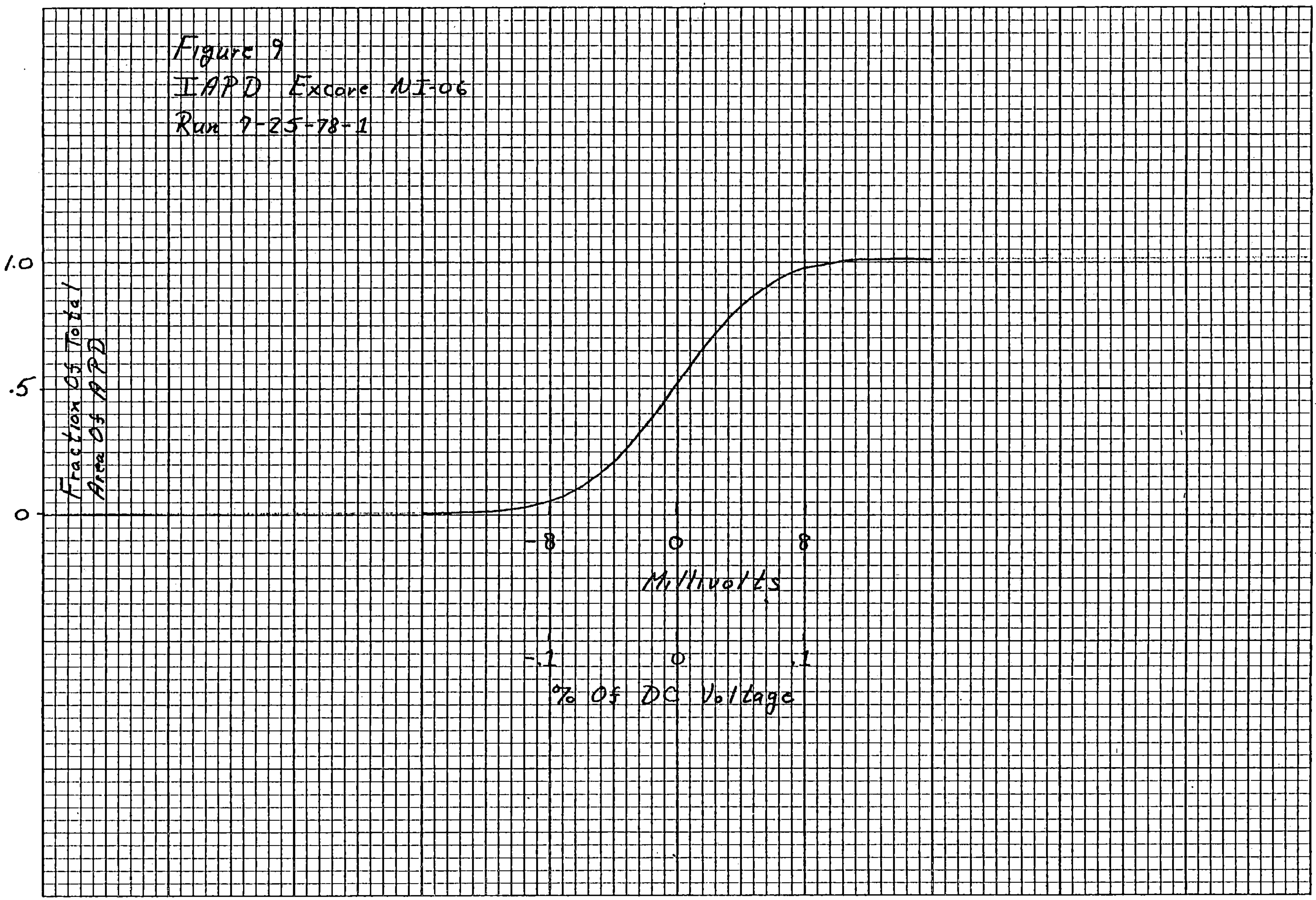


Figure 9
IAPD Excore NI-06
Run 9-25-78-1
1.0
.5
0
Fraction Of Total
Area Of APD
-8
0
8
Millivolts
-.1
0
.1
% Of DC Voltage

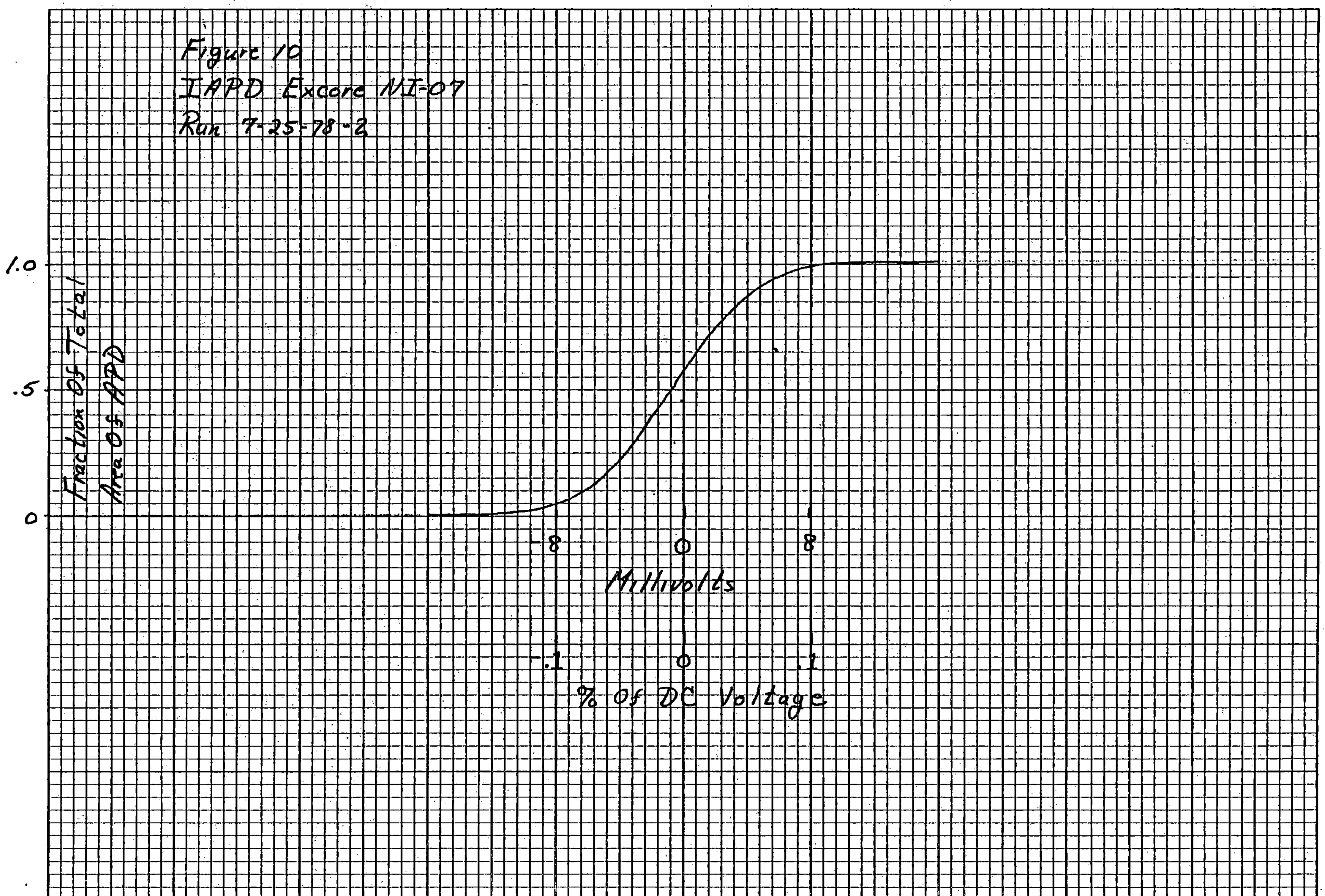


Figure 10
IAPD Excore NI-07
Run 7-25-78-2
1.0
.5
0
Fraction Of Total
Area Of APD
-8
0
8
Millivolts
-.1
0
.1
% Of DC Voltage

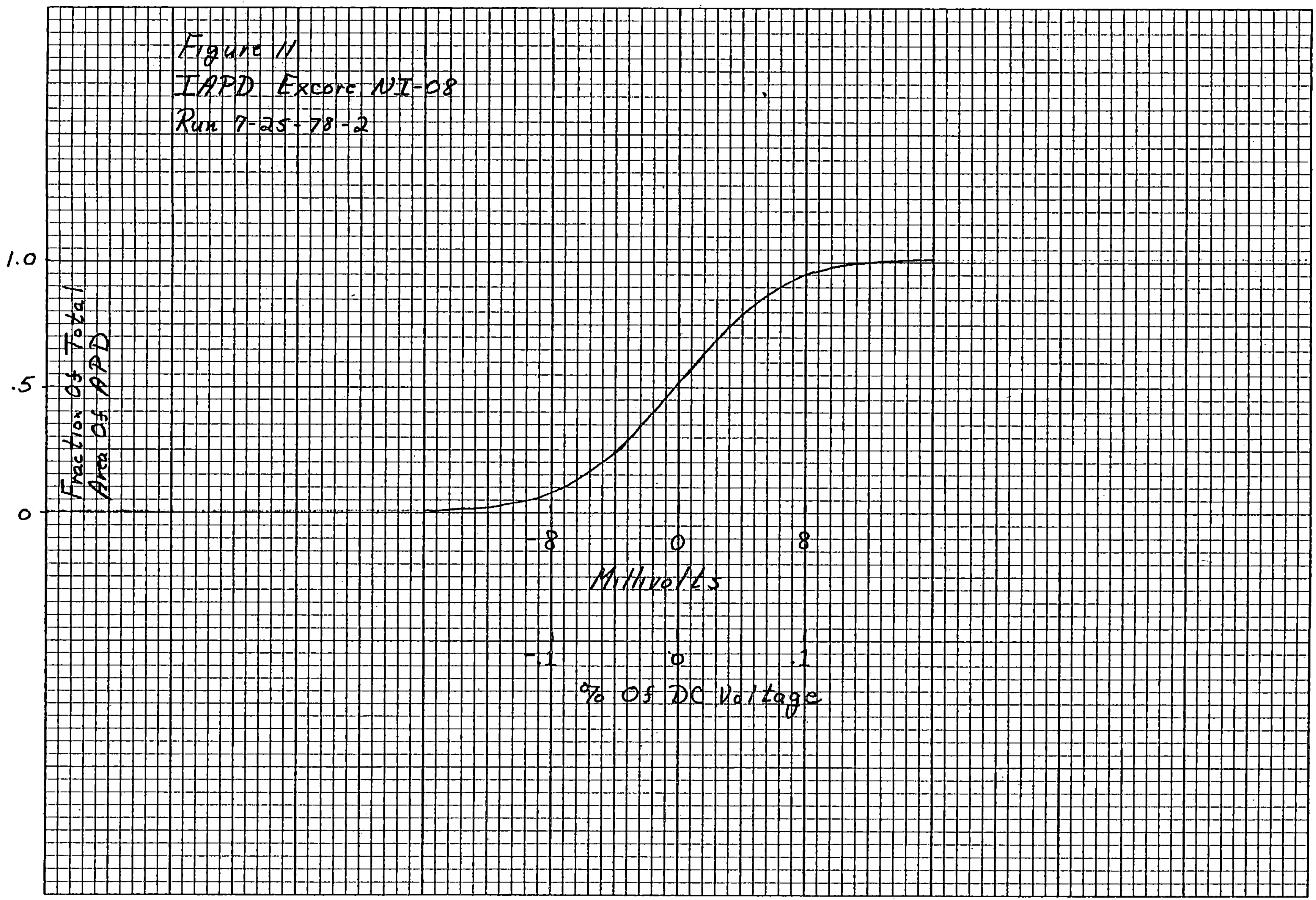


Figure 11
IAPD Excore NI-08
Run 7-25-78-2
1.0
.5
0
Fraction Of Total
Area Of APD
-8
0
8
Millivolts
-.1
0
.1
% Of DC Voltage

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PROBABILITY X 90 DIVISIONS

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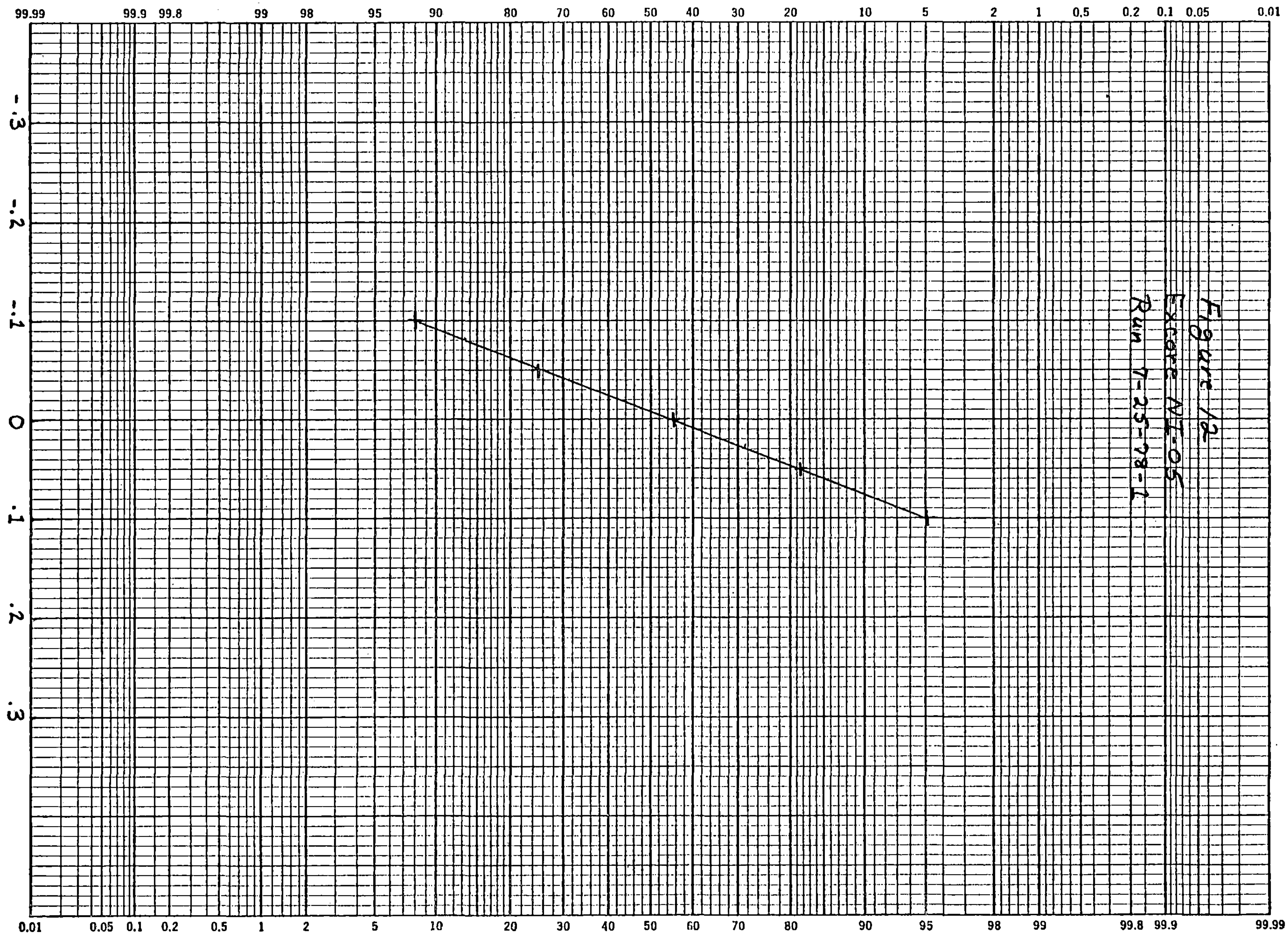
MADE IN U. S. A.



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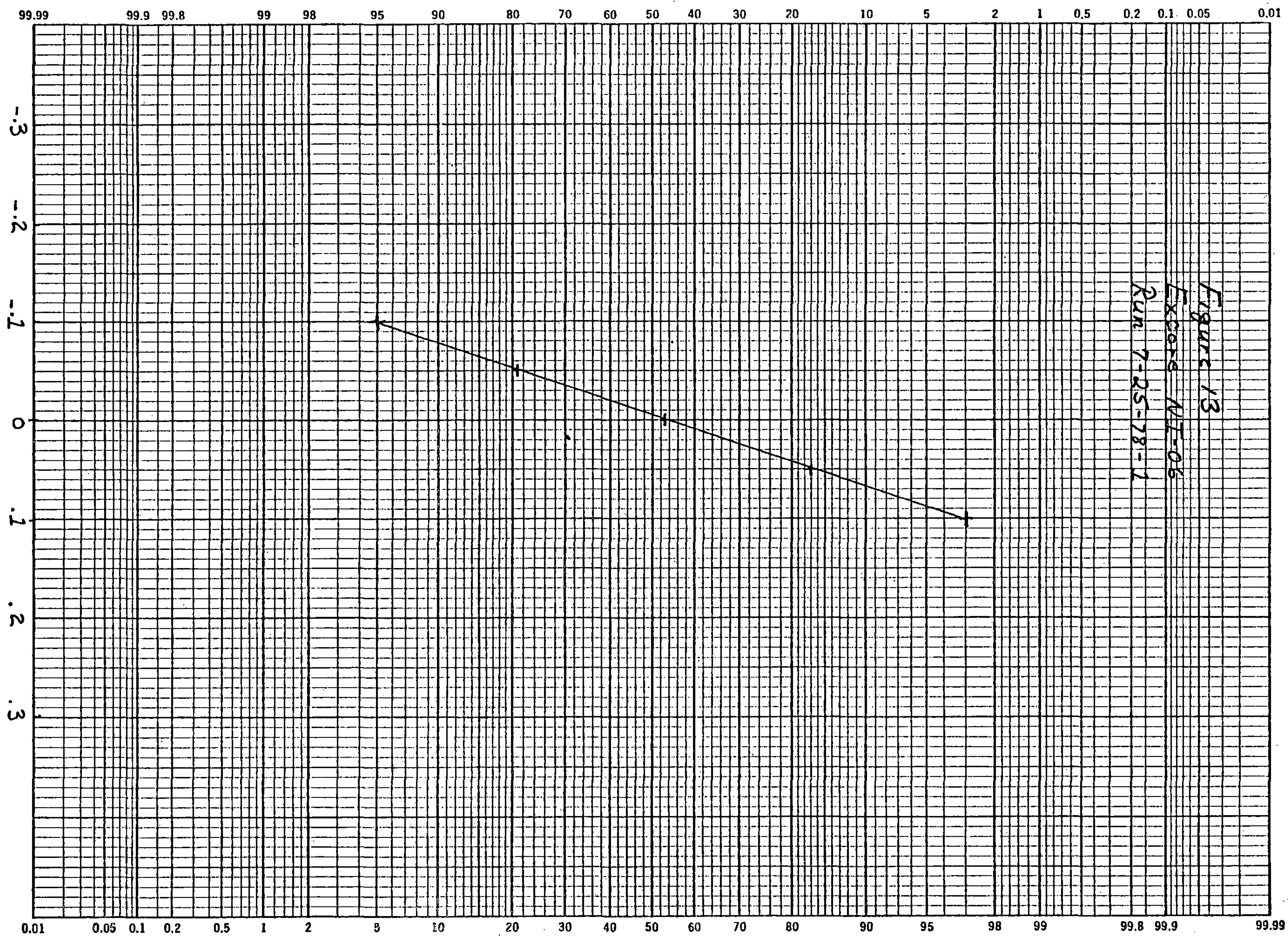

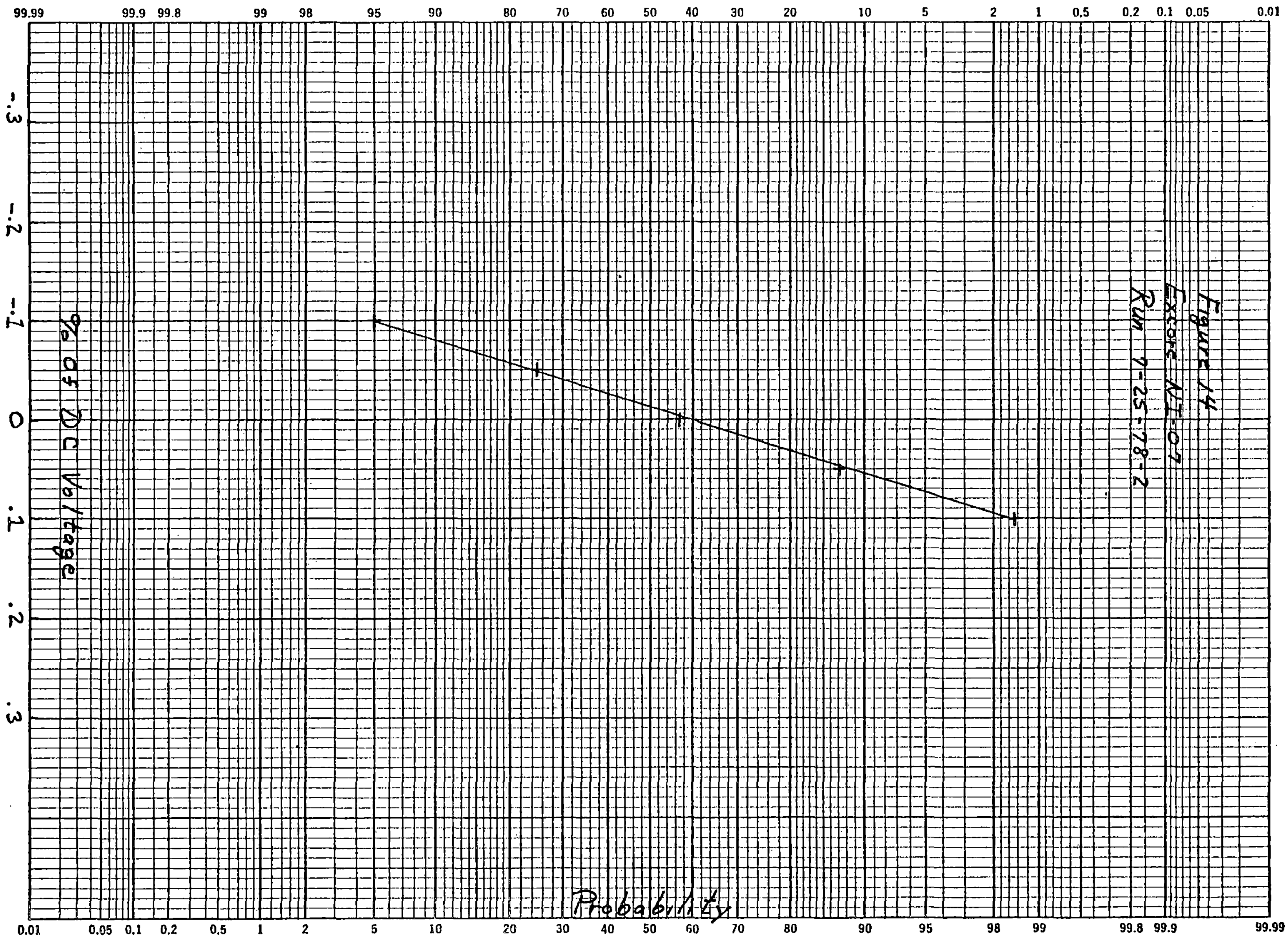
Figure 14
Run 7-25-78-2
% of DC Voltage
Probability

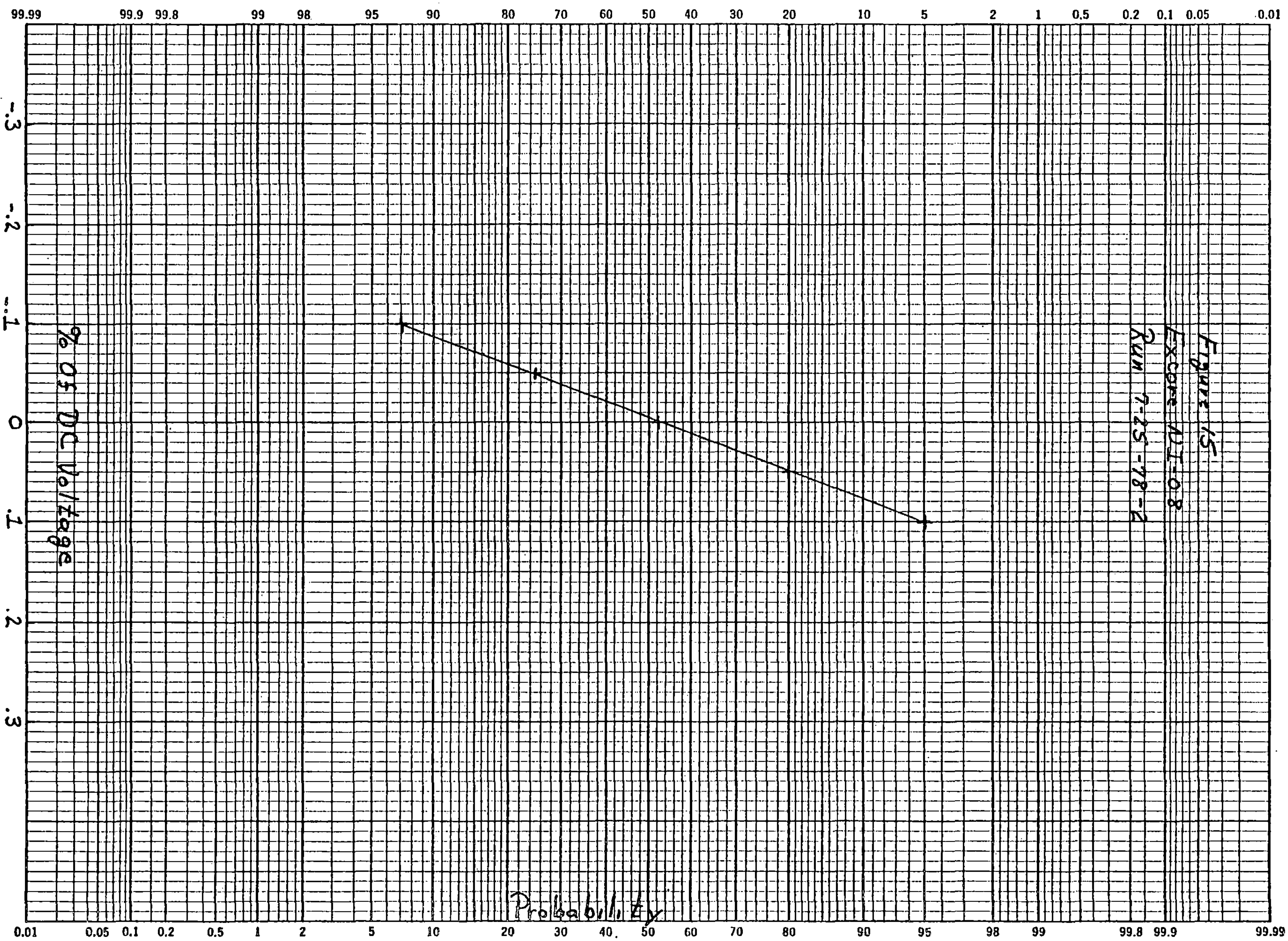
Figure 15
Excore NI-08
Run 7-25-78-2
% of DC Voltage
Probability
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
-.3
-.2
-.1
0
.1
.2
.3

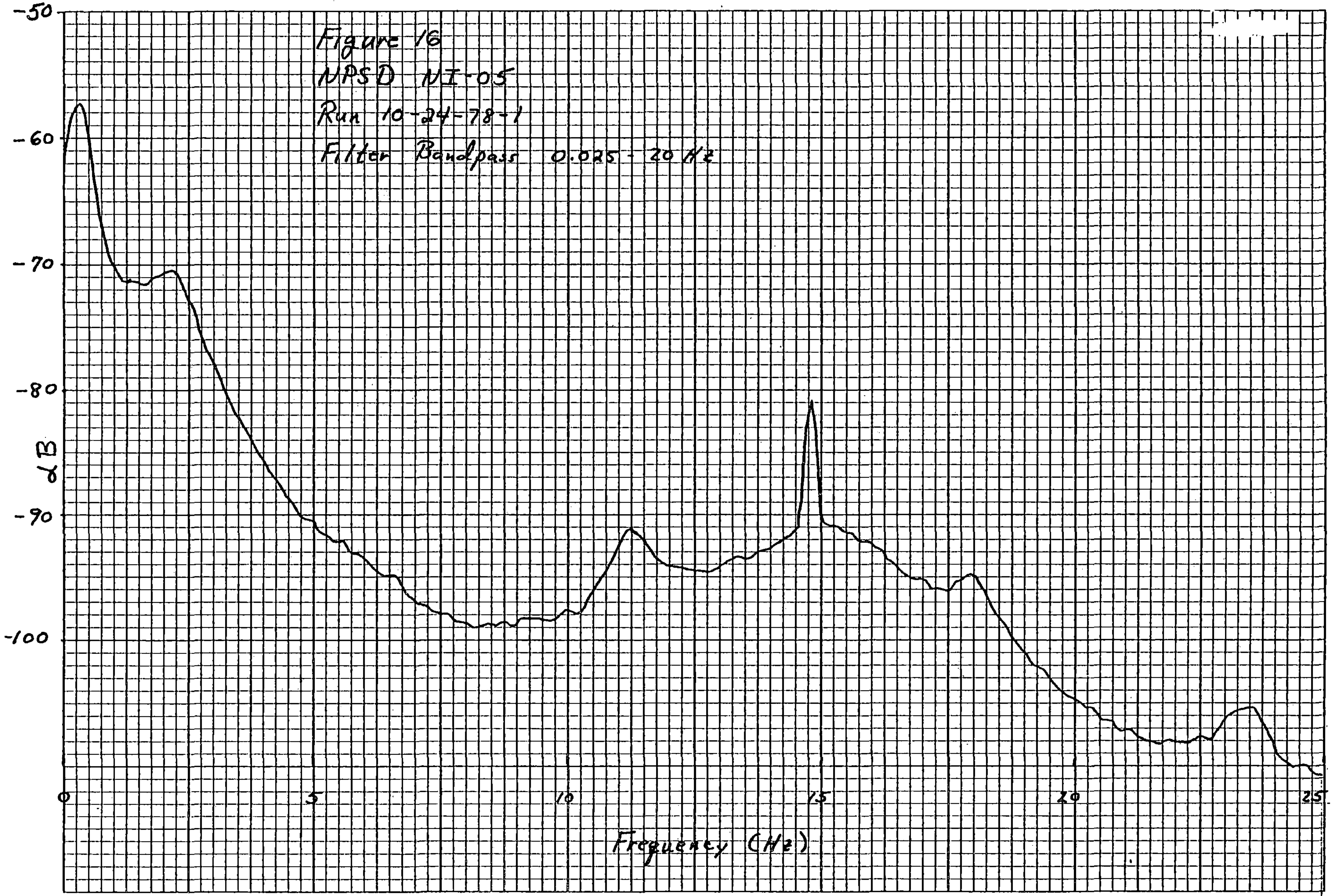
Figure 16
NPSD NI-05
Run 10-24-78-1
Filter Bandpass 0.025 - 20 Hz
-50
-60
-70
-80
-90
-100
dB
0
5
10
15
20
25
Frequency (Hz)

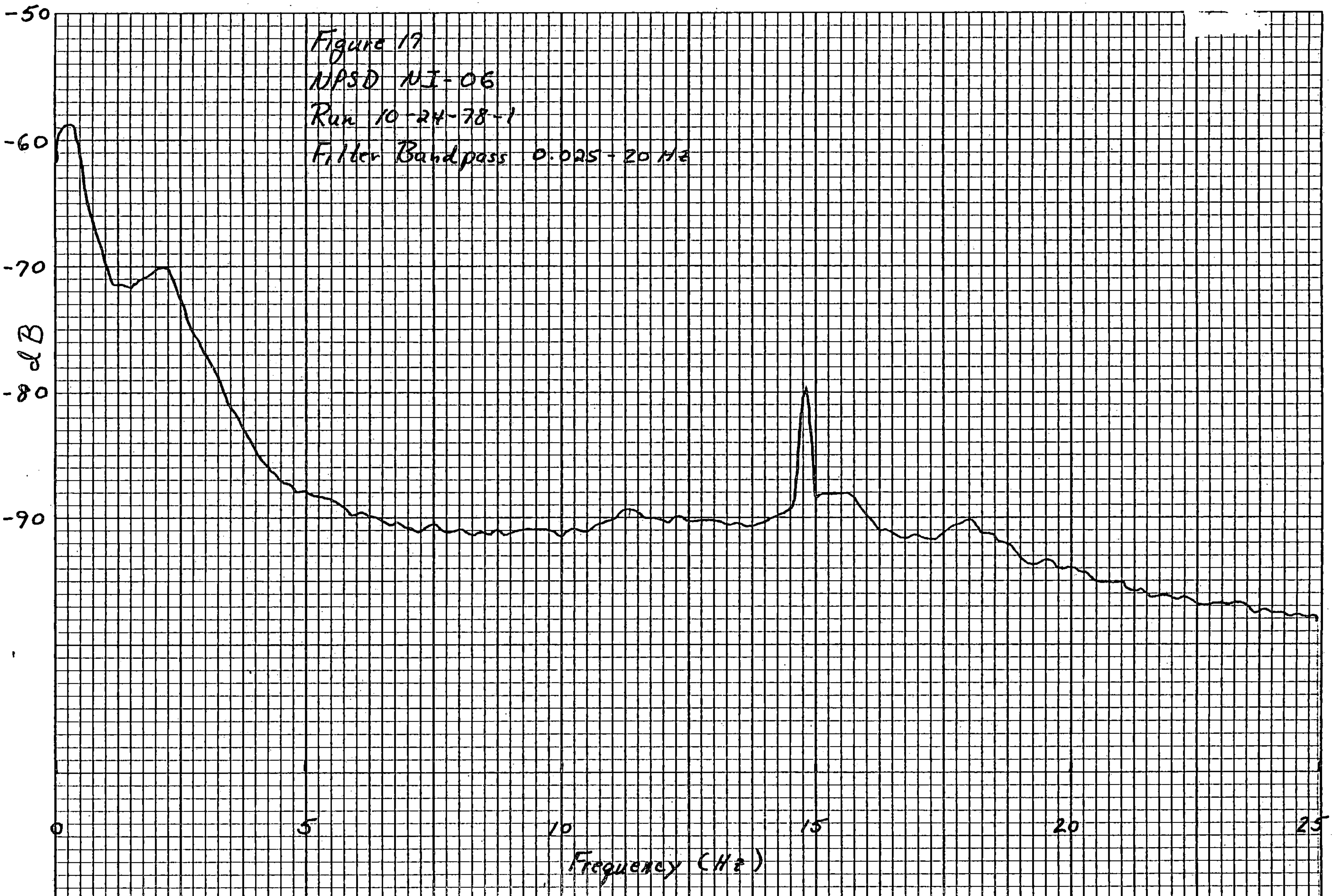
Figure 17
NPSD NI-06
Run 10-24-78-1
Filter Bandpass 0.025-20 Hz
-50
-60
-70
-80
-90
dB
0
5
10
15
20
25
Frequency (Hz)

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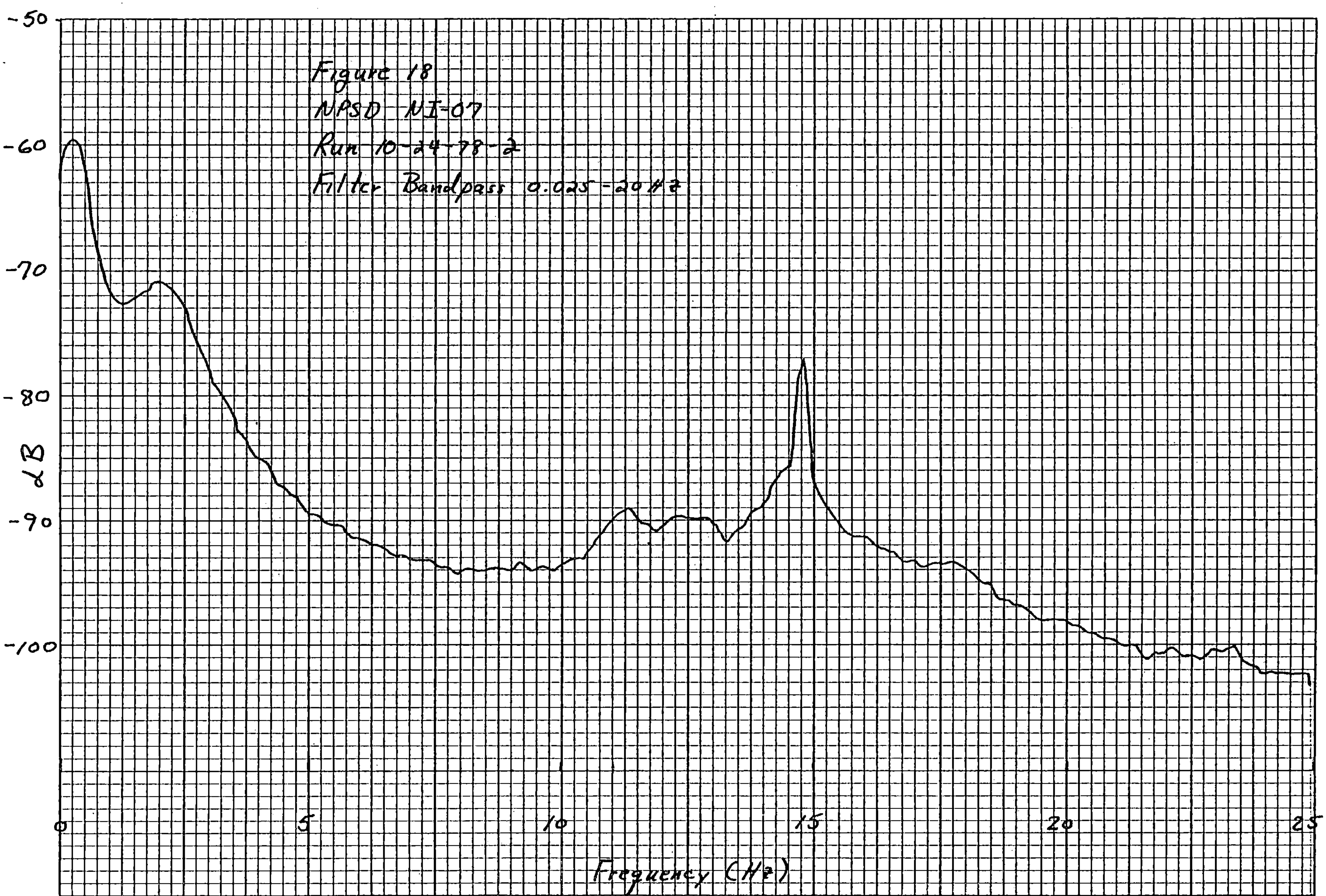

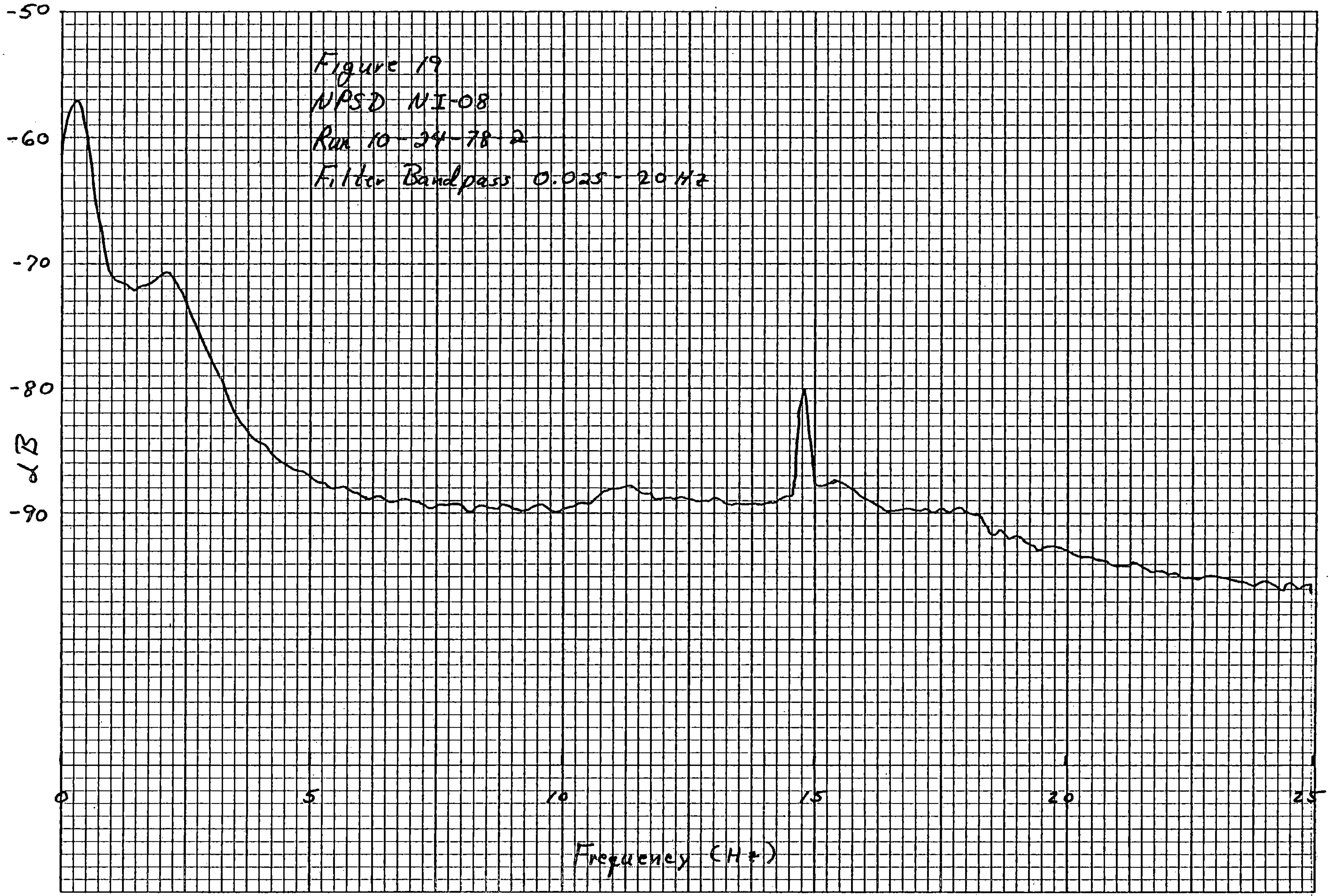
Figure 19
NPSD NI-08
Run 10-24-78-2
Filter Bandpass 0.025 - 20 Hz
-50
-60
-70
-80
-90
dB
0
5
10
15
20
25
Frequency (Hz)

46 0782

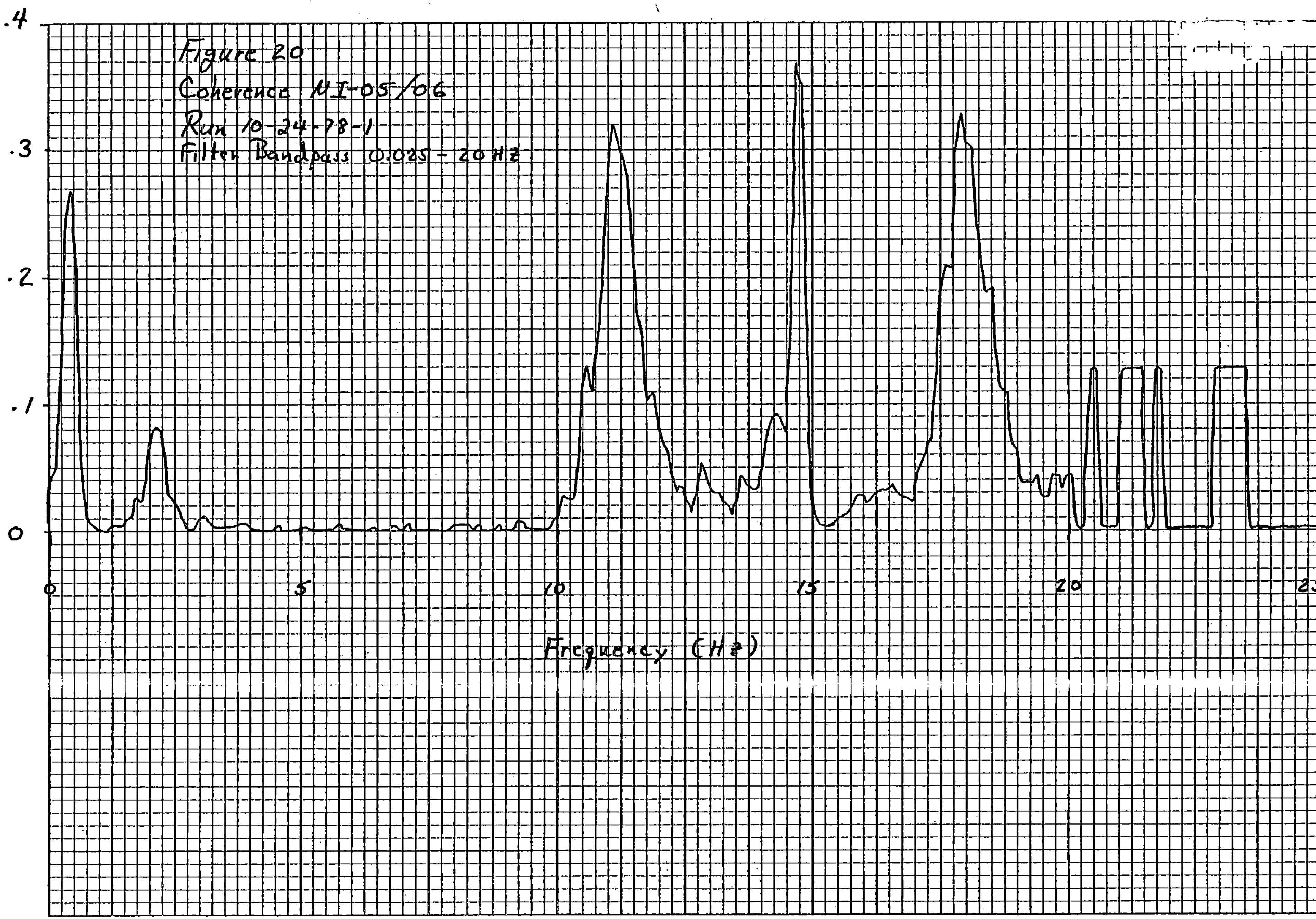
Figure 20
Coherence NI-05/06
Run 10-24-78-1
Filter Bandpass 0.025 - 20 Hz
.4
.3
.2
.1
0
0
5
10
15
20
25
Frequency (Hz)

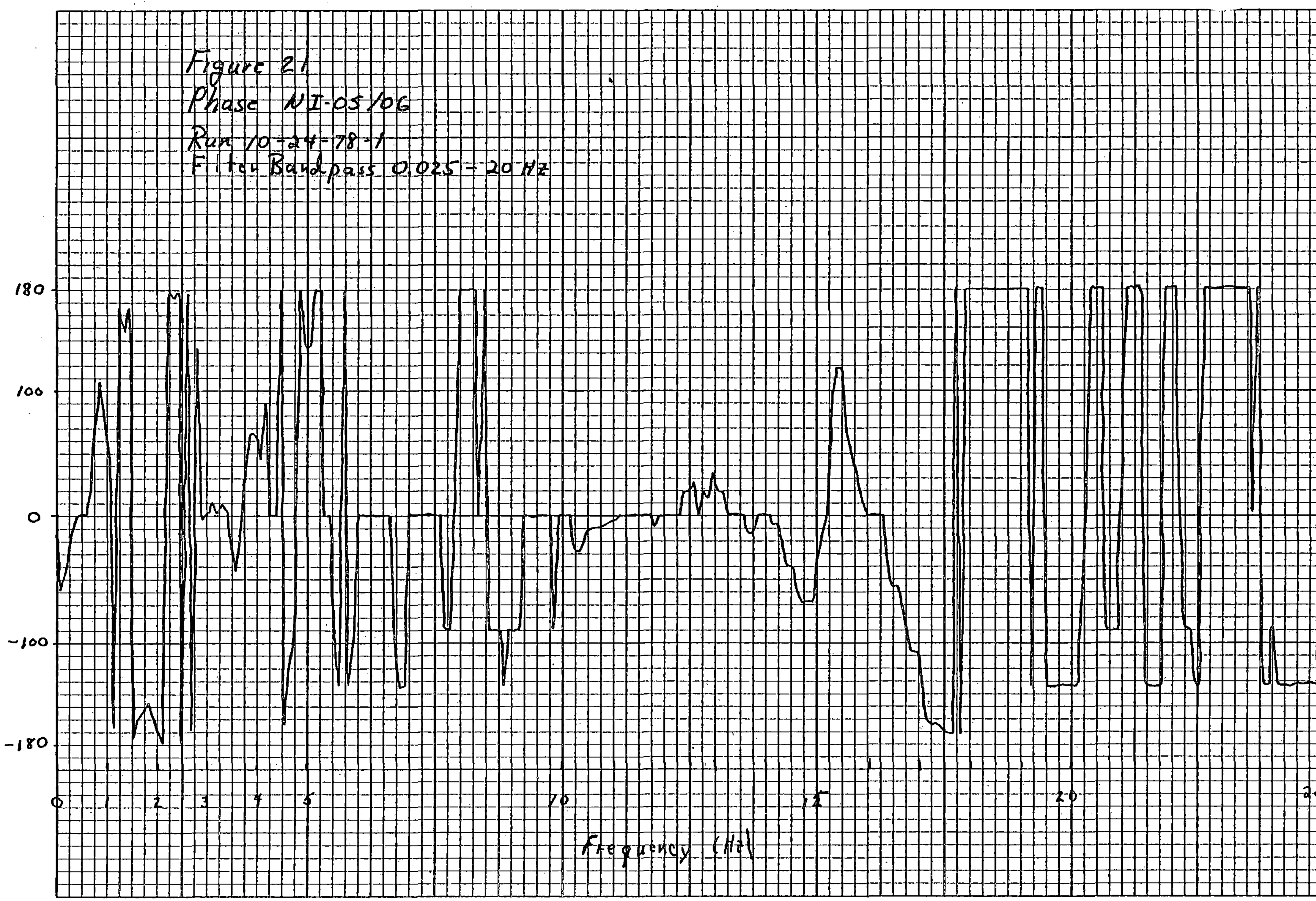
Figure 21
Phase NI-05/06
Run 10-24-78-1
Filter Bandpass 0.025 - 20 Hz
180
100
0
-100
-180
0
1
2
3
4
5
10
15
20
25
Frequency (Hz)

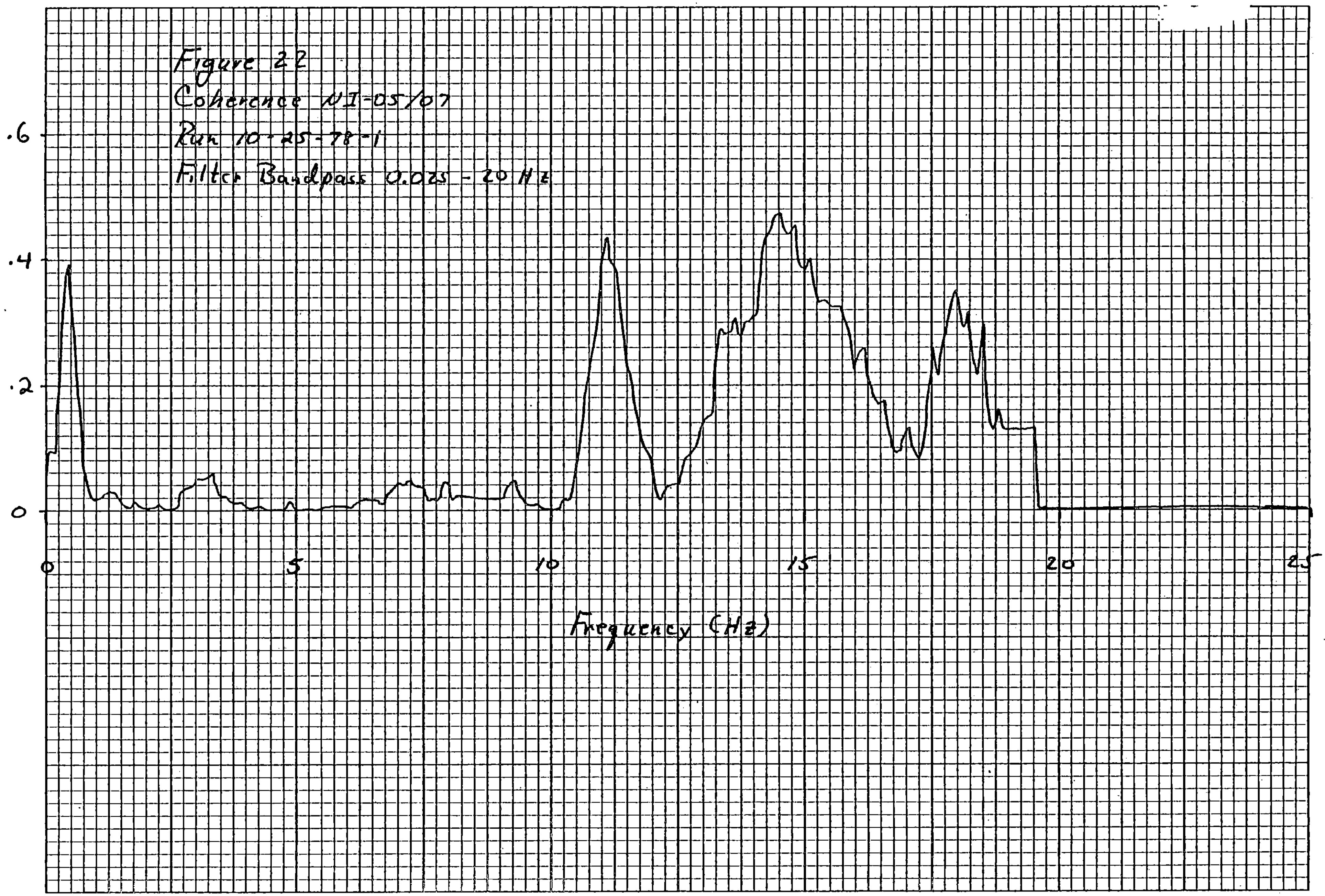
Figure 22
Coherence WI-05/07
Run 10-25-78-1
Filter Bandpass 0.025 - 20 Hz
.6
.4
.2
0
0
5
10
15
20
25
Frequency (Hz)

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

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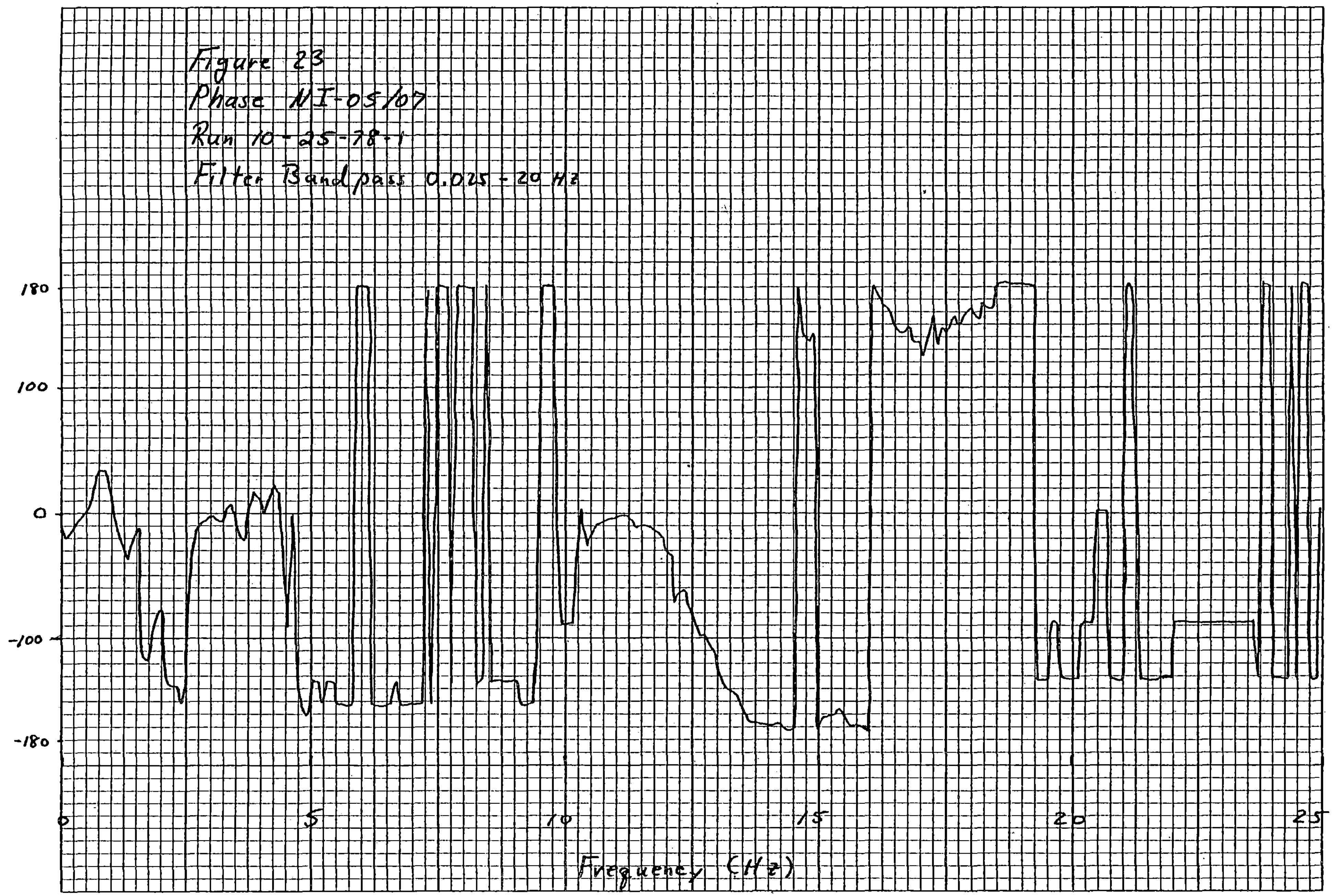

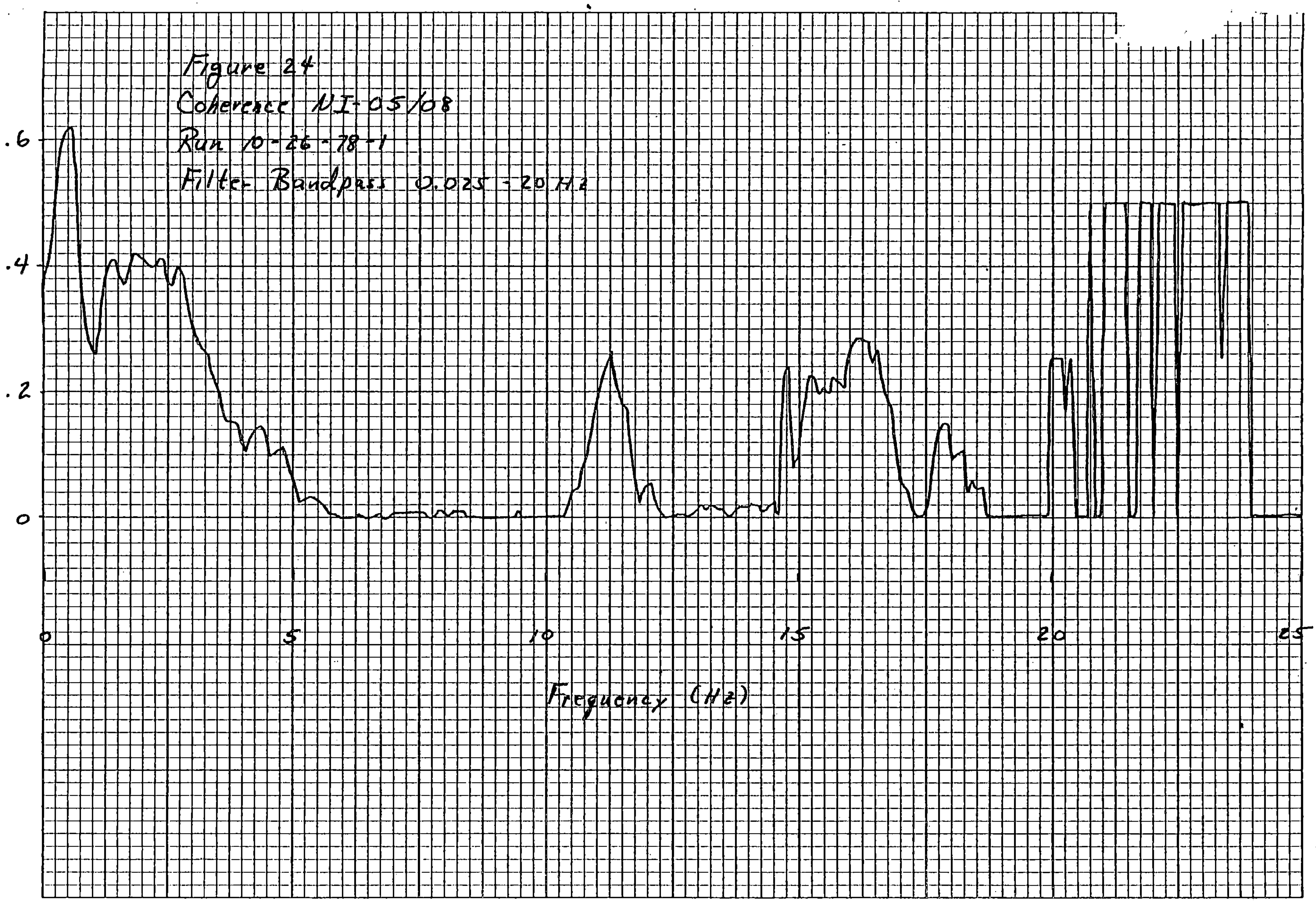
Figure 24
Coherence NI-05/08
Run 10-26-78-1
Filter Bandpass 0.025 - 20 Hz
.6
.4
.2
0
0
5
10
15
20
25
Frequency (Hz)

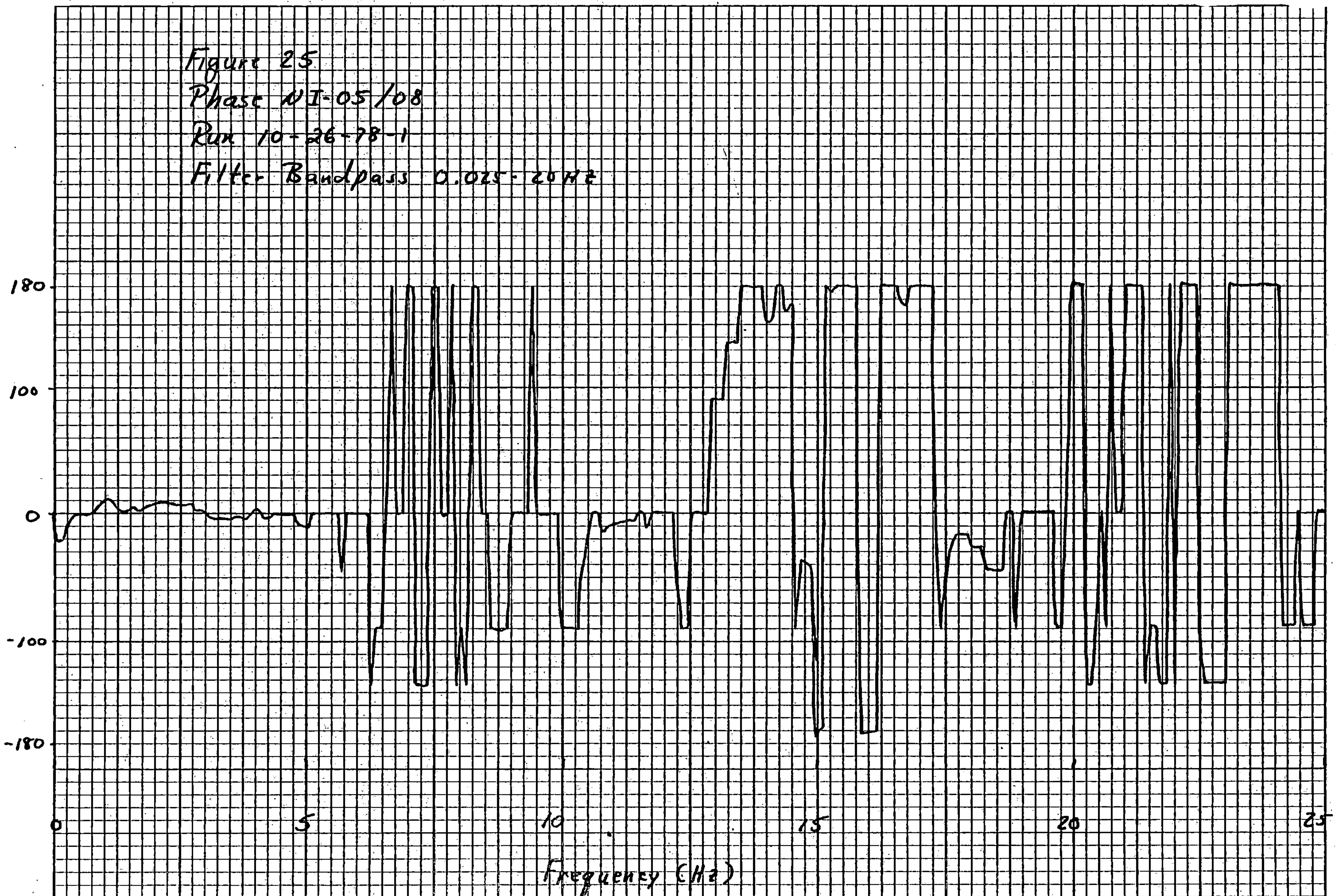
Figure 25
Phase NI-05/08
Run 10-26-78-1
Filter Bandpass 0.025-20Hz
180
100
0
-100
-180
0
5
10
15
20
25
Frequency (Hz)

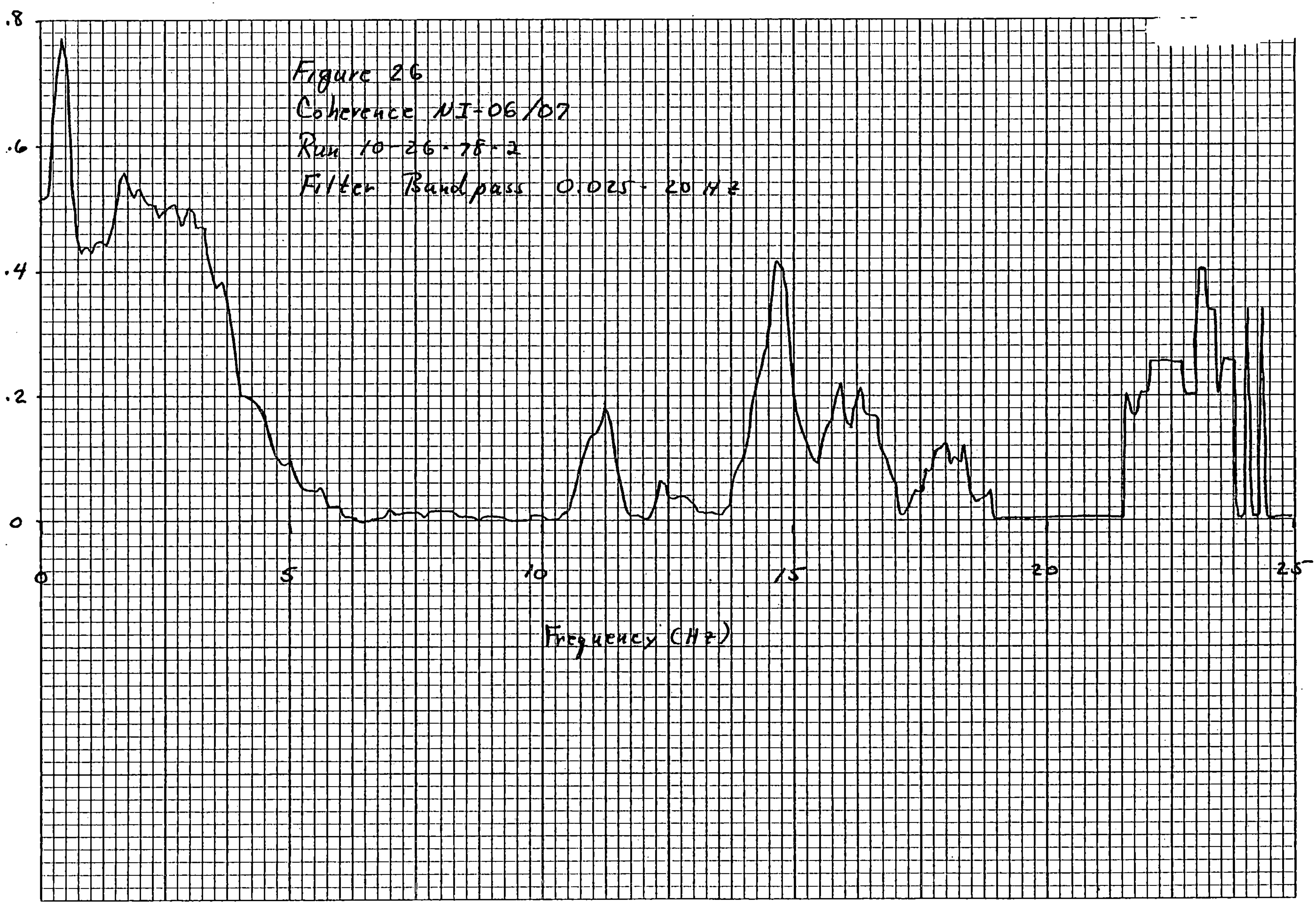
Figure 26
Coherence NI-06/07
Run 10-26-78-2
Filter Bandpass 0.025 - 20 Hz
.8
.6
.4
.2
0
0
5
10
15
20
25
Frequency (Hz)

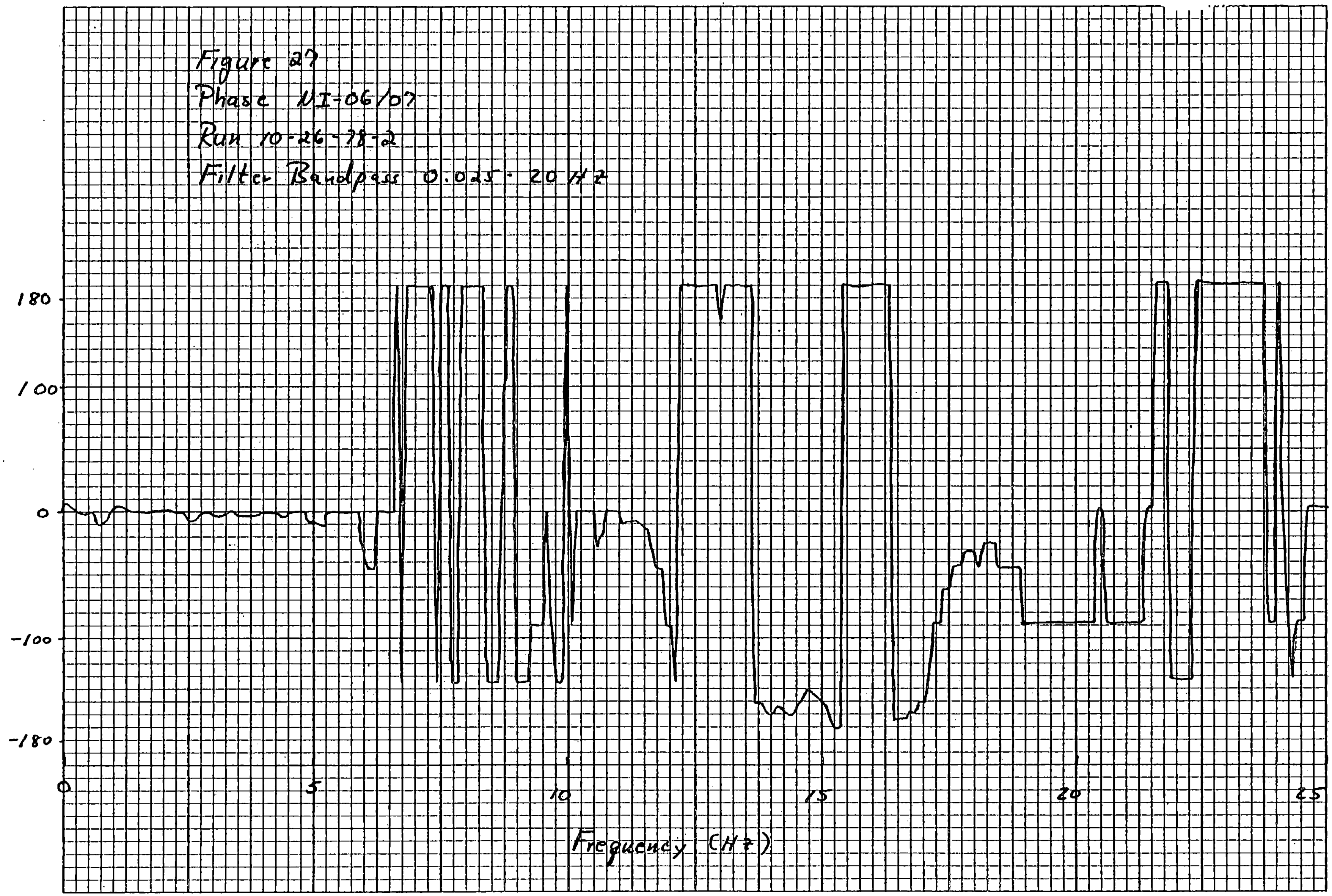
Figure 27
Phase NI-06/07
Run 10-26-78-2
Filter Bandpass 0.025 - 20 Hz
180
100
0
-100
-180
0
5
10
15
20
25
Frequency (Hz)

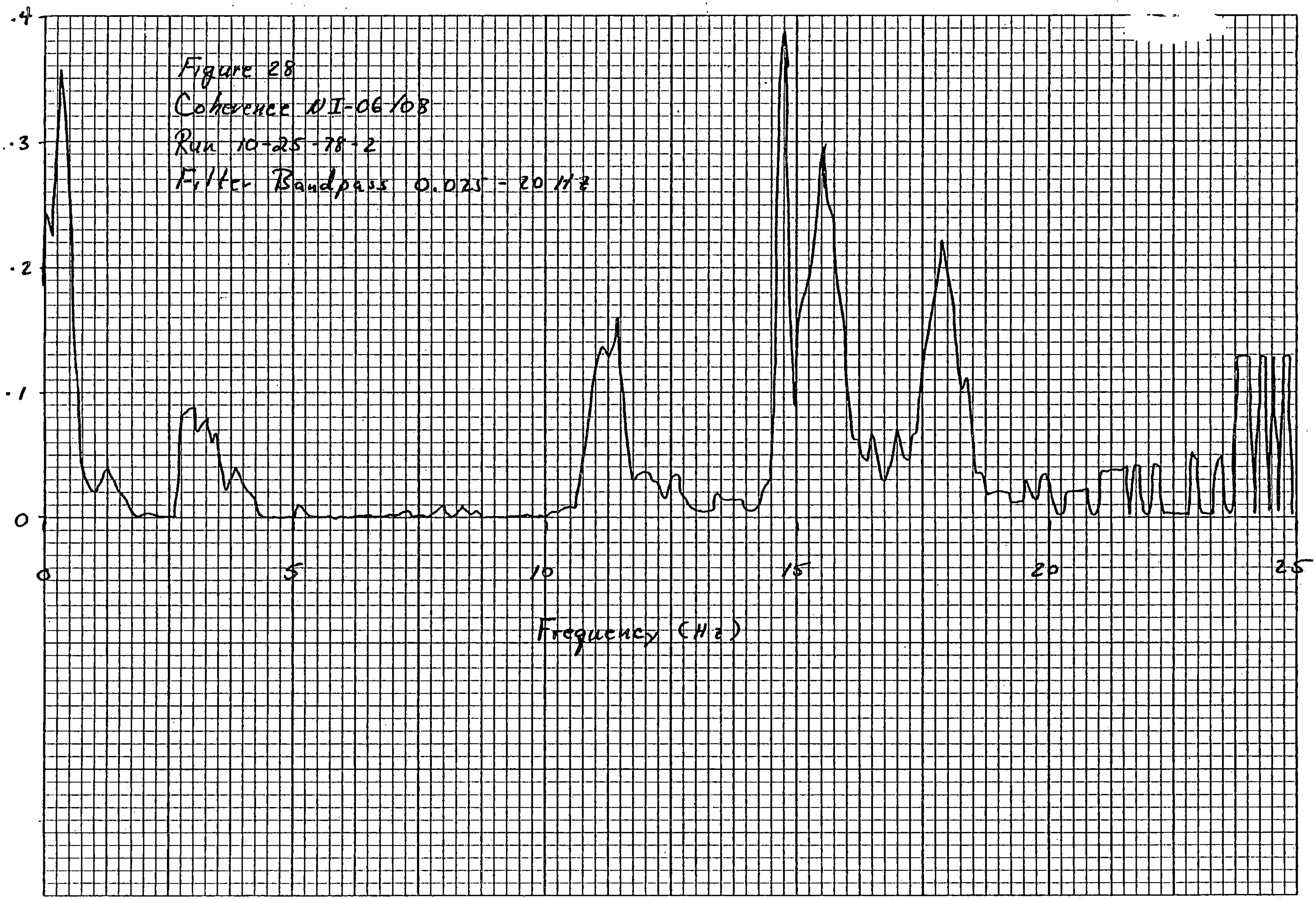
Figure 28
Coherence WI-06/08
Run 10-25-78-2
Filter Bandpass 0.025 - 20 Hz
.4
.3
.2
.1
0
0
5
10
15
20
25
Frequency (Hz)

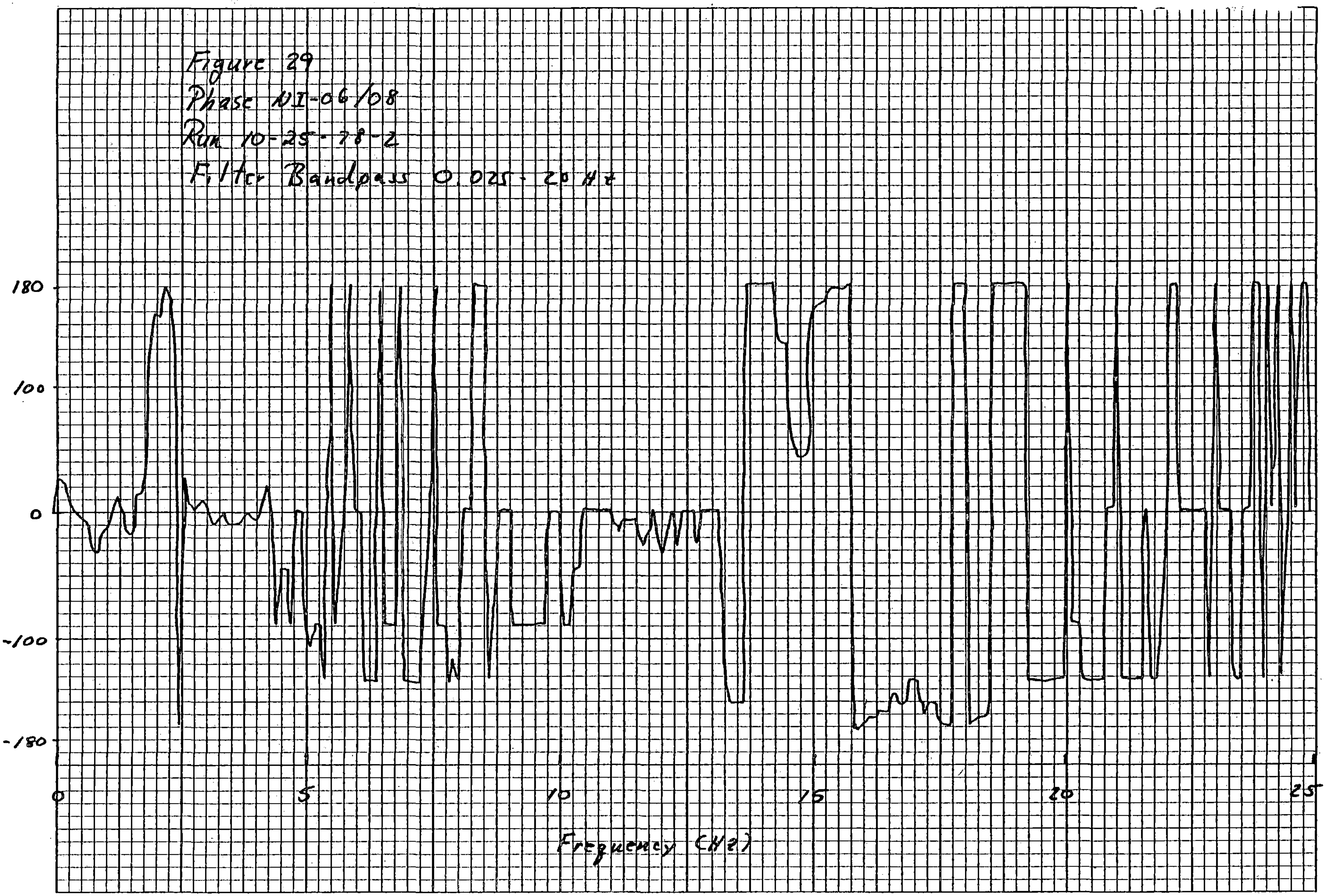
Figure 29
Phase NI-06/08
Run 10-25-78-2
Filter Bandpass 0.025 - 20 Hz
180
100
0
-100
-180
0
5
10
15
20
25
Frequency (Hz)

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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46 0782

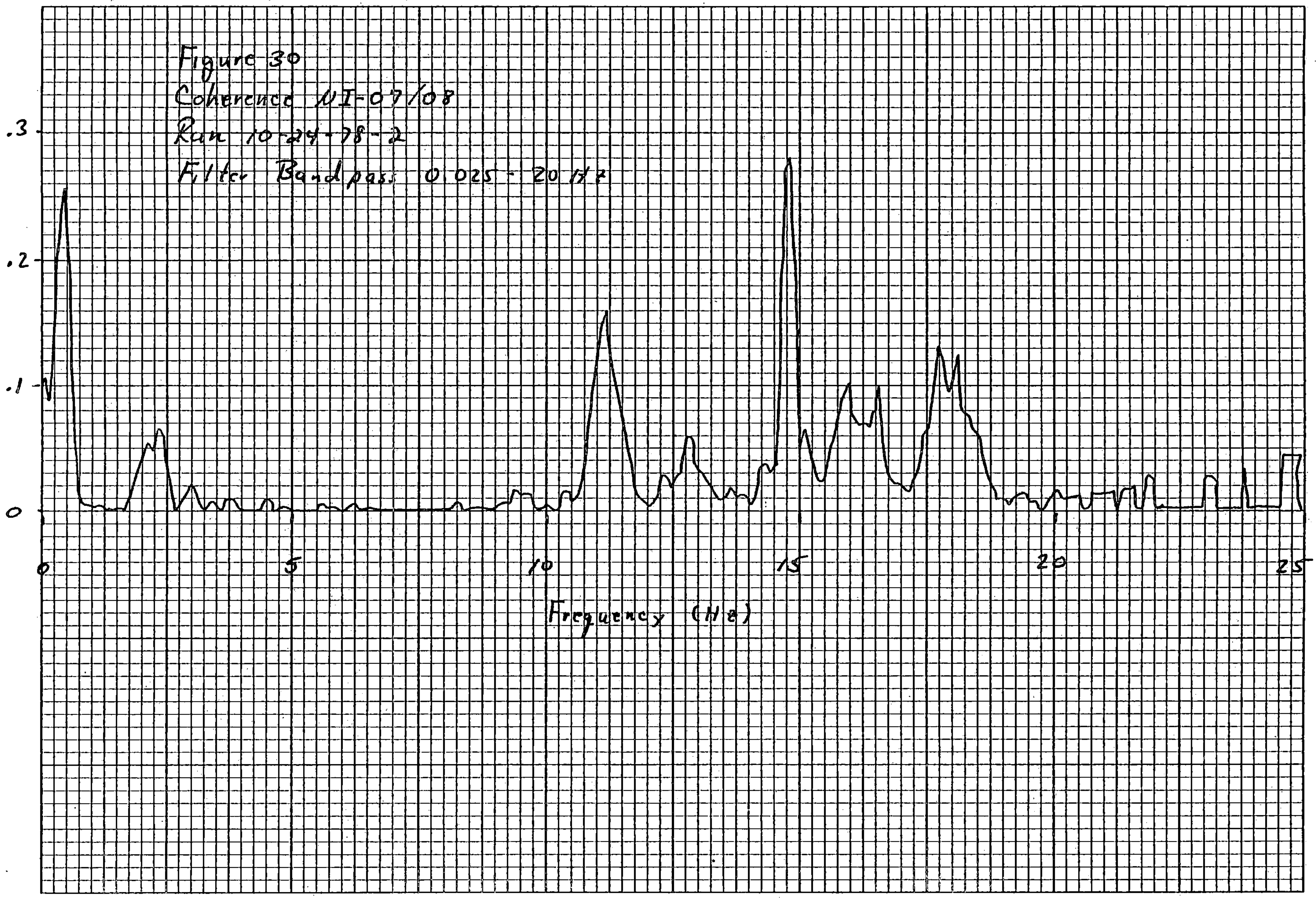

Figure 31
Phase NI-07/08
Run 10-24-78-2
Filter Bandpass 0.025 - 20 Hz

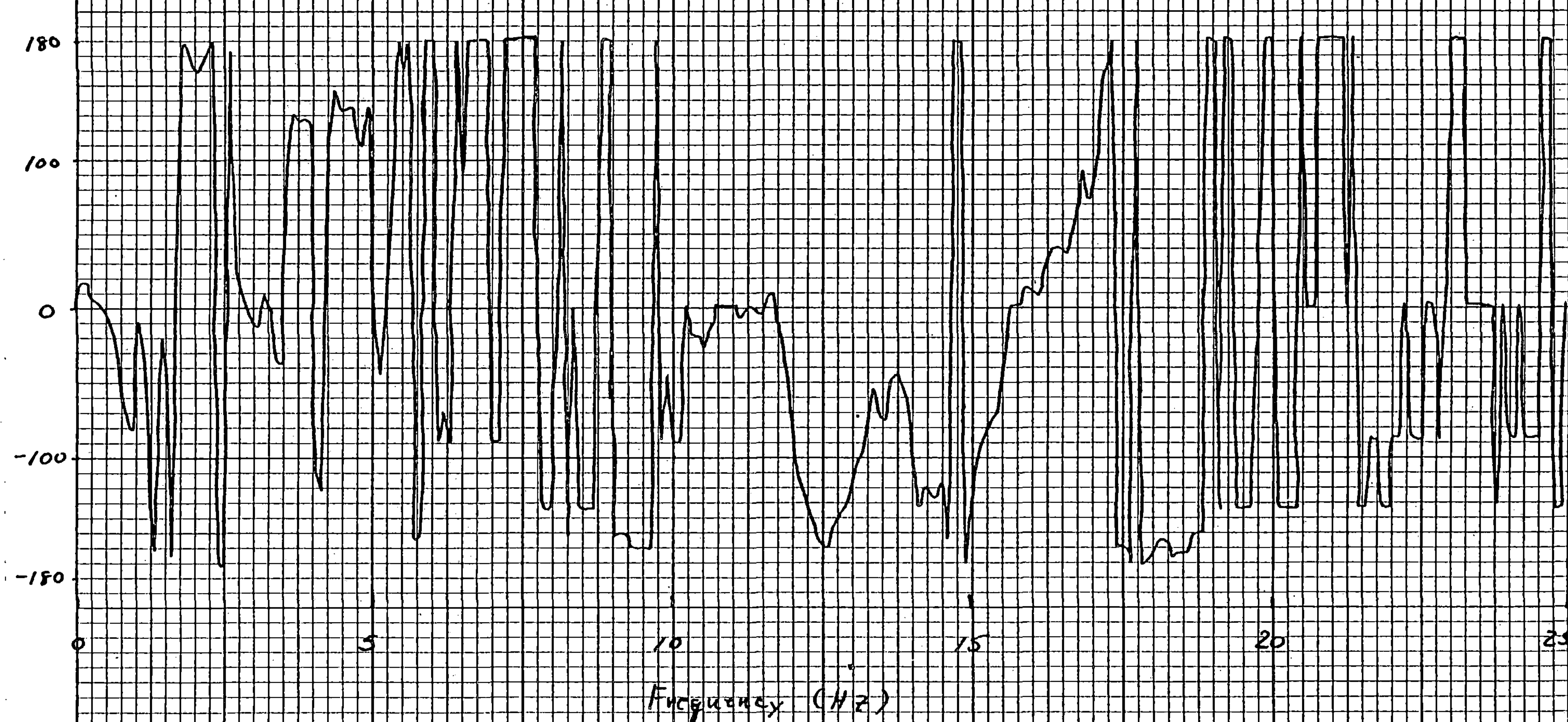

FIGURE 32

PHASE DIAGRAMS