CONSUMERS POWER COMPANY NUCLEAR PRODUCTION DEPARTMENT: PALISADES NUCLEAR PLANT REACTOR NOISE MONITORING TESTS MAY 1977
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CONSUMERS POWER COMPANY
Nuclear Production Department

Palisades Nuclear Plant
Reactor Internals Noise Monitoring Tests

May 1977

REACTOR INTERNALS NOISE MONITORING TESTS

ABSTRACT

Reactor internals noise monitoring tests are being conducted on the Palisades reactor core 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 determining the auto-power spectrol densities, coherences and phase relationships of the sensor noise. Action limits of 0.25% rms and 0.48% rms have been set on the noise amplitudes.

The subject matter of this report covers the period from November 1976 thru April 1977. The reactor is in its second core (core 2) following a full core reload early in 1976. During the reporting period the plant has operated at 100% full power. The barrel motion is nominally 1.25 mills rms. At no time were the established action limits exceeded.

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 vibration occurring initially in 1972. Two measurement phases are implemented for the analysis. Phase One measurements include the analysis of the power range excore detector signed noise for gross amplitude of core movement. The analysis is performed by determining the amplitude probability distributions, the standard deviations and the root mean square values of the measured data. Phase

Two measurements require overall noise characteristics to be analyzed including amplitude power distributions, frequency content and azimuthal relationships of the measured data. This is done by determing the auto-power spectrol densities, coherence functions, and phase relationships of the data.

This report represents data taken at stable 100% reactor power. The period covered by this report is the middle of life for core 2.

II. SIGNAL CHOICES

Operating power range excore detectors, NI-05 through 10, compromise the primary source of information used for the analysis of the reactor internals. The power range excore signals are supplemented with the use of incore detector 7-5 and accelerometers placed on the reactor vessel. Figures 1(a) and 1(b) indicate the locations of the above sensors.

III. SIGNAL CONDITIONING

Excore signals NI-05 through 08, are processed through a dc "bucking box" which bucks out the dc component of the signal. The signal is then amplified and filtered before being connected to a Hewlett-Packard 5451B Fourier analyzer. The other sensors are connected as above except the "bucking box" is not used. All signals (except accelerometers) are high pass filtered at 0.025 hz and low pass filtered depending upon the analysis requirements. The filters have a characteristic roll-off of 24db/octave. Figure 1(c) is a schematic representation of the signal conditioning equipment.

IV. PHASE ONE MEASUREMENTS

Phase One measurements consist of determining the amplitude probability distribution (APD), the standard deivation (sigma, σ), and the root mean square (rms) of the noise component of the power range excore detectors. APD's of the excore detectors as of the end of the period covered by this report are plotted in figures 2, 4, 6 and 8. In addition, the integrals of the APD's (IAPD) are plotted in figures 3, 5, 7 and 9. Since the integral of the APD up to a given amplitude is just the probability, a plot of the integral versus the amplitude will form a straight line if plotted on a probability scale, if the APD is gaussian (random data). The significance of this is that if the APD were biased in one direction it could indicate restriction of motion in one direction such as core support barrel hitting the snubbers.

Percent rms is monitored for the following frequency bands: 0-0.5hz, 0.5-5hz, 0-5hz, 5-25hz, and 5-50hz. The reason for the monitoring percent rms for two regions in the 0-5hz band is to better monitor changes in rms that occur in that region. The rms value for a given frequency band is calculated by integrating the measured power spectrol density over the band of interest.

In order to determine if the low frequency region by itself is gaussian (random) APD's and associated IAPD's are calculated for low frequency bands. The band chosen was 0.75 to 3 hz since this is the region of high coherence and out of phase relationship between detectors located diagonally across the core, indicating motion (figure 10-13).

V. PHASE TWO MEASUREMENTS

Phase Two test measurements consist of determining the power spectral density (PSD) of excore detector signal noise as well as the coherence and phase relationships of the various excore combinations. Figures 19, 20, 21 and 22 are PSD's, normalized (NPSD) with respect to dc voltage, from 0.025hz to 25hz. This band was chosen since the frequencies of interest are in this region and better resolution is provided. In any case, PSD's from 0.025 - 50hz and 0.025 - 100hz are routinely calculated to monitor any charges or phenomenon at higher frequencies (figures 23 and 24).

Coherence and phase relationships for all detector combinations are determined. Representative plots are shown in figures 27 - 34. The data is best summarized to use of phase diagrams as shown in figure 47.

VI. ADDITIONAL MEASUREMENTS

Measurements were taken of incore detector 7 - 5 and of accelerometers on the reactor vessel. A PSD of the incore is shown in figure 26 and it's relationships with excore detectors NI-05 and NI-06 are shown in figures 39 - 42. For the reactor vessel accelerometers its gross amplitude is depicted on an APD, fugure 14. Its power spectrum is shown in figure 25 and its relationship to excore detectors NI-07 and NI-08 is shown in figures 35 - 38.

VII. SUMMARY OF FINDINGS AND DATA OBSERVATIONS

A. Amplitude Probability Distribution (APD and IAPD)

The APD's are gaussian for both wide band and narrow band frequency ranges, indicating random phenomenon. This is verified by the fact that the IAPD versus amplitude plot is a straight line when plotted on a probability scale as verified in figures 3, 5, 7, 9, 11 and 13.

B. Root Mean Square (rms) Values

Table 1 below compares the percent rms in March, 1977 to November, 1975. The percent rms in the 0.025 - 5 hz region is tabulated for the various excore detectors in figures 15 - 18. Note that the rms has been increasing since November 1976. This is opposite to the first six months of core 2 during which the noise in this region had decreased with core life. Note from table 1 that this increase is primarily due to an increase in the 0.025 to .5 hz region. As explained later in this report this is believed to be a neutronic effect and does not indicate CSB motion.

TABLE 1: Percent rms

Excore	0-.5hz		.5-5hz		0-5hz		5-25hz		5-50hz	
Detector	NOV	MAR	NOV	MAR	NOV	MAR	NOV	MAR	NOV	MAR
NI5	.047	.066	.036	.040	.059	.077	.0093	.0083	.0083	.0071
NI6	.039	.054	.037	.037	.054	.066	.0074	.0067	.0075	.0086
NI7	.035	.053	.036	.038	.050	.065	.0089	.0100	.0087	.0100
NI8	.045	.069	.034	.043	.057	.081	.0085	.0083	.0083	.0091

C. Power Spectrol Densities (PSD's)

1. Low frequency (<5hz)

All four excore detectors continue to display resonances at 0.25hz and 2.25hz. The amplitude at 0.25hz has been increasing linearly with burnup, as explained later. The amplitude at 2.25hz, decreasing during the first six months of core 2 stabilized. Beginning in March, 1977 of core 2, the amplitude has begun to increase (by about 1db).

2. High Frequency (>5hz)

All four excore detectors displayed resonances at about 11.6hz. As shown in table 2 below this peak, which was present for core 1, has been increasing in amplitude.

TABLE 2: Amplitude of PSD at 11.6hz (in decibels)

	NI05	NI06	NI07	NI08
April 77	-92	-92.5	-90.5	-91.5
November 76	-95	-96.5	-94.5	-95
November 75	-91.5	-93	-91	-92

Horizontal barrel motion has been previously identified (Ref 1) at approximately 12.8hz, 15.3hz and 18.5hz. As before the 12.8hz peak is most significant for detectors NI07 and NI08 while the 18.5hz peak is most significant for NI05 and NI06. As shown in table 3 the amplitude at the 12.8hz resonance has increased in the past six months.

TABLE 3: Amplitude of CSB Cantilevred Beam Resonances

Detector	Resonance (hz)	April 1977	November 1977
NI05	18.5	-98db	-97db
NI06	18.5	-94.5db	-95db
NI07	12.8	-88.5db	-91.8db
NI08	12.8	-91db	-94.2db

The 15.3hz resonance has been determined to be a shell mode vibration (Ref 1). As of April the average for core 2 is -88.9db as compared to core 1 of -88.6db.

The narrow band resonance at 14.8hz is still visible. It is currently believed that this is vessel vibration about the CSB caused by a once per turn imbalance in the primary coolant pumps. A resonance at 29.6hz is believed to be the first harmonic of 14.8hz.

High frequency resonances occur at 23.5hz and 74.5hz. The 23.5hz has remained relatively stable. The 74.5hz peak has been previously identified as the blade passing frequency of the primary coolant pumps (Ref 1). G6 cycle electrical noise is present on the detector signals with a first harmonic at 120hz. For a maximum frequency of 50hz this G6hz noise will be aliased to 40hz and for a maximum frequency of 100hz the 120hz harmonic will be aliased to 80hz.

D. Coherence and Phase

1. Low frequency (<5hz)

In the 0-5hz band there are 2 regions of coherence. One region is centered about 0.5hz. This coherence has been visible since the first of November 1976 and is in phase for all detector pairs. The average coherence for the past six months is listed in table 4. Due to the observed in phase relationship it is felt that the coherence in this region is due to neutronics effects. Similar behaviour has been observed elsewhere and has been shown to be possibly due to oscillations in feedwater flow.

TABLE 4: Coherence/Phase at 0.5hz

Detector Pair	Average Coherence	Phase Angle
NI5/6	.16	0°
NI7/8	.19	0°
NI5/7	.31	0°
NI6/8	.21	0°
NI5/8	.42	0°
NI6/7	.52	0°

The second region of coherence in the 0-5hz band is at 2.3hz. As shown in figures 28 and 30 detectors located diagonally across the core are presently out of phase as they were for the first six months of core 2. However, during the period of November, 1976 through March, 1977 the phase shifted to 0° (in phase) and remained there until the end of March when it shifted back out of phase. During this same period a region of coherence, in phase for all detector pairs, in the 3 to 5hz region shifted to lower frequencies and increased in amplitude. This region of coherence, greater in magnitude, dominated the information at 2.3hz as it shifted to that frequency - causing the phase at 2.3hz to go to 0°. It is believed that the cause of this coherence disappeared in the end of March as evidenced by an abrupt drop in coherence and a phase shift to 180°. Note that this same phenomenon occurred during core 1 also.

2. High Frequency ($\geq$5hz)

Each detector pair combination has a coherence at 11.5hz with a phase angle of 0°. Since the appearance of this coherence peak in November 1976 the amplitude has been increasing to an average coherence of 0.3 in April 1977. Since all detector combinations are in phase this is not considered to be core barrel motion in any horizontal plane.

In the region from 12hz to 14.5hz there appears to be two regions of coherence - one at 12 - 13.5hz and the other from 13.5 - 14.5hz. For adjacent detectors these two peaks merge, forming one peak. For each detector pair the phase is the same for both frequency bands.

The phase indicates motion perpendicular to the outlet nozzels of the reactor vessel.

At 15.3hz detectors diagonally across the core are in phase while all other detector combinations are out of phase indicating the shell mode vibration. At 17.5hz the phase indicator motion in the general direction of the outlet nozzels. The indicated motions at these two frequencies are the same as reported for core 1 and the first six months of core 2. As observed in core 1 the coherence has decreased during core life (see table 5).

TABLE 5: Coherence\Phase Relationships

Detector Pair	Frequency Range (hz)	Coherence Nov 76	Coherence Apr 77	Phase Nov 76	Phase Apr 77
NI5,6	15 - 16.5	.09	.05	0	0
NI7,8	15 - 16.5	.31	.27	0	0
NI5,6	16.5 - 20	.39	.33	180	180
NI7,8	16.5 - 20	.12	.08	180	180

VIII. BORON CONCENTRATION EFFECTS

It has been observed for core 1 and for core 2 that the NPSD amplitude at 0.25hz increased significantly with core life. This same effect has been observed for other reactors (Ref 3). The increase in rms in the 0-5hz region is a result of increase in noise at 0.25hz. It has been theorized that noise at 0.25hz is the result of local temperature fluctuations in the vicinity of each detector (Ref 3). This temperature fluctuation is converted to reactivity through the Moderator Temperature Coefficient (MTC). Since the MTC is a function of boron concentration the detected signal from the local temperature effects will be a function of boron concentration as well. Therefore, the NPSD amplitude at 0.25hz

was plotted as a function of boron concentration in figures 43 - 46. Then a correlation coefficient was determined to see how linear the relationship was, see table 6 below.

TABLE 6: Correlation Coefficient for 0.25hz versus Boron Concentration

Detector	Correlation Coefficient*	Slope
NI05	.99	-.023
NI06	.99	-.018
NI07	1.0	-.017
NI08	.99	-.028

* A value of 1 is perfect correlation, 0 no correlation.

As seen in table 6 the amplitude at 0.25hz is very linearly correlated with boron concentration. Note that in figures 43 - 46 that the first two data points are not linear with the remaining data points. These first few points were not used in the determination of correlation coefficient. The justification for this is that during this period of time the amplitude at 2.3hz was decreasing as reported earlier. Thus, due to the wide band width of this resonance it affected the amplitude at 0.25hz as well. The data used was for a period when the 2.3hz amplitude was stable.

VIII. CONCLUSION

The increasing rms observed over this reporting period has been shown to be a neutronic effect and not an increase in CSB motion. In the 0-5hz region there remains a high coherence and out of phase relationship for across the core detectors, an indication of motion. The magnitude of the motion can be determined using the following equation (Ref 4).

$$\# \text{ mills rms motion} = \frac{100}{.0376} \sqrt{(NPSD_a)^{1/2} \cdot (NPSD_b)^{1/2} (f_2 - f_1) \gamma}$$

where γ^2 coherence $NPSD_a$ is the area under the normalized PSD for detector a in the frequency band f_2-f_1.

Using data from run 4-26-77-1 the amount of motion is 1.25 mills rms.

In the higher frequency ranges the resonant frequencies of the CSB at 12.8hz, 15.3hz and 18hz are still present, exhibiting no shifting in frequency. Thus, the barrel remains well clamped with no indication of loosening.

In the near future a request will be made for relaxation of data collection. This is based upon the fact that to date no substantial increase in CSB motion has been measured and that historically problems tend to develop over a period of weeks rather than days.

References

1. Consumers Power Company, Reactor Internals Noise Monitoring Test; Completion of Baseline Noise Data, May 22, 1975.

2. Thie, J. A., Review of the 1976 Palisades Noise Program, December 22, 1976.

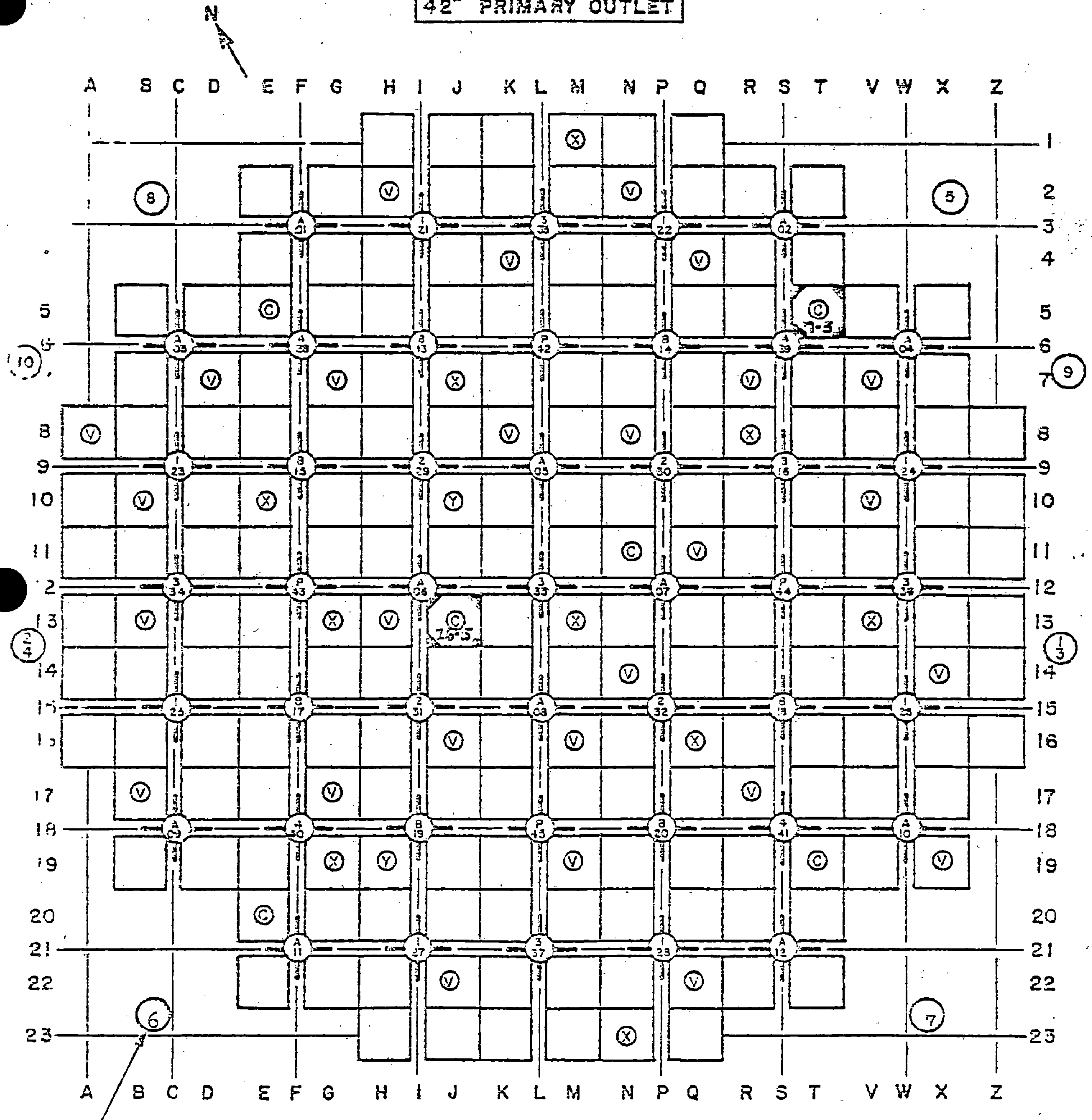
3. Thie, J. A., Analysis and Casual Identifications of Calvert Cliffs Noise.

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

FIGURE #1(a)

Palisades Plant - Reactor Core Plan

42" PRIMARY OUTLET

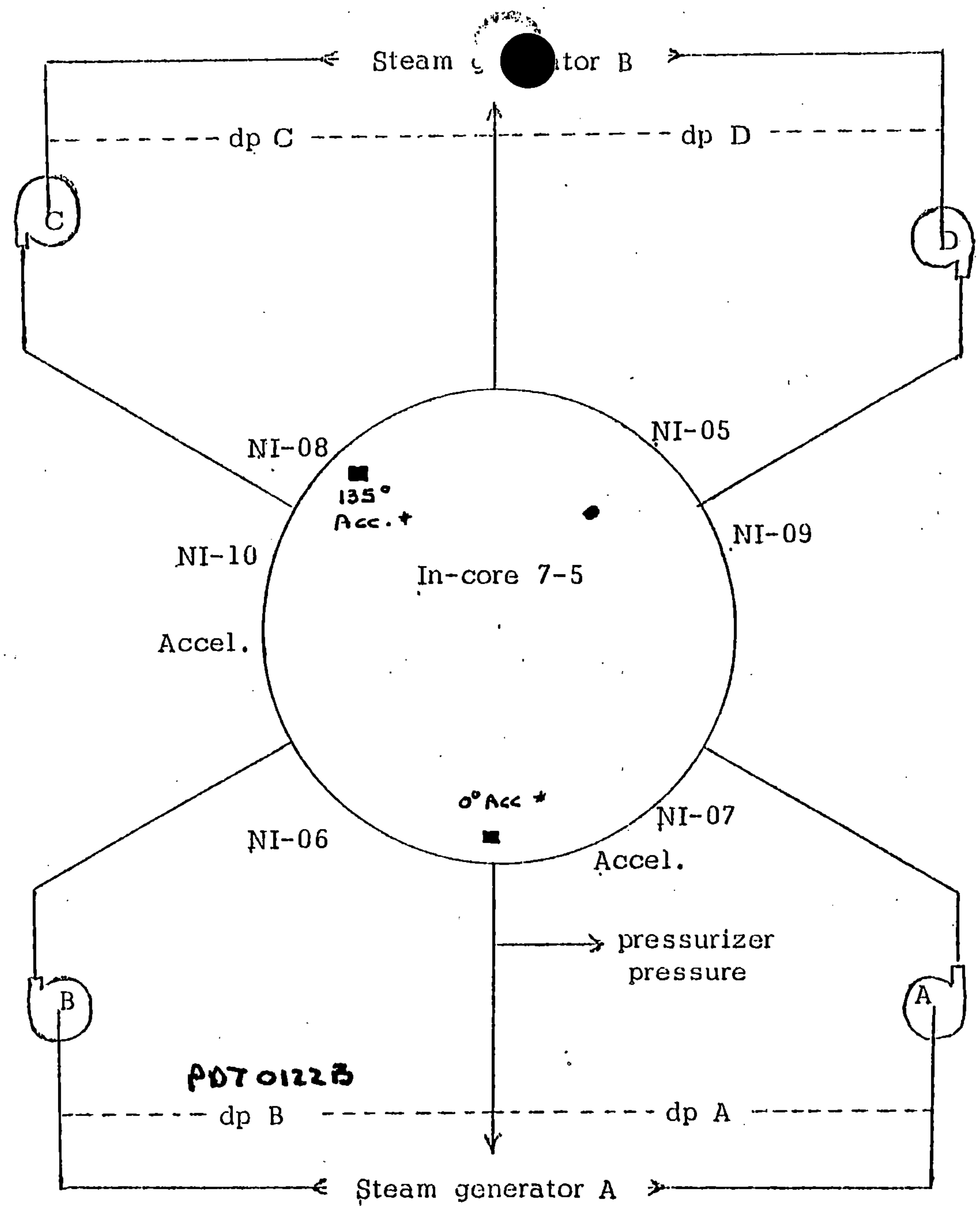


42" PRIMARY OUTLET

In-core Detectors:

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

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



* located on Vessel side at about the snubber level (bottom of CSB)

Fig. 1(b) Instrumentation locations for noise tests

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10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

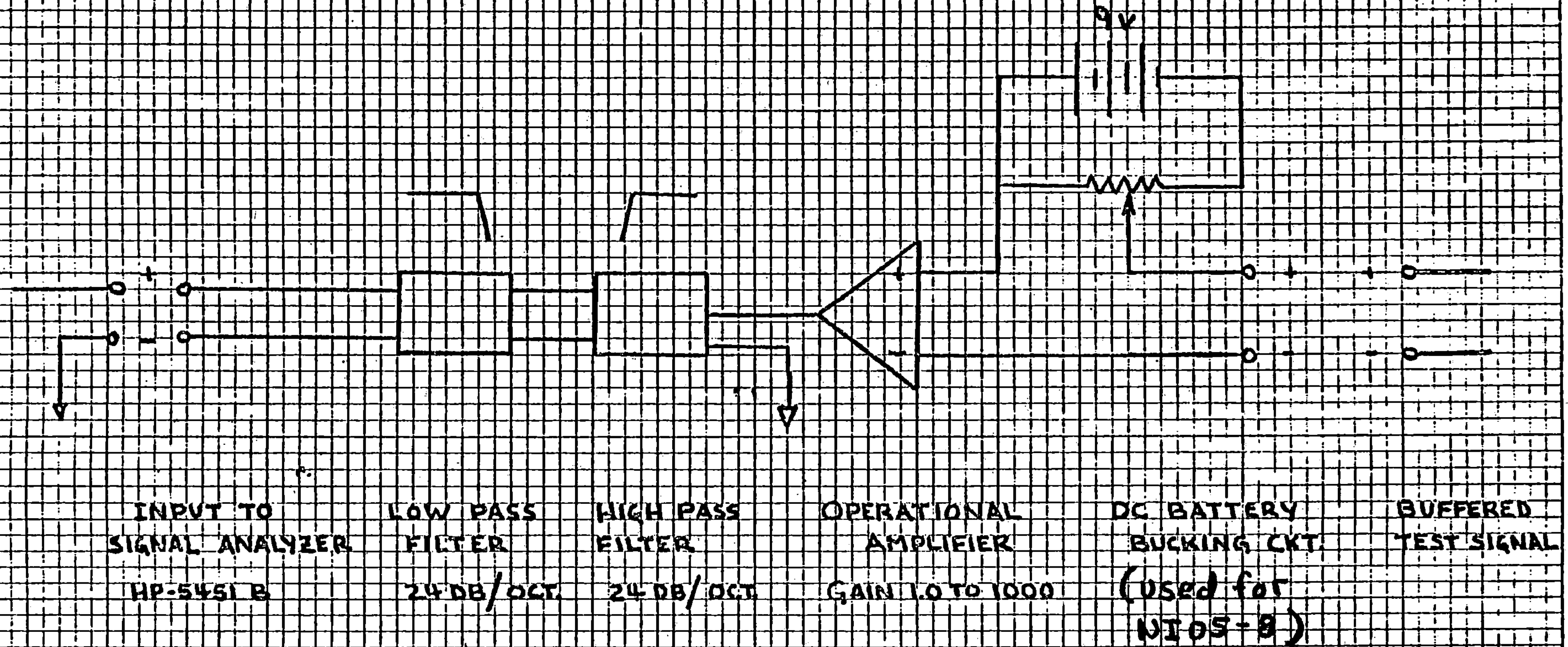

FIGURE 1(C)

SIGNAL PROCESSING
FOR NOISE ANALYSIS

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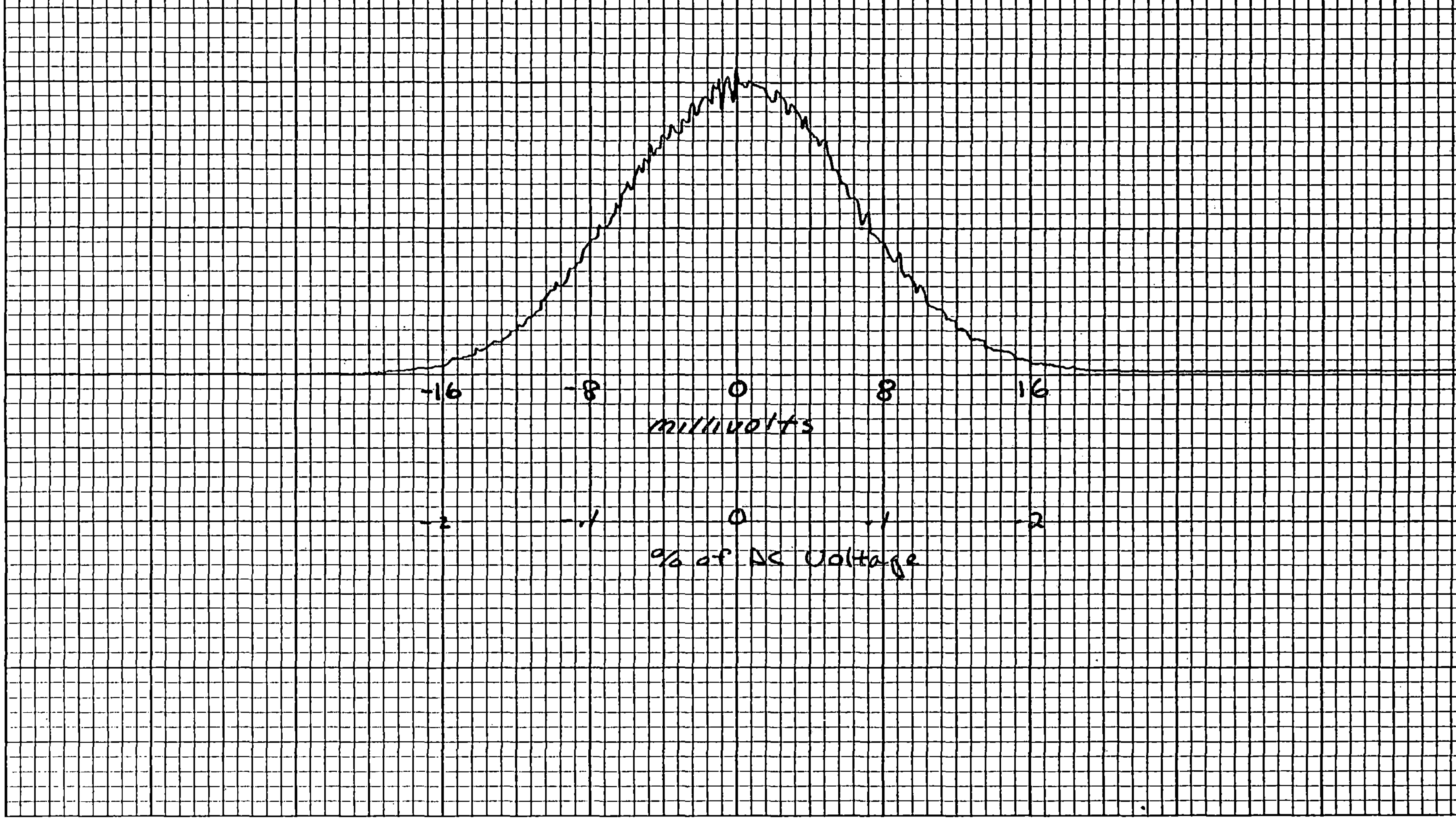
FIGURE 2
APD EXCORE NI-05
RUN 4-26-77-2 100% POWER
FILTER BANDPASS 0.025-20Hz
500 SAMPLES



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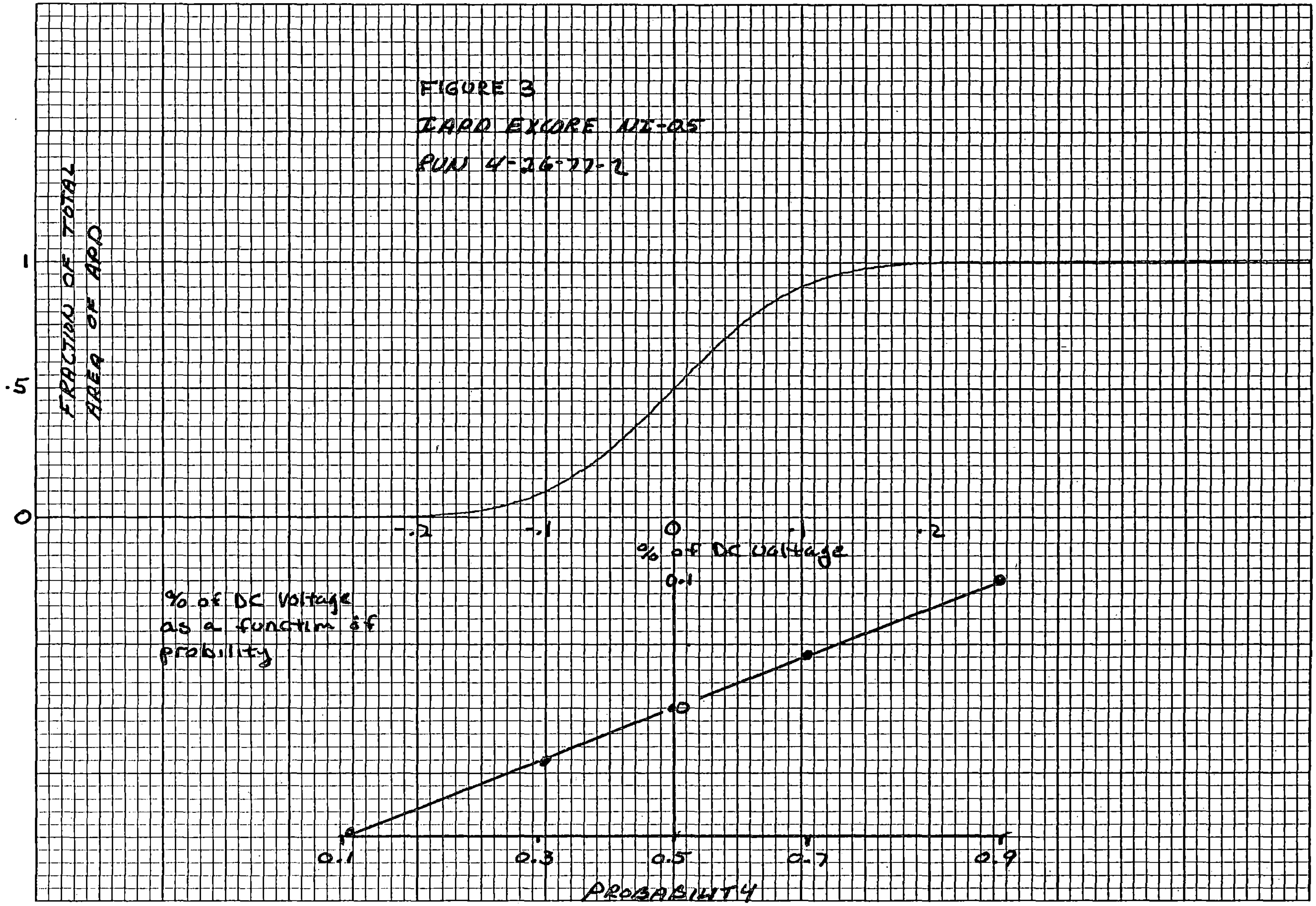

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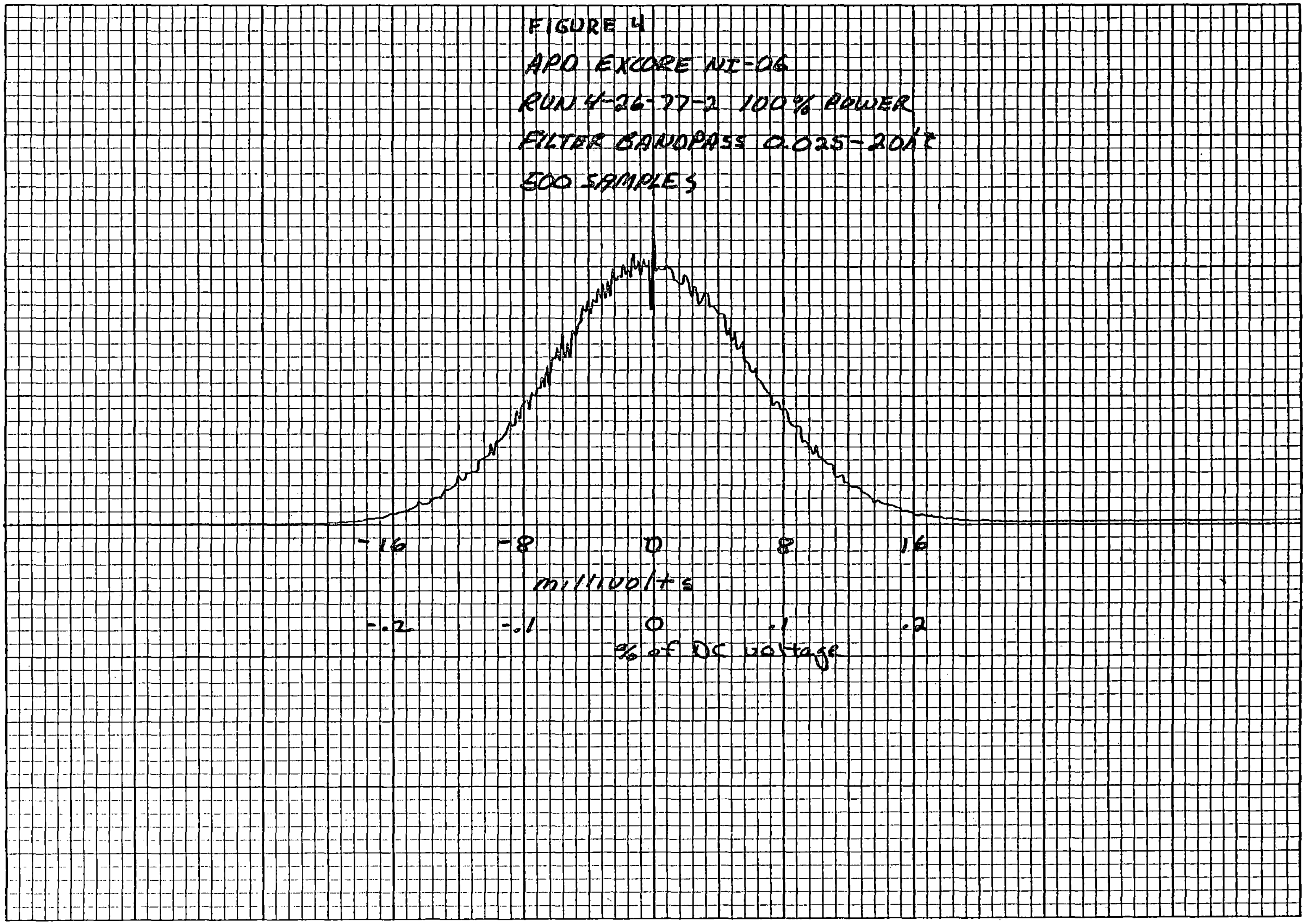

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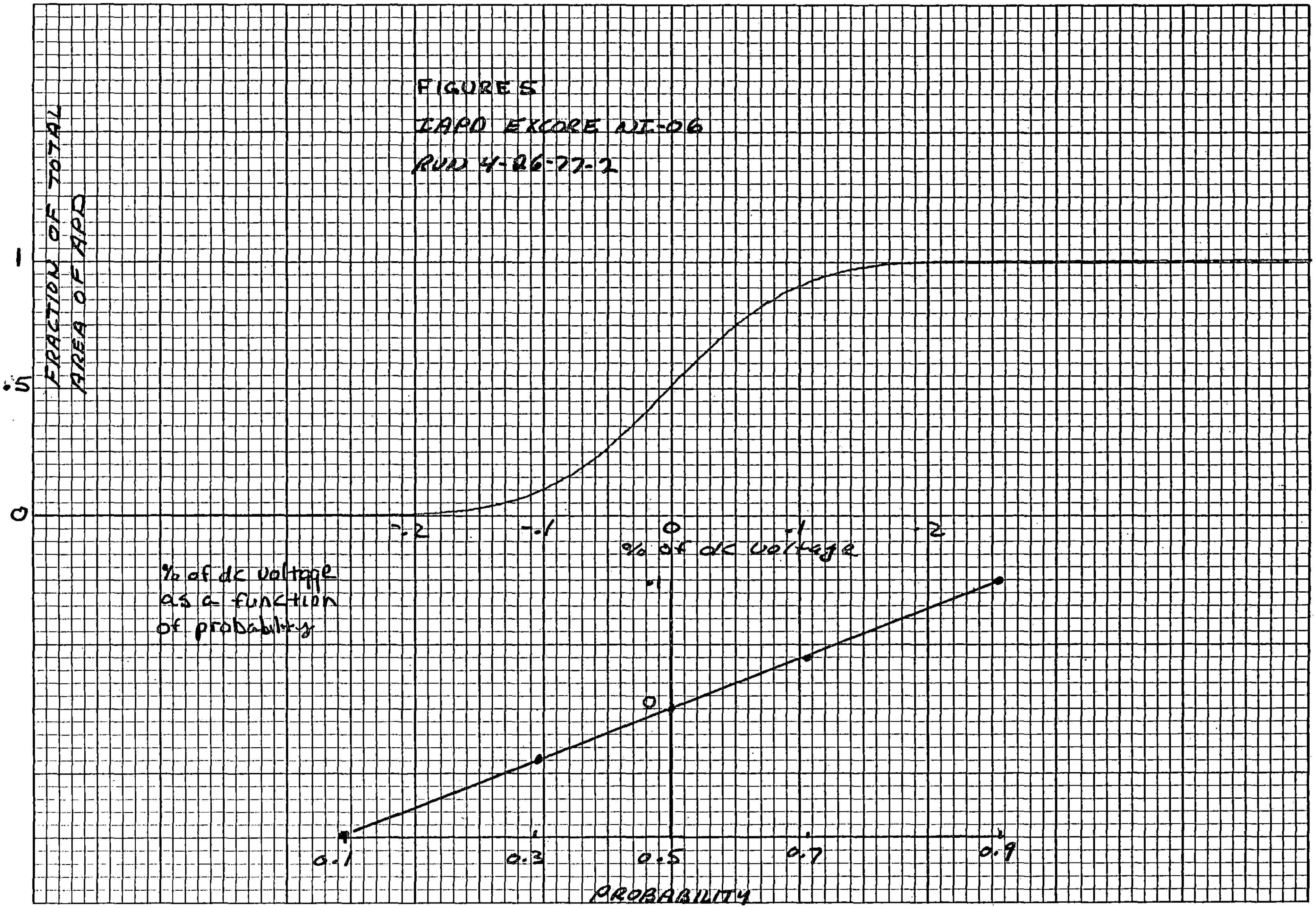

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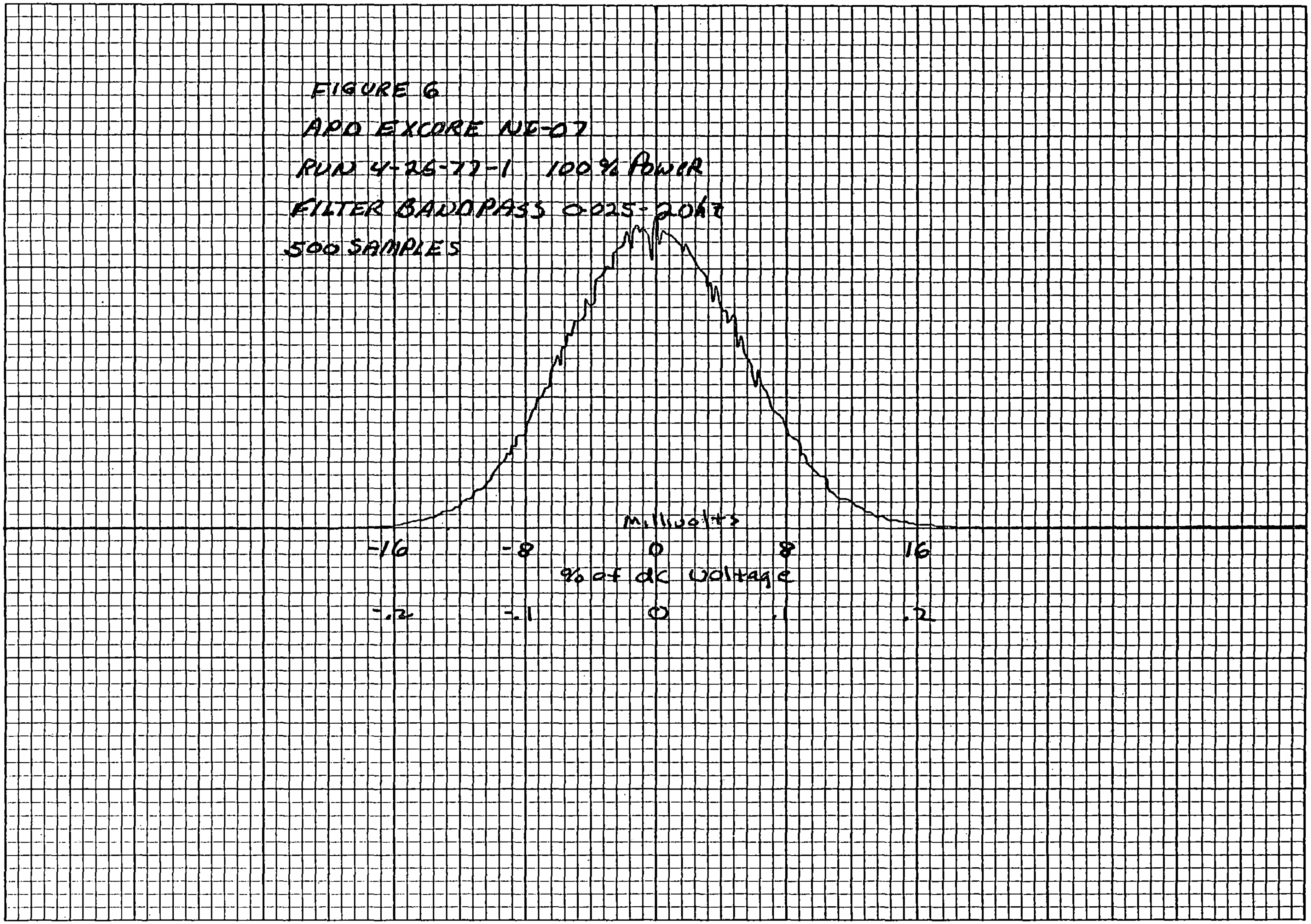

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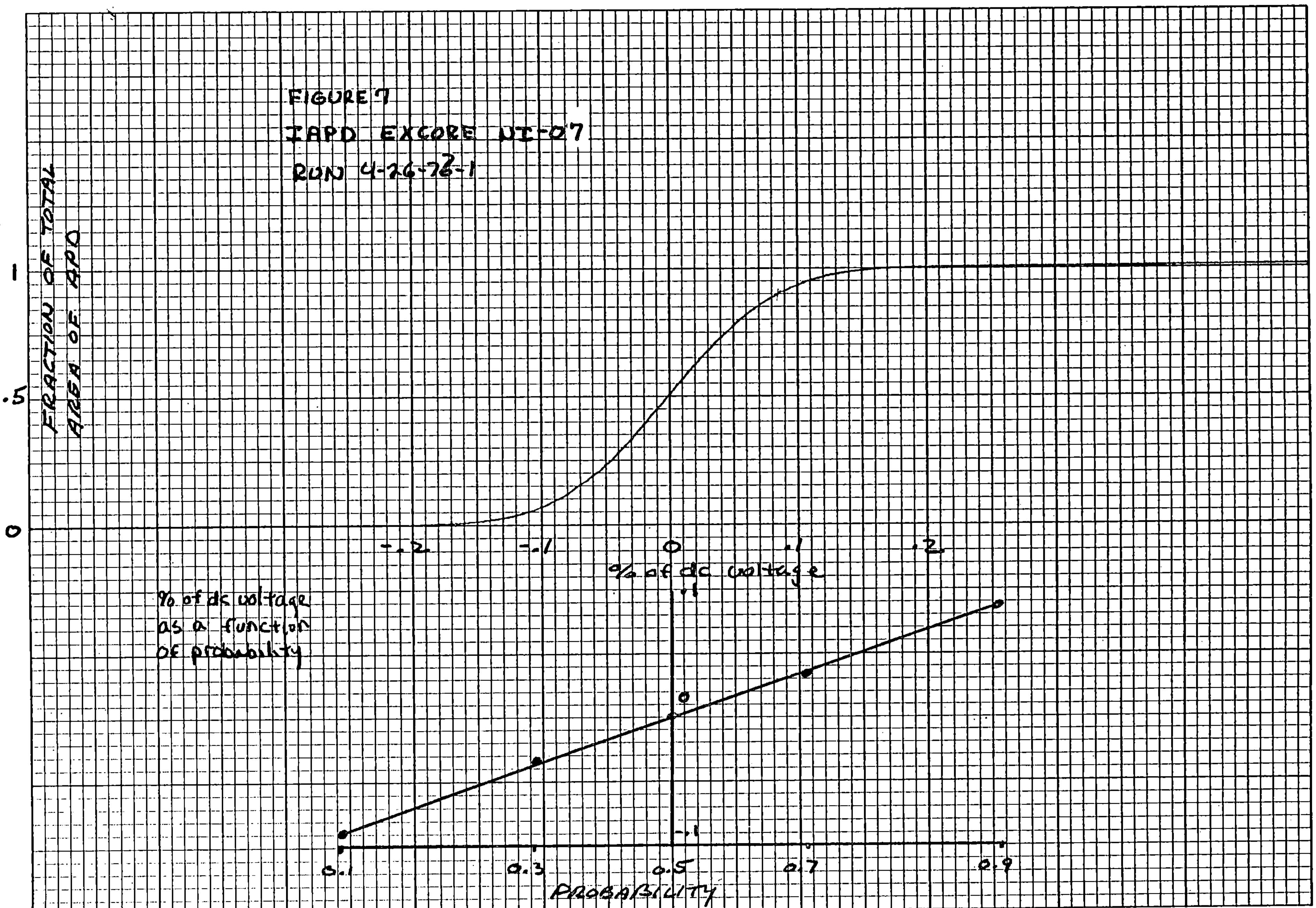

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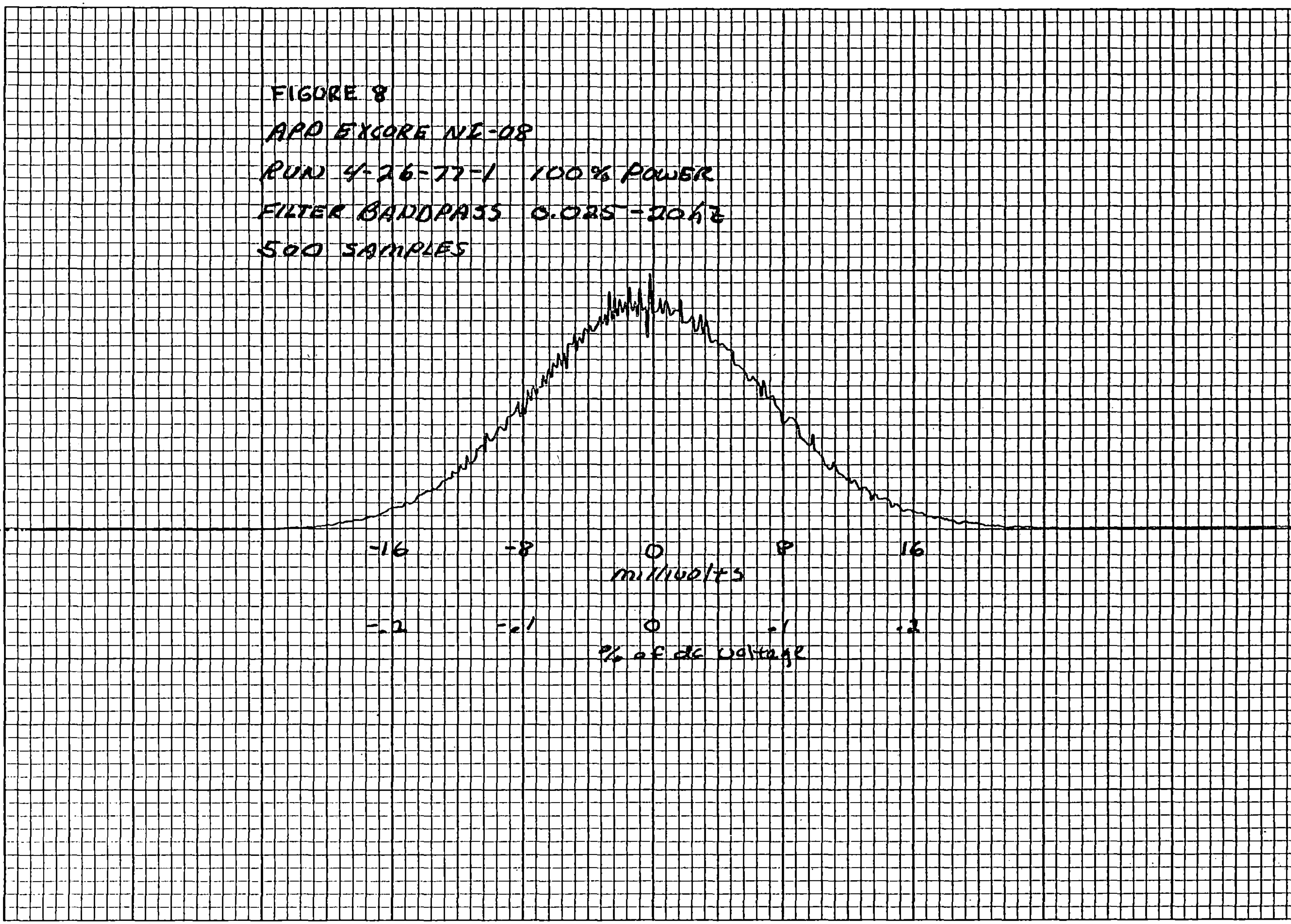

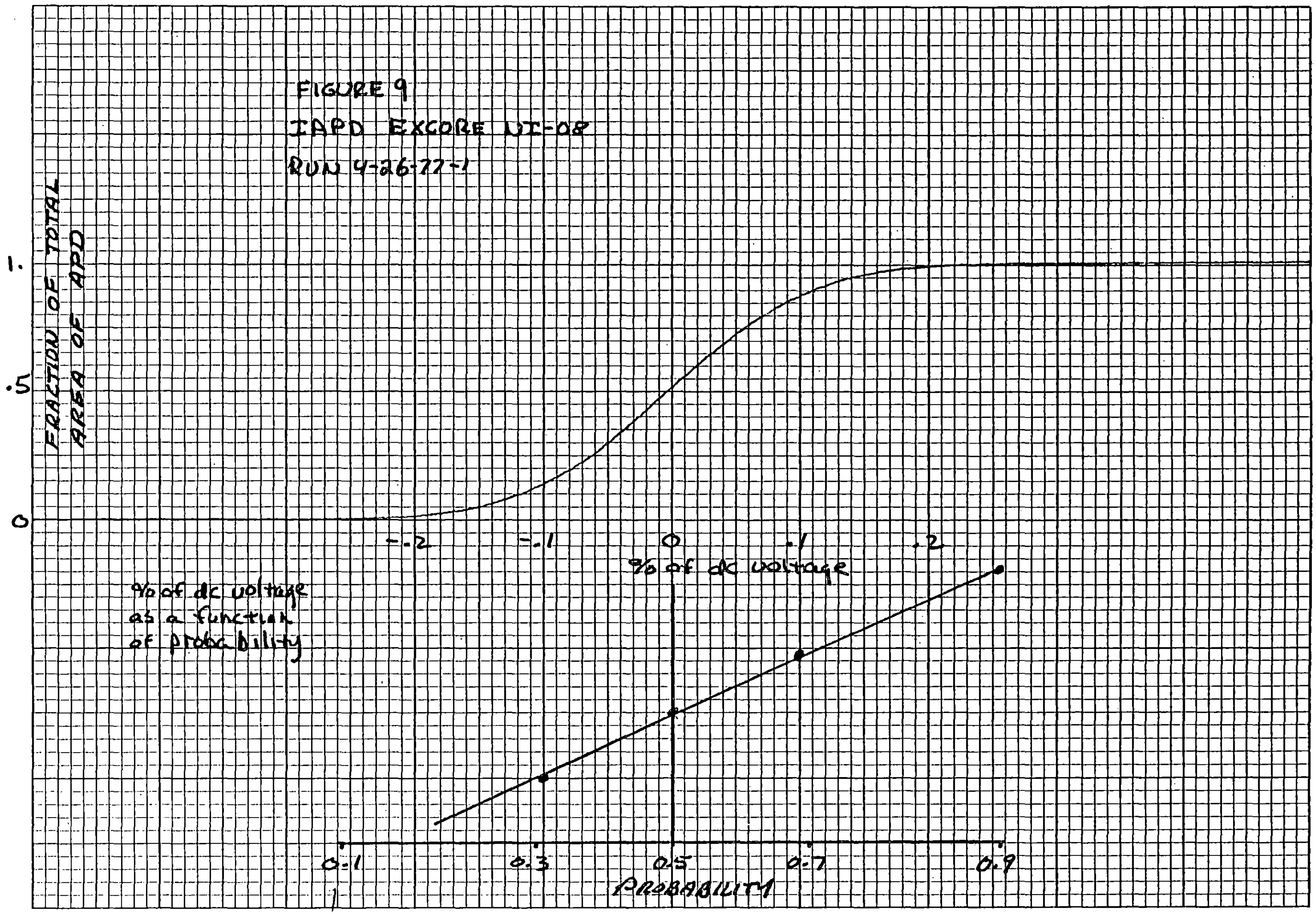
FIGURE 9
IAPD EXCORE UI-08
RUN 4-26-77-1
FRACTION OF TOTAL
AREA OF APD
1.
.5
0
-.2
-.1
0
.1
.2
% of dc voltage
% of dc voltage
as a function
of probability
0.1
0.3
0.5
0.7
0.9
PROBABILITY

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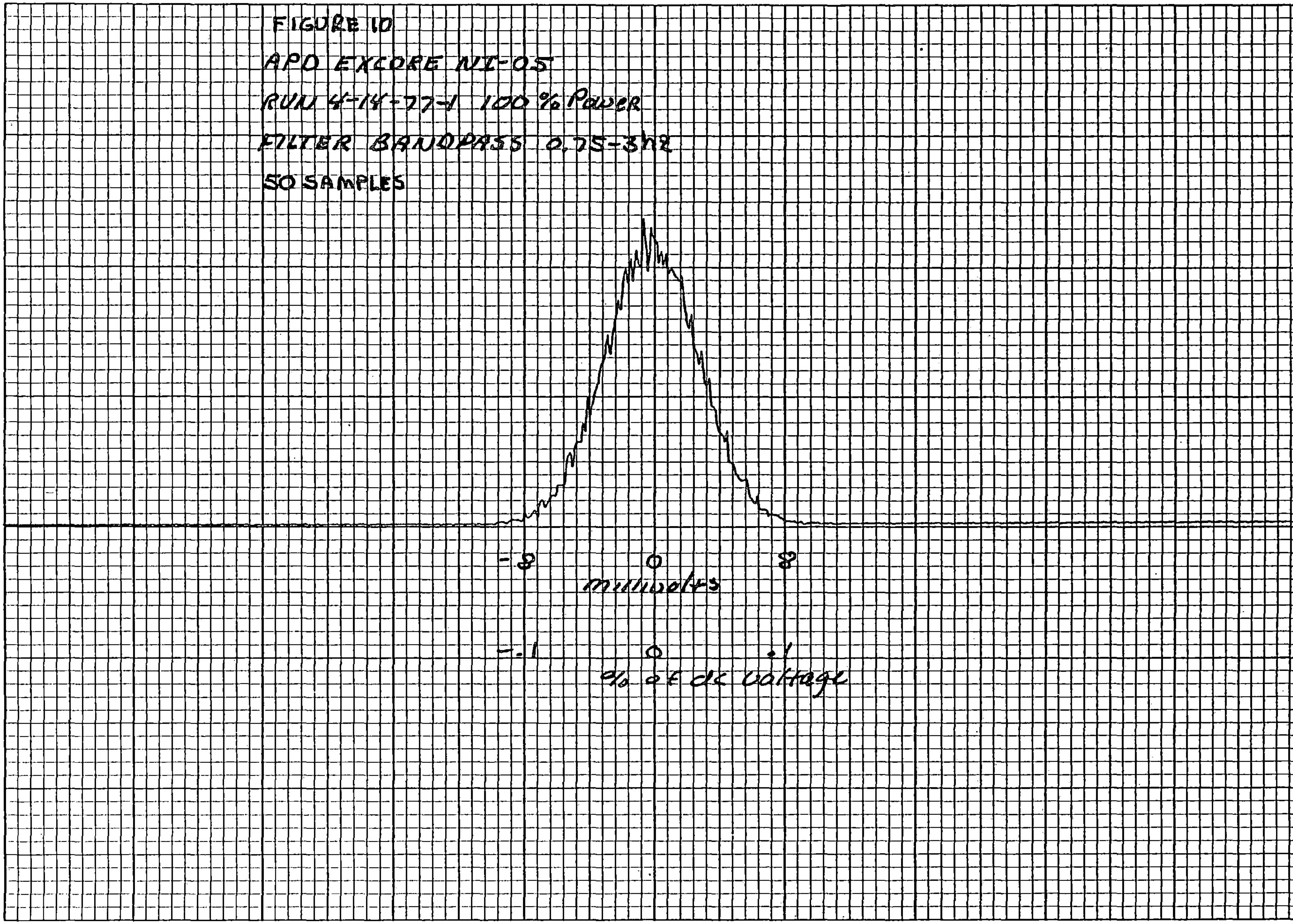

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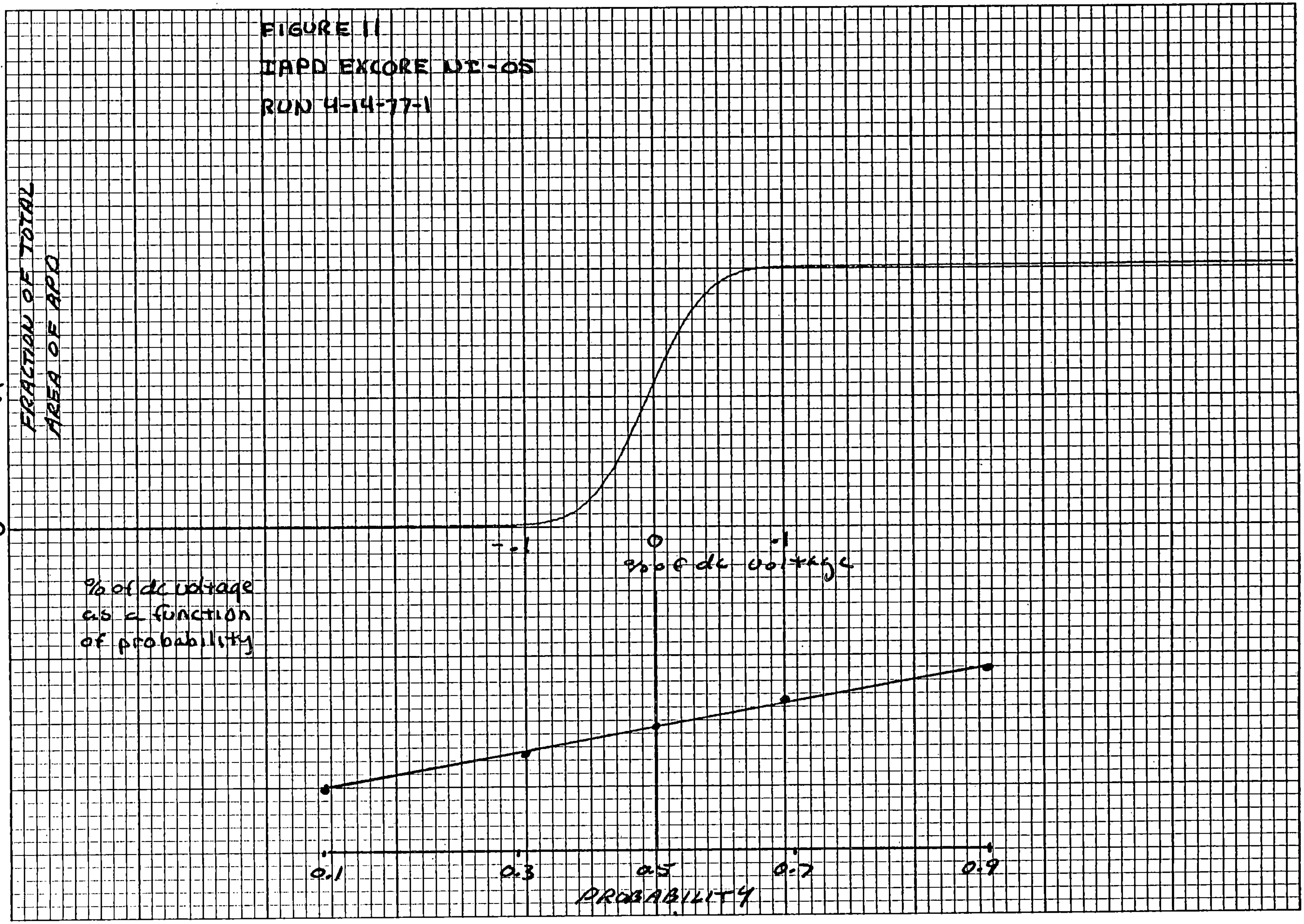

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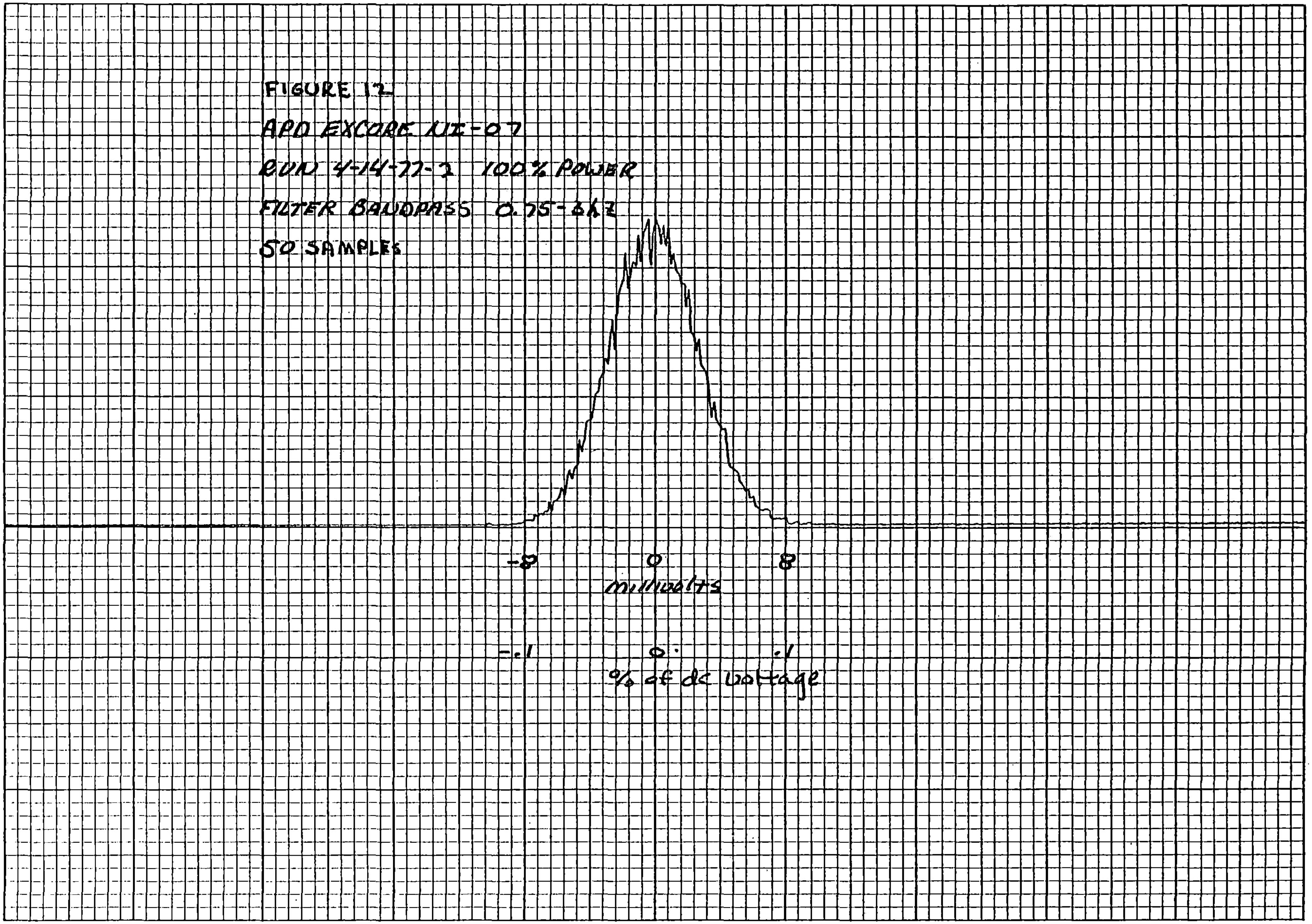

FIGURE 12
APD EXCORE NI-07
RUN 4-14-77-2 100% POWER
FILTER BANDPASS 0.75-6Hz
50 SAMPLES

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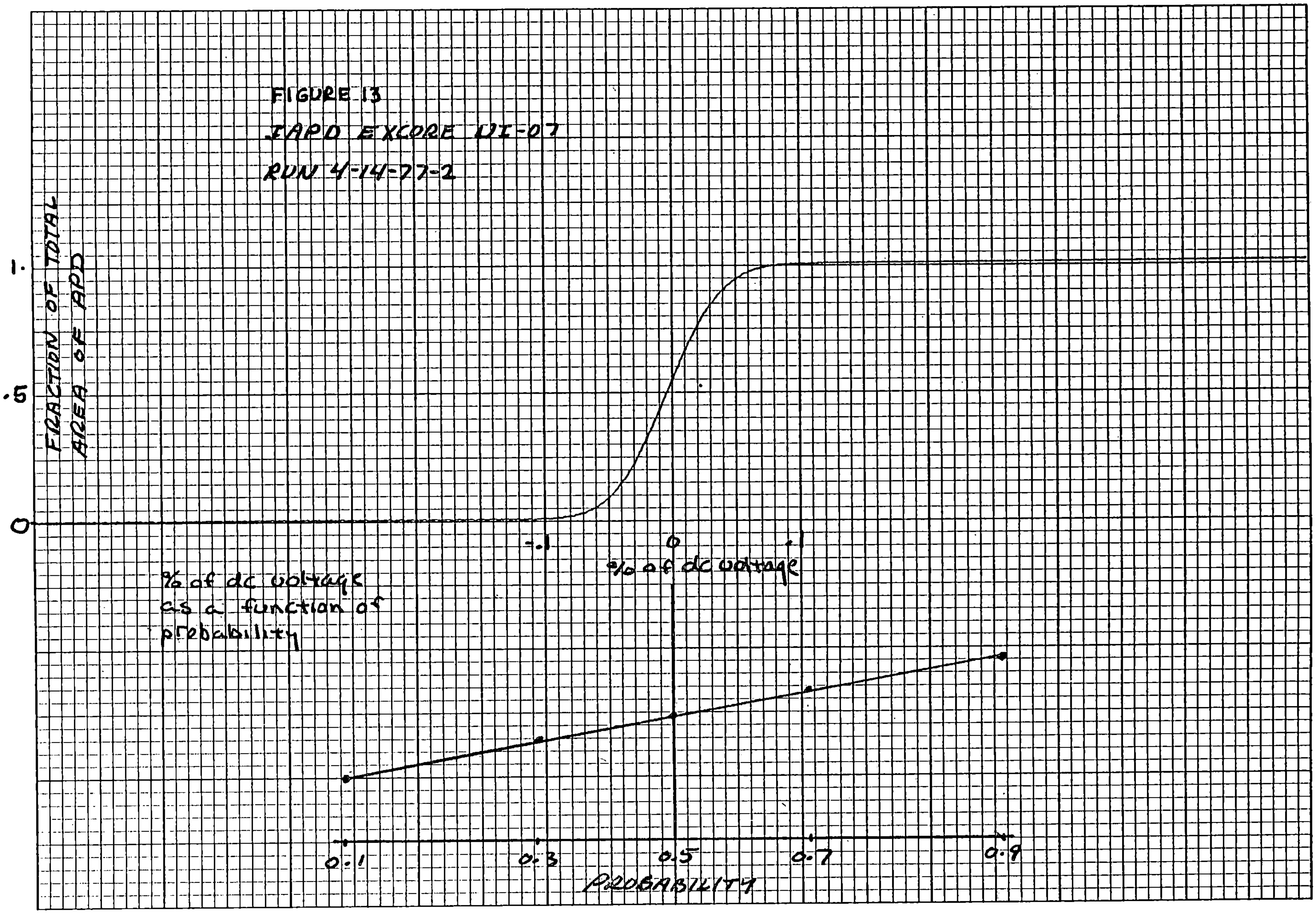

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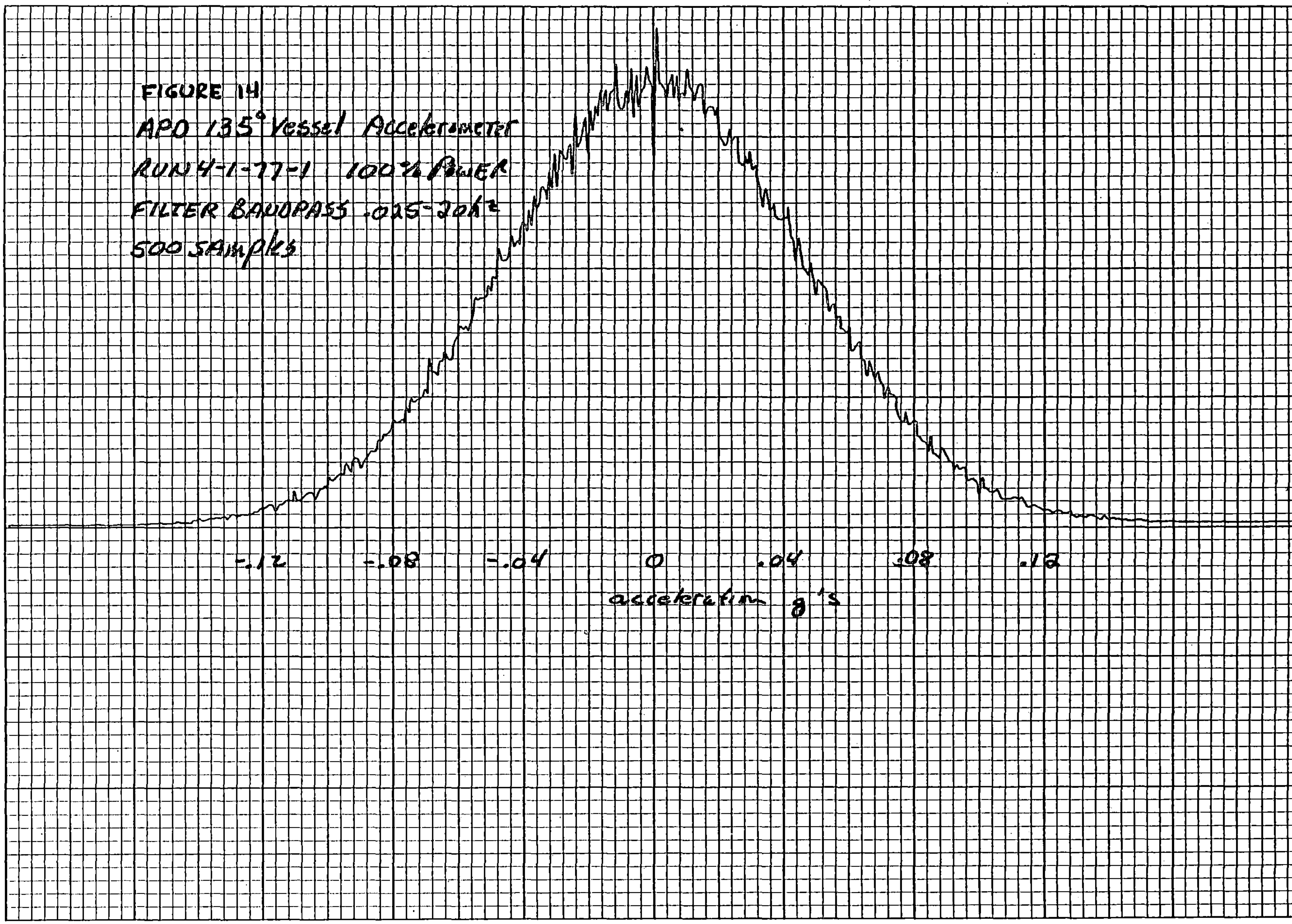

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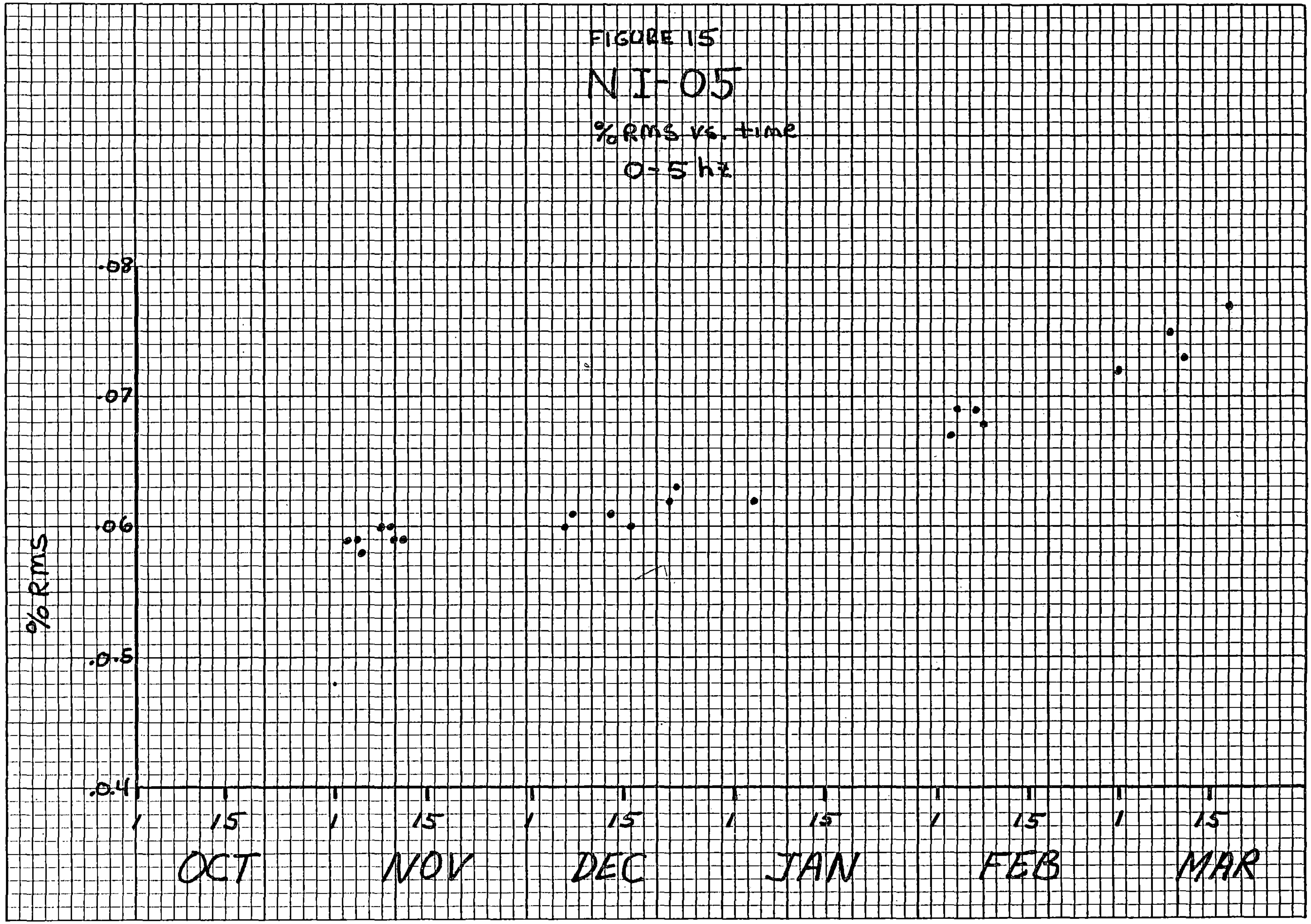

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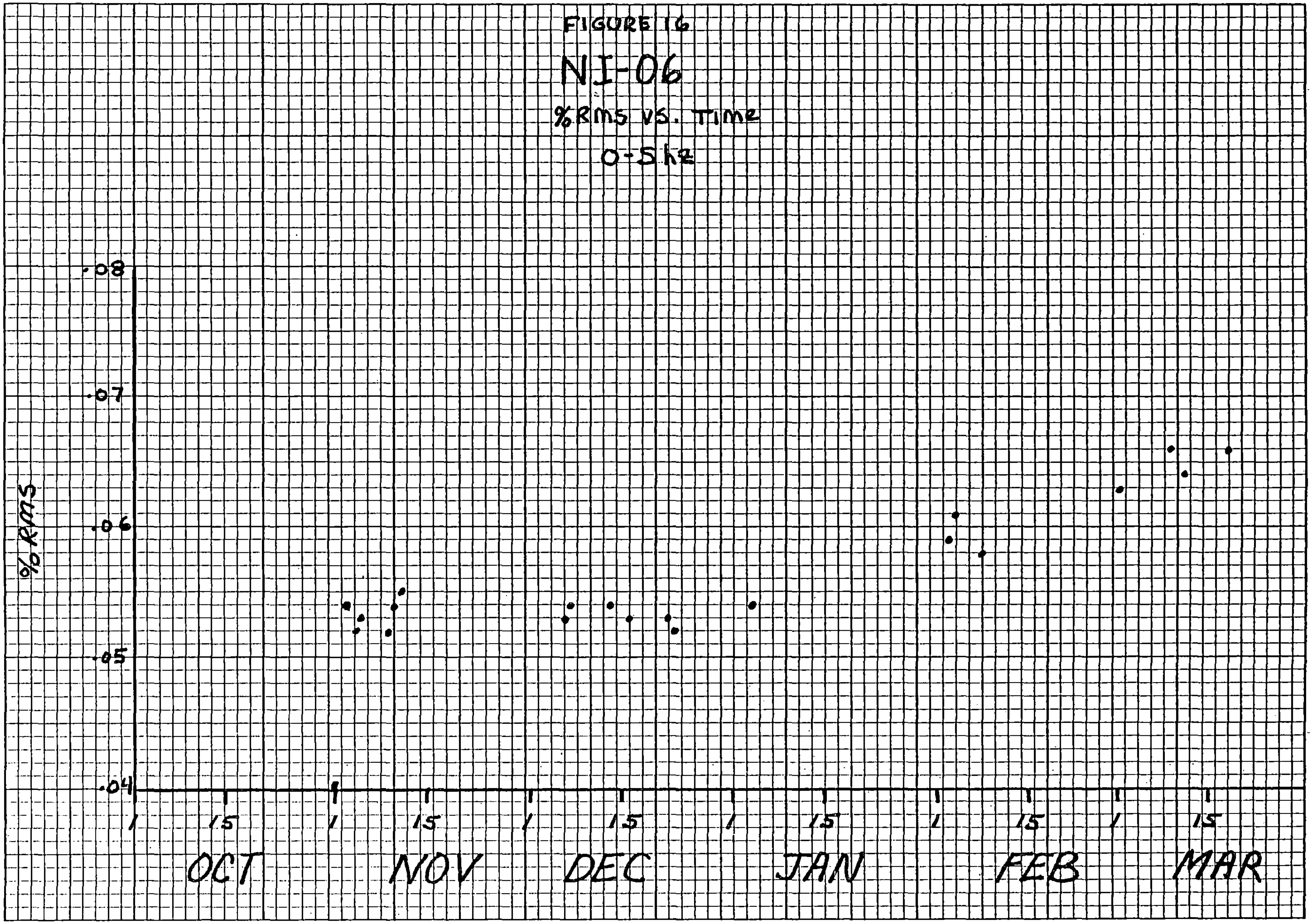

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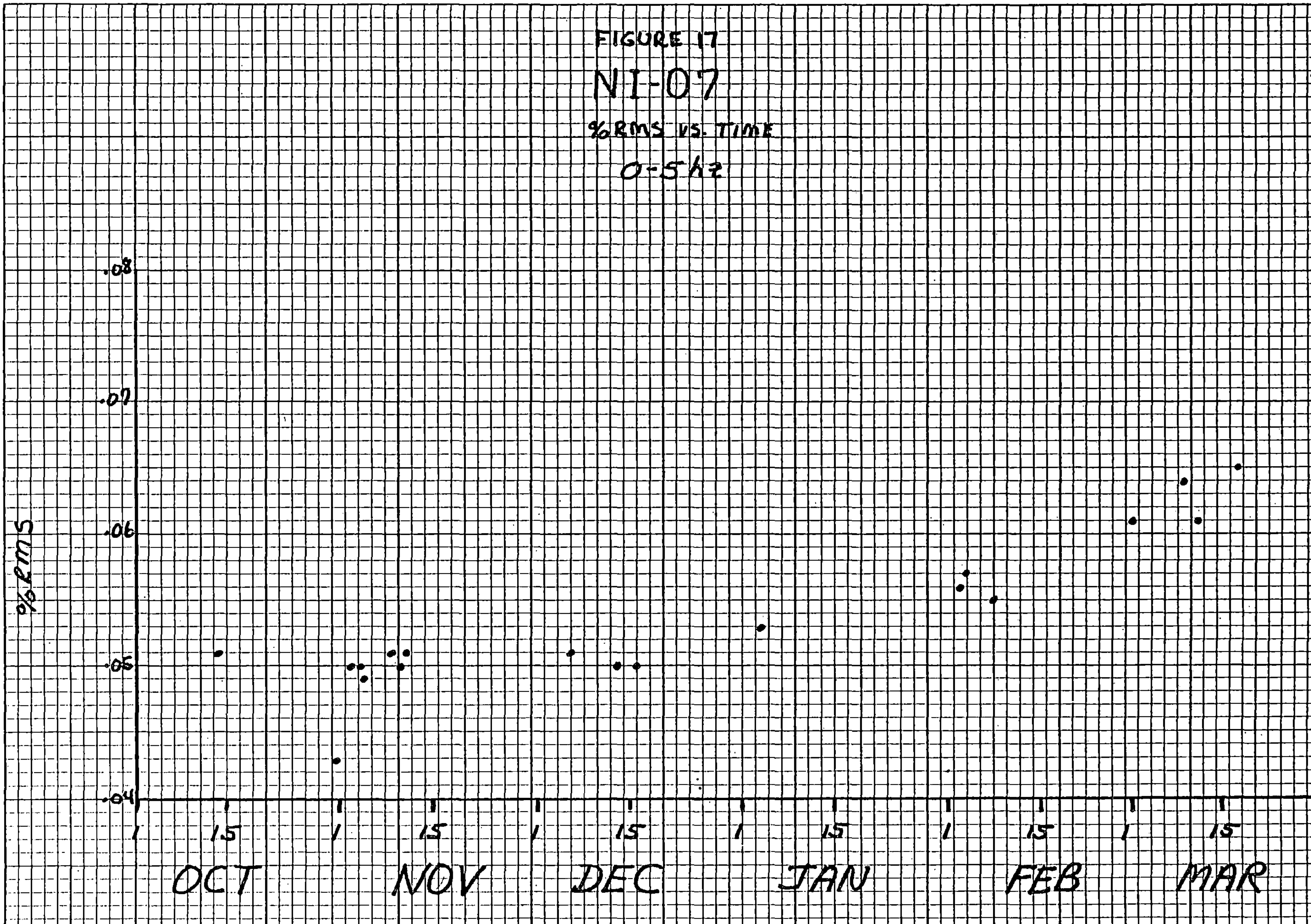

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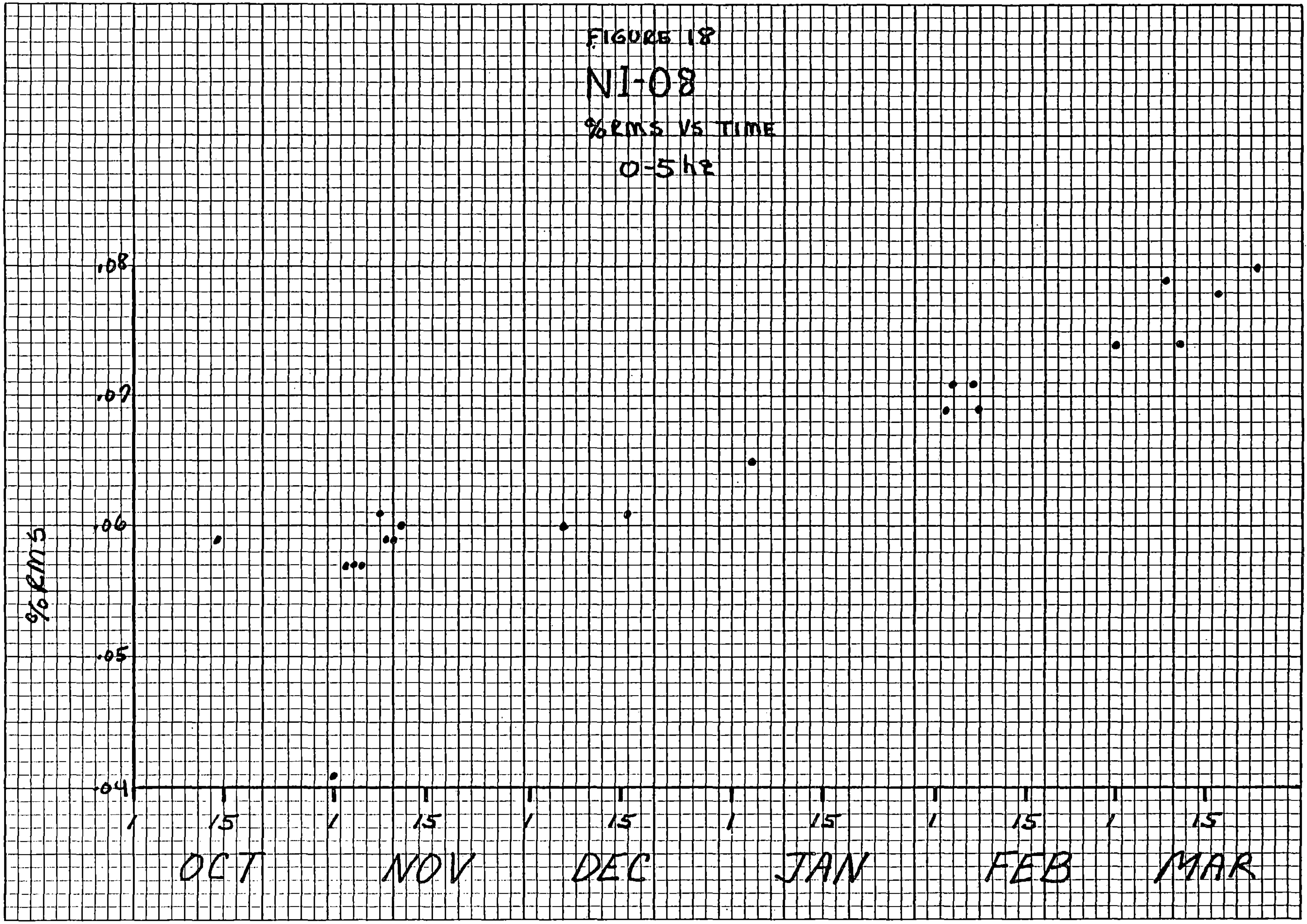

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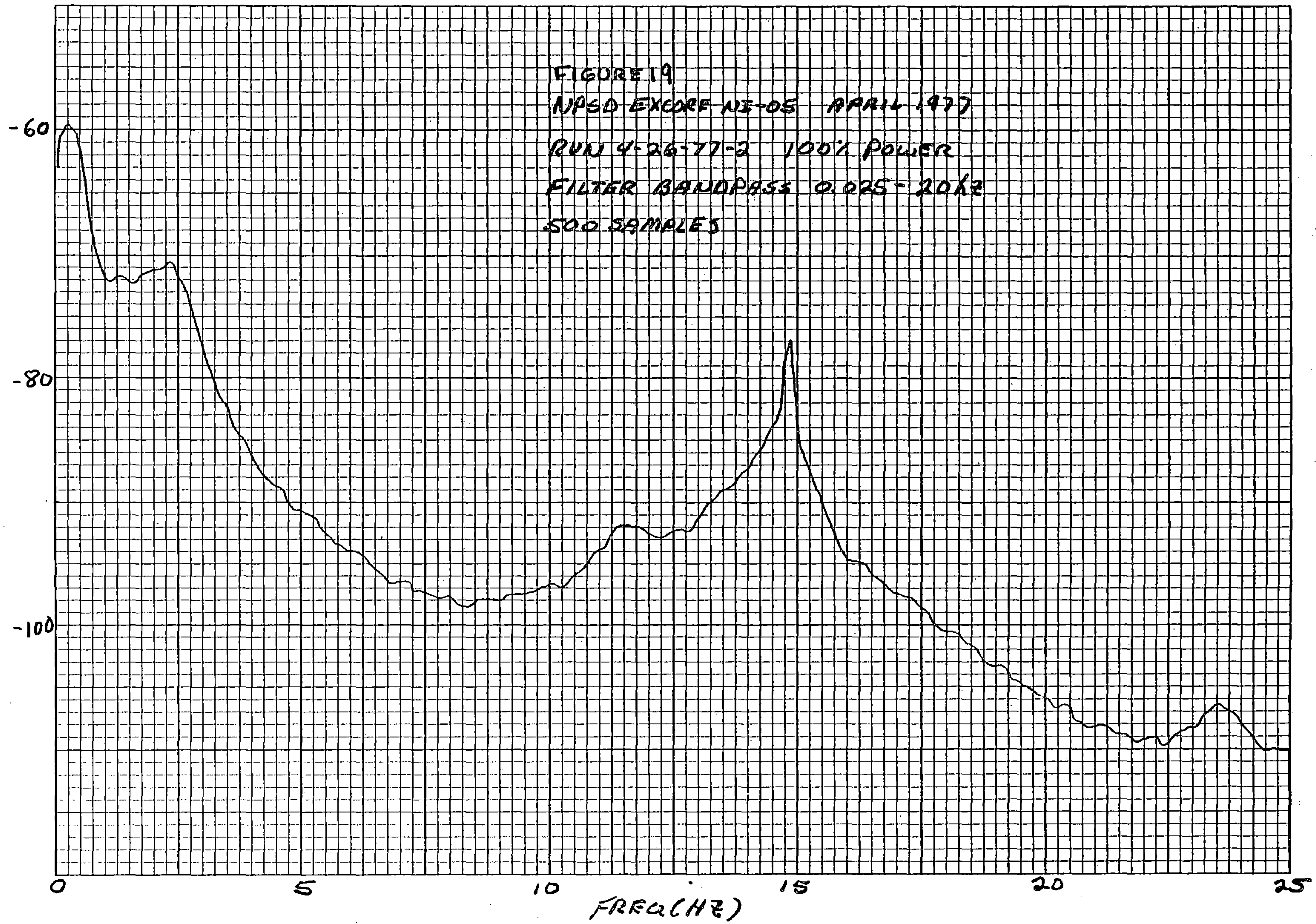

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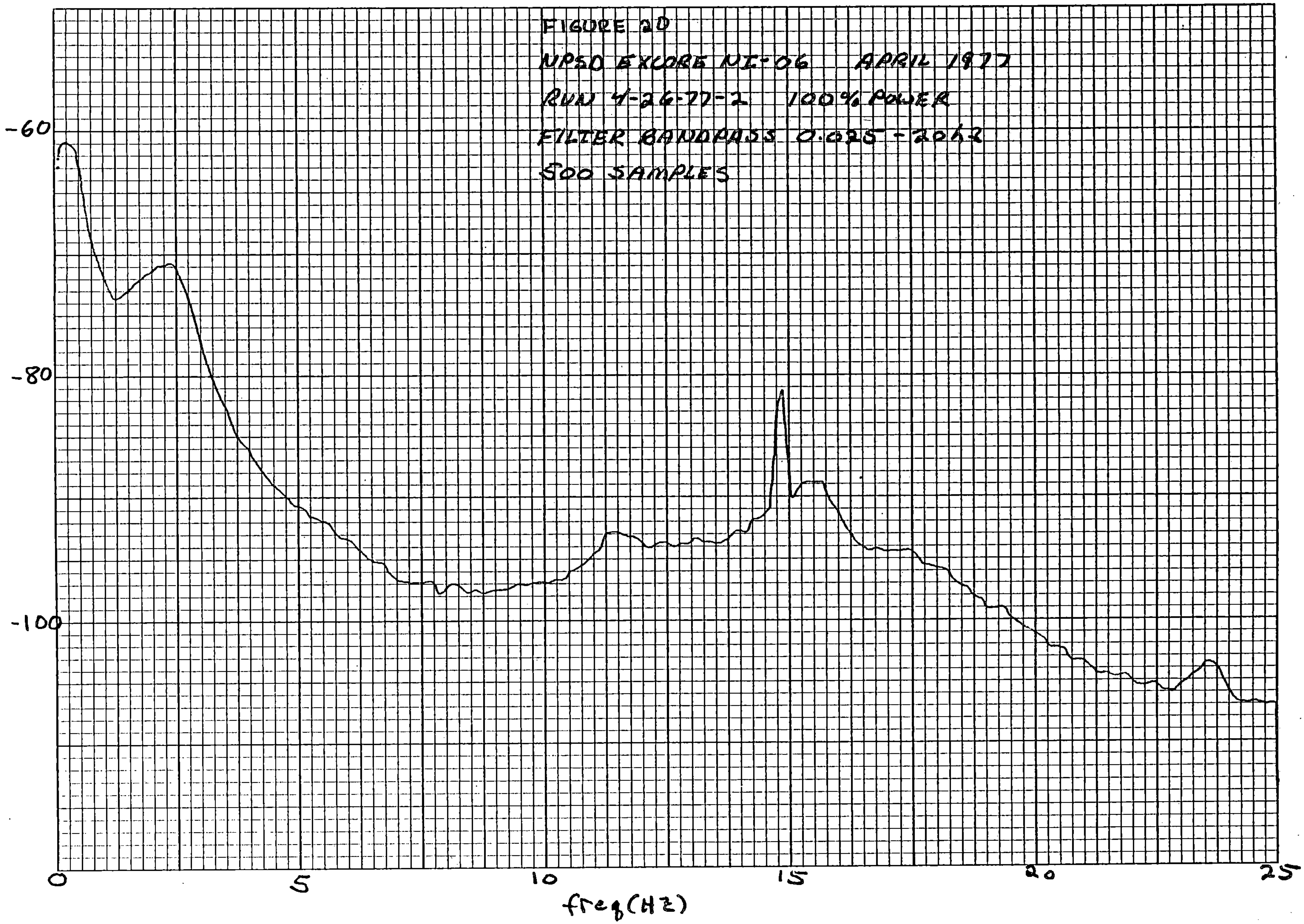

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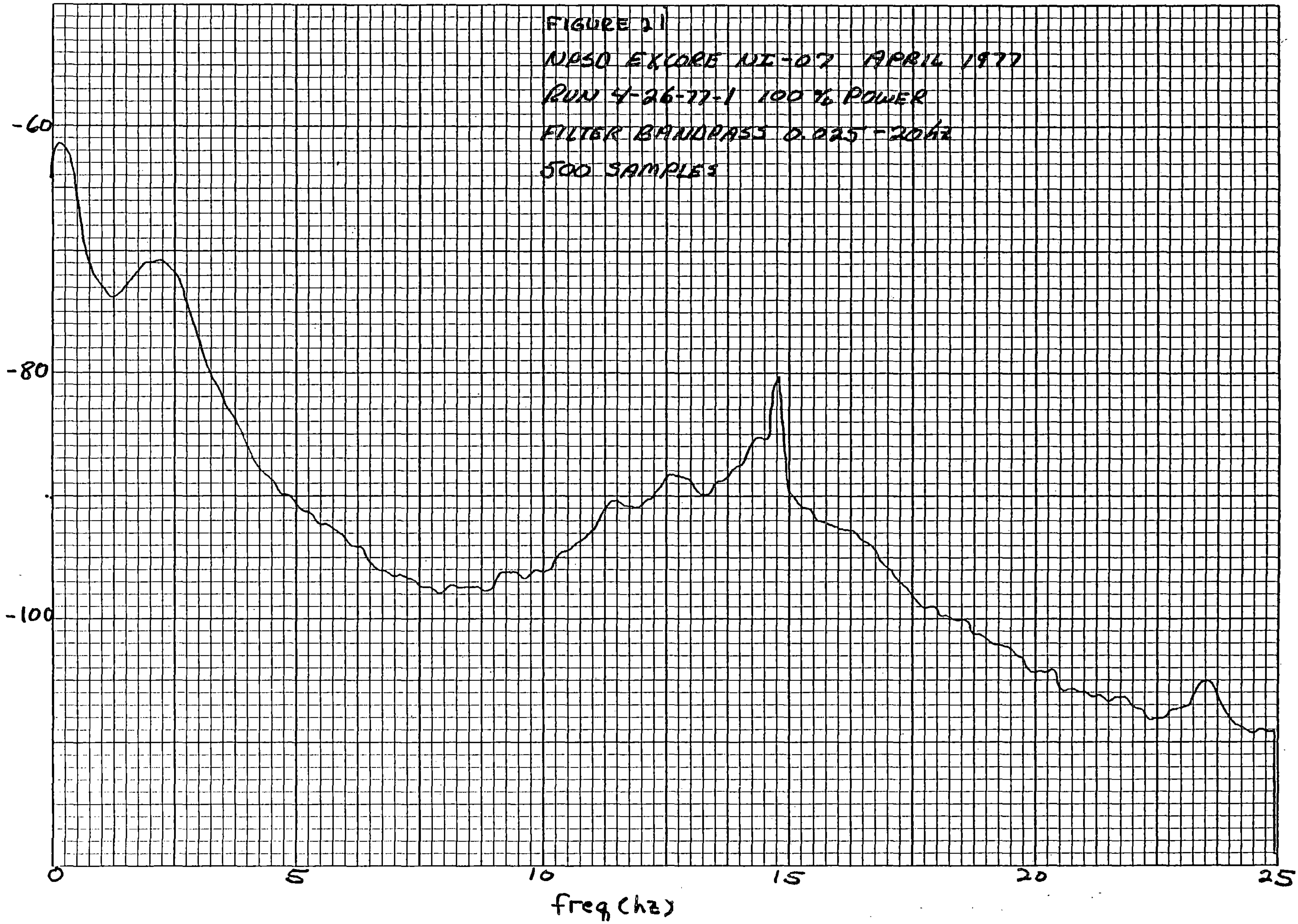

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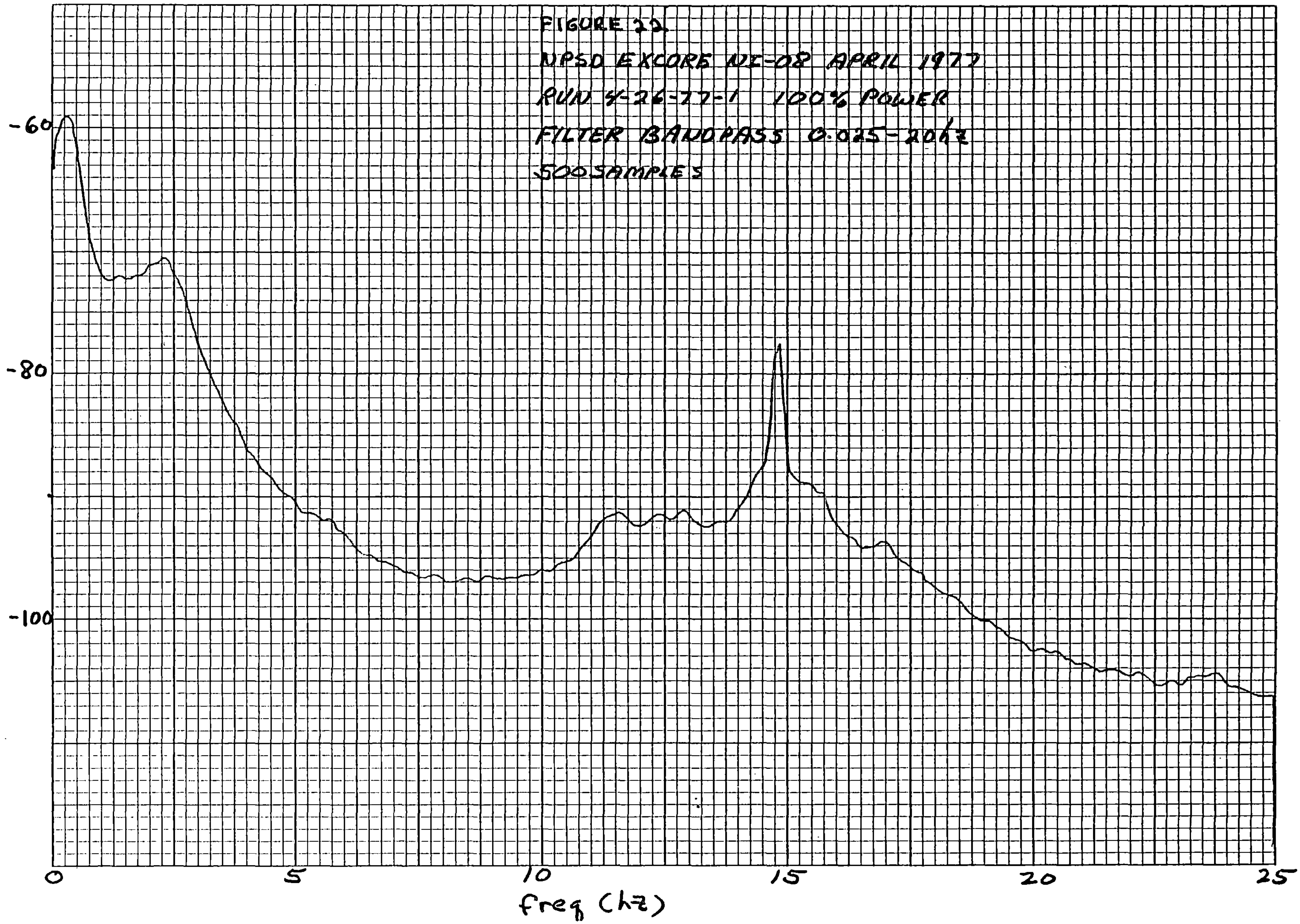

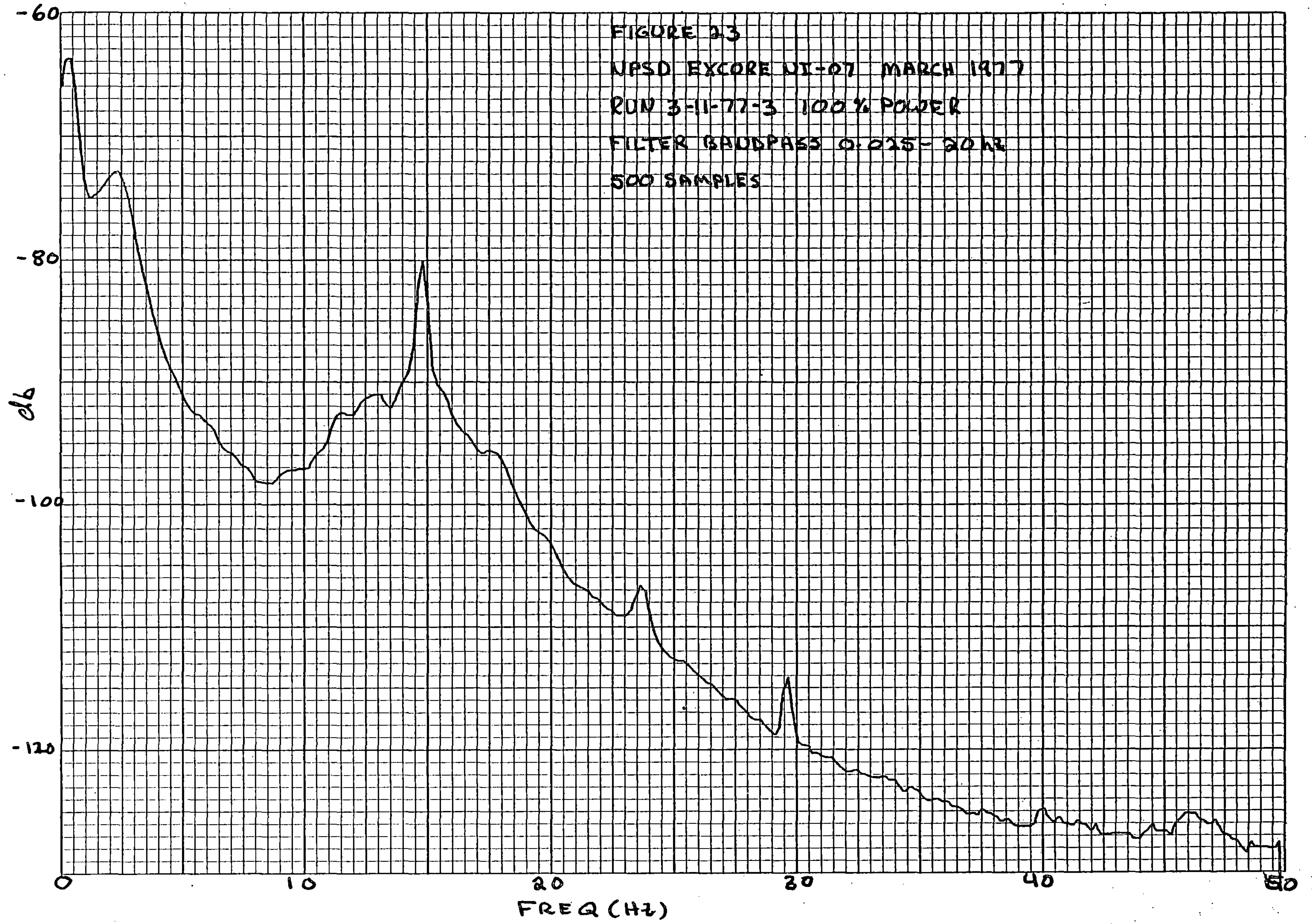
FIGURE 23
NPSD EXCORE NI-07 MARCH 1977
RUN 3-11-77-3 100% POWER
FILTER BANDPASS 0.025 - 20 hz
500 SAMPLES
-60
-80
-100
-120
db
0
10
20
30
40
50
FREQ (Hz)

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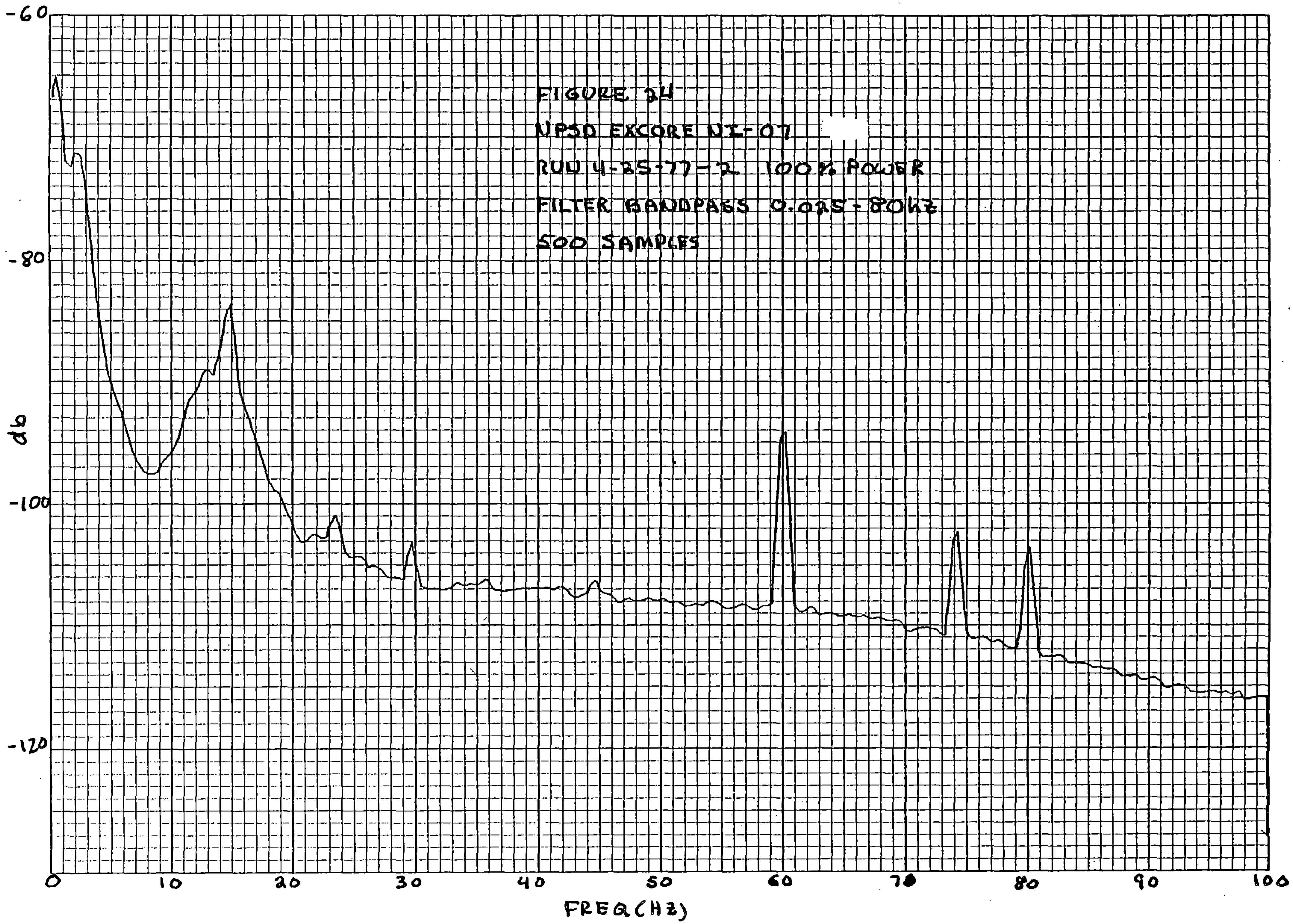

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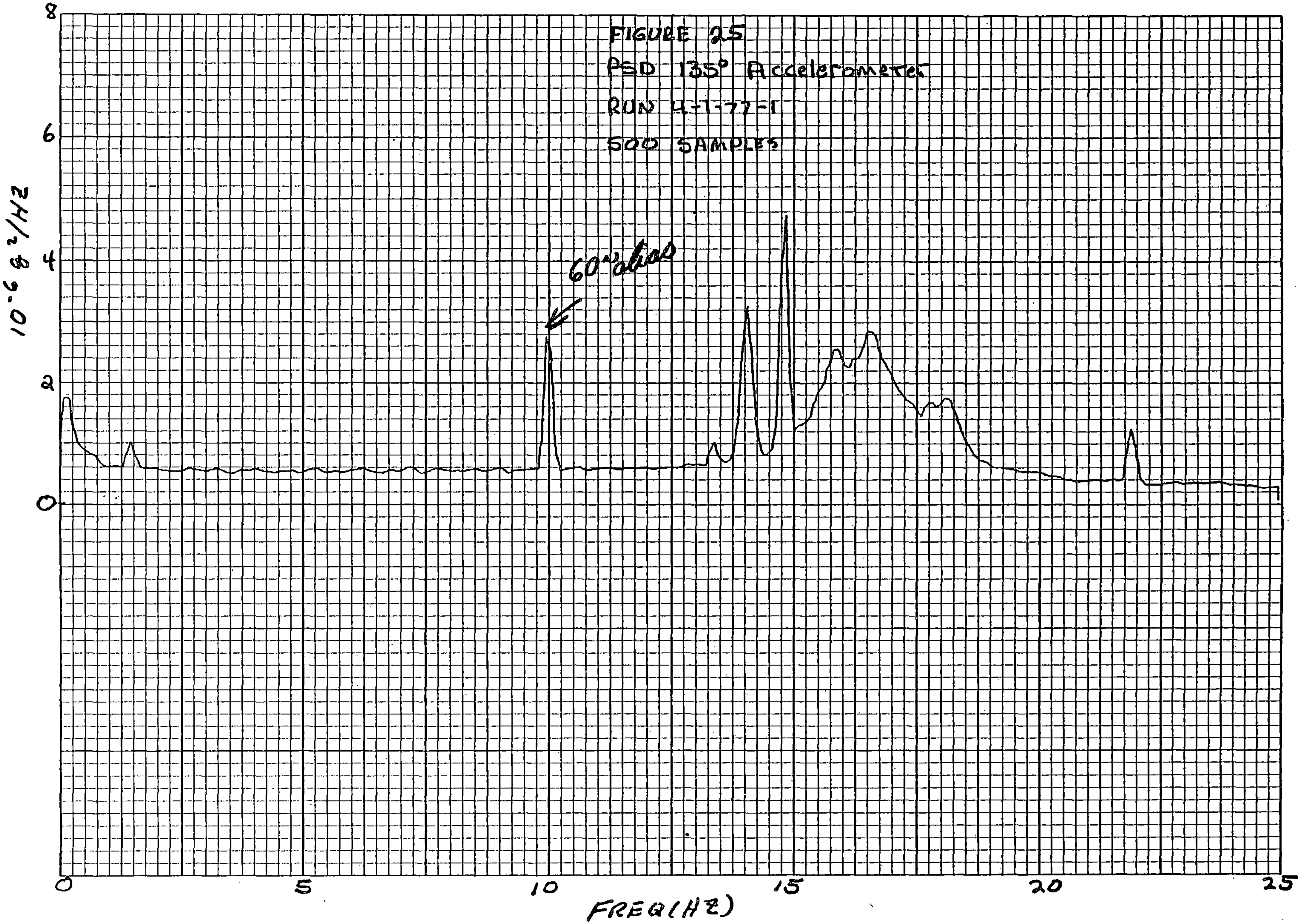

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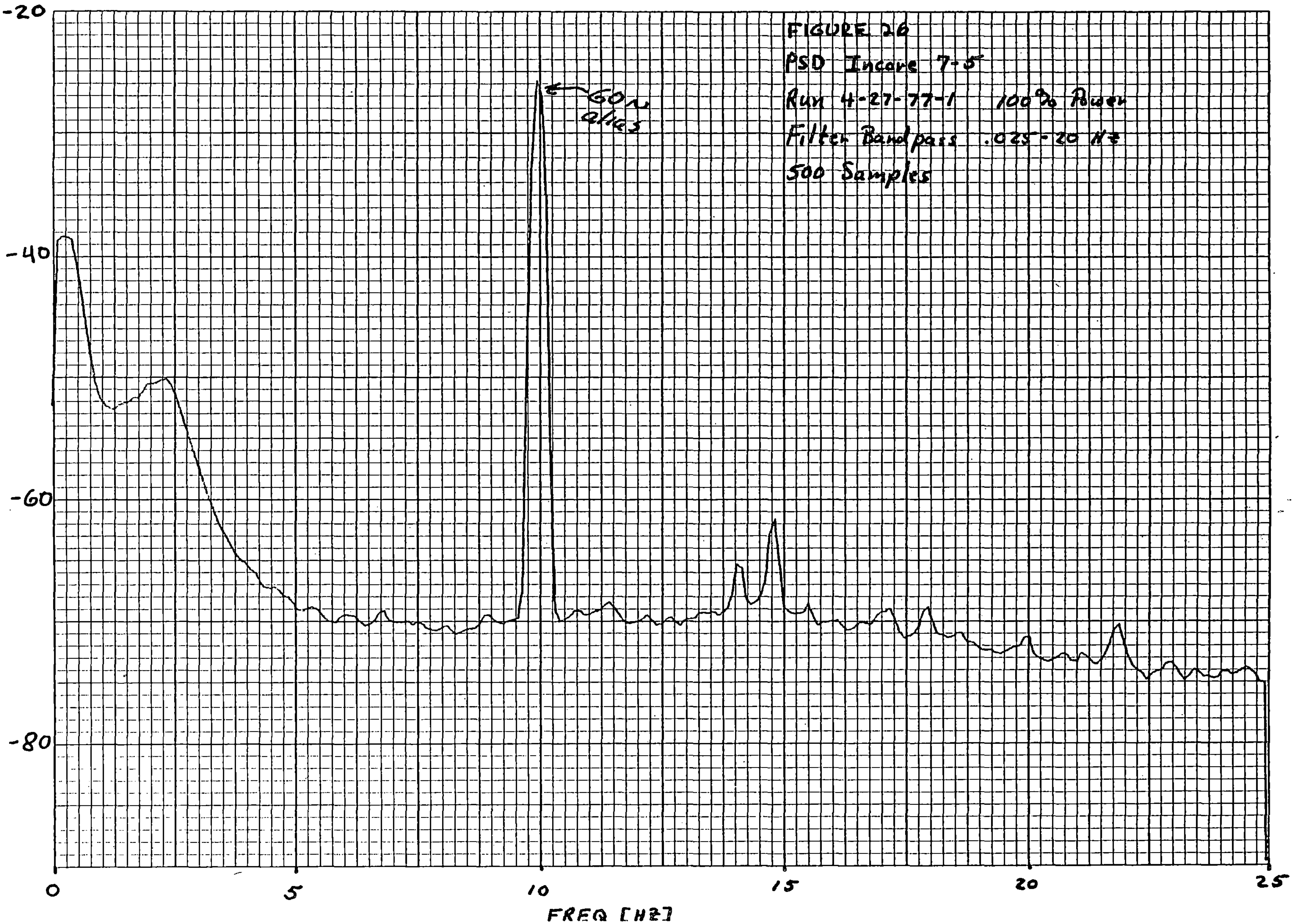

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

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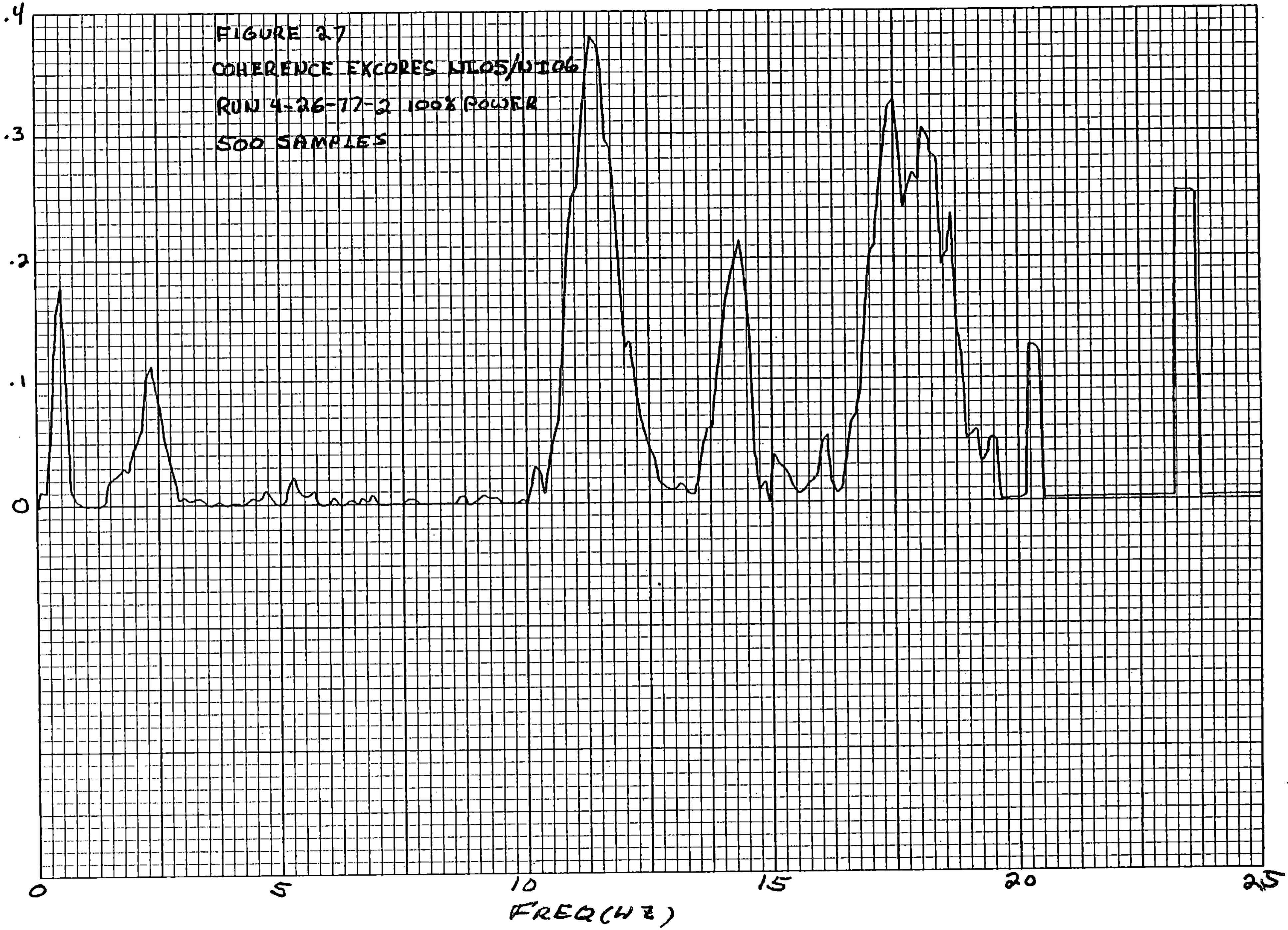

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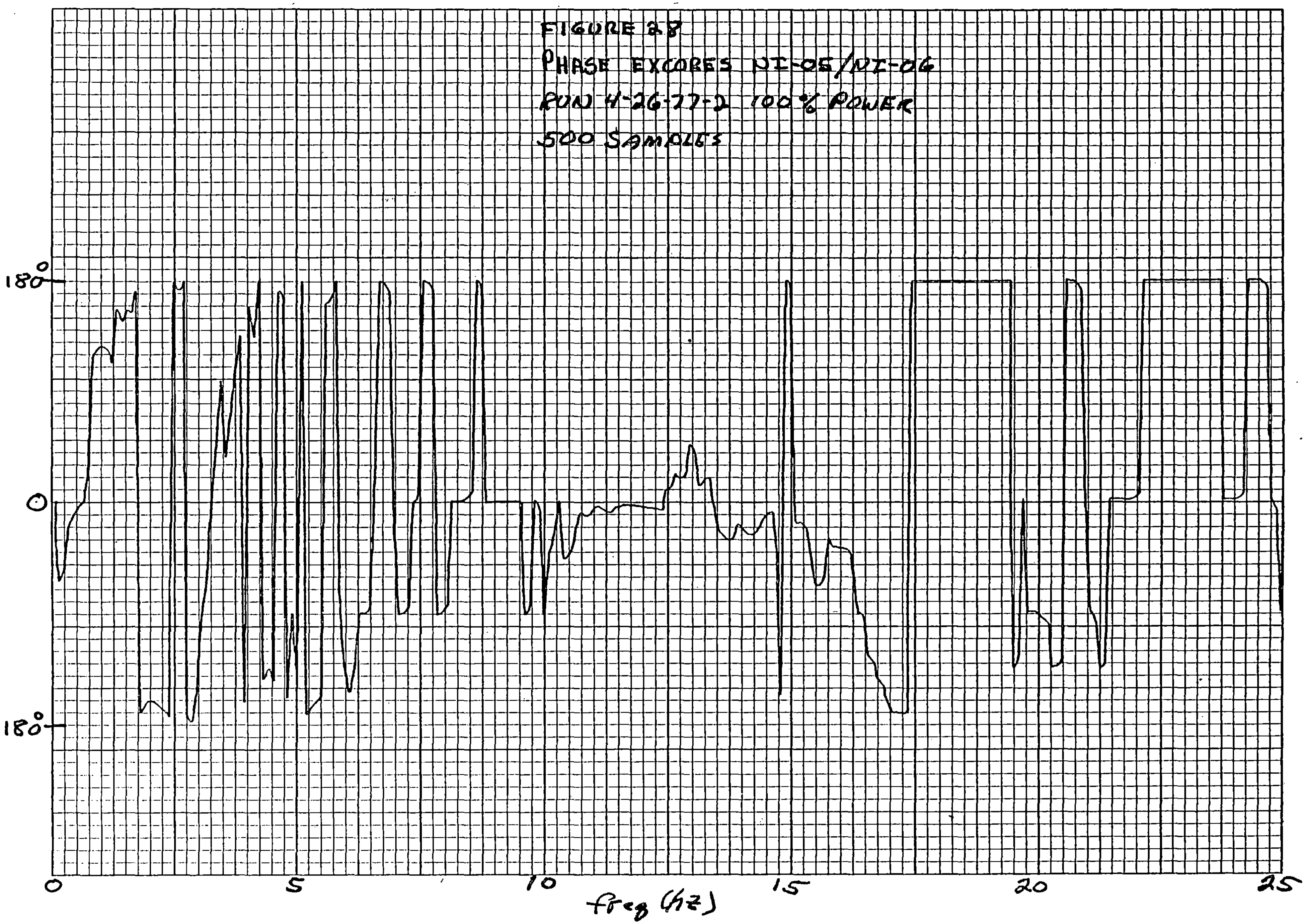

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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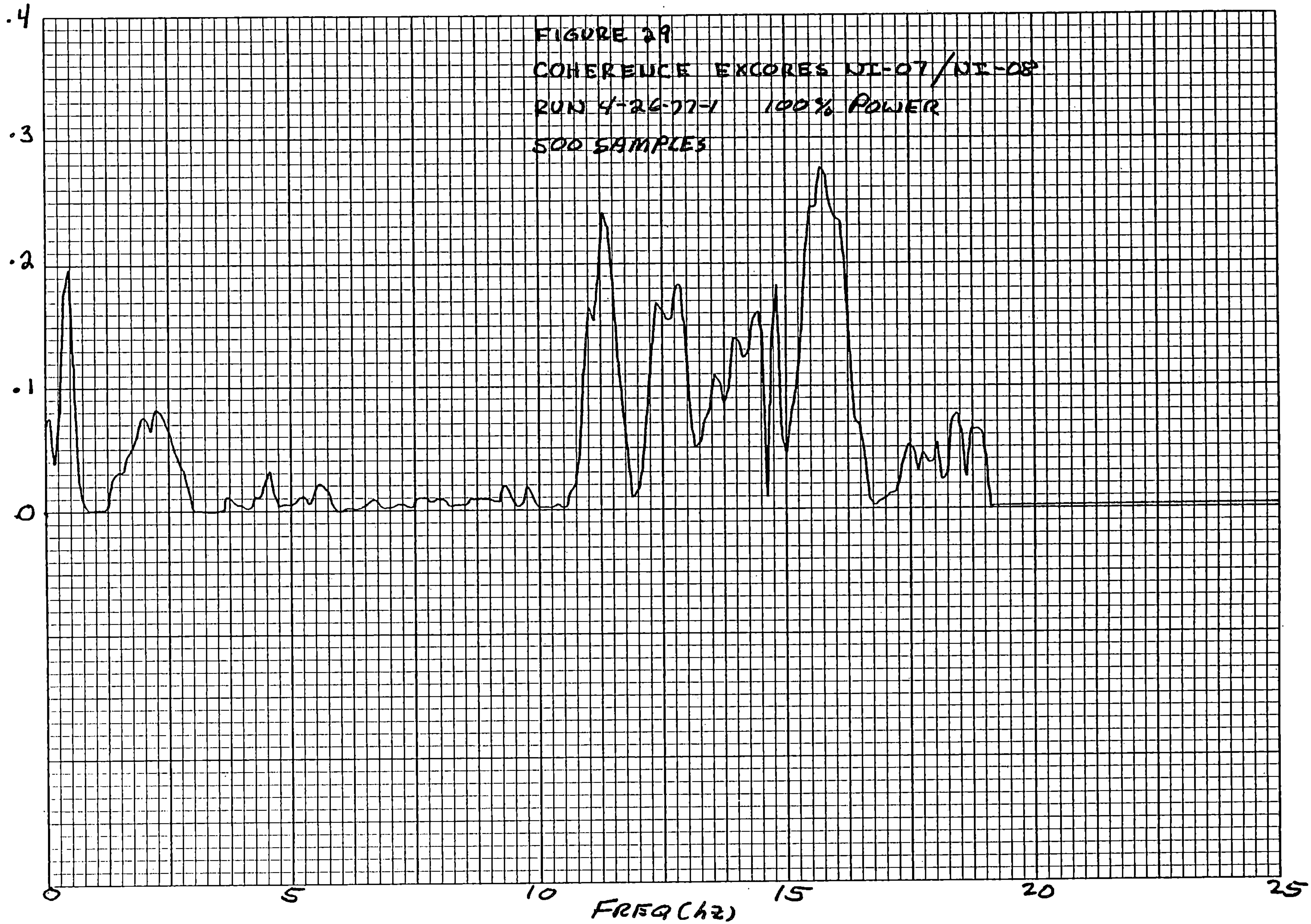

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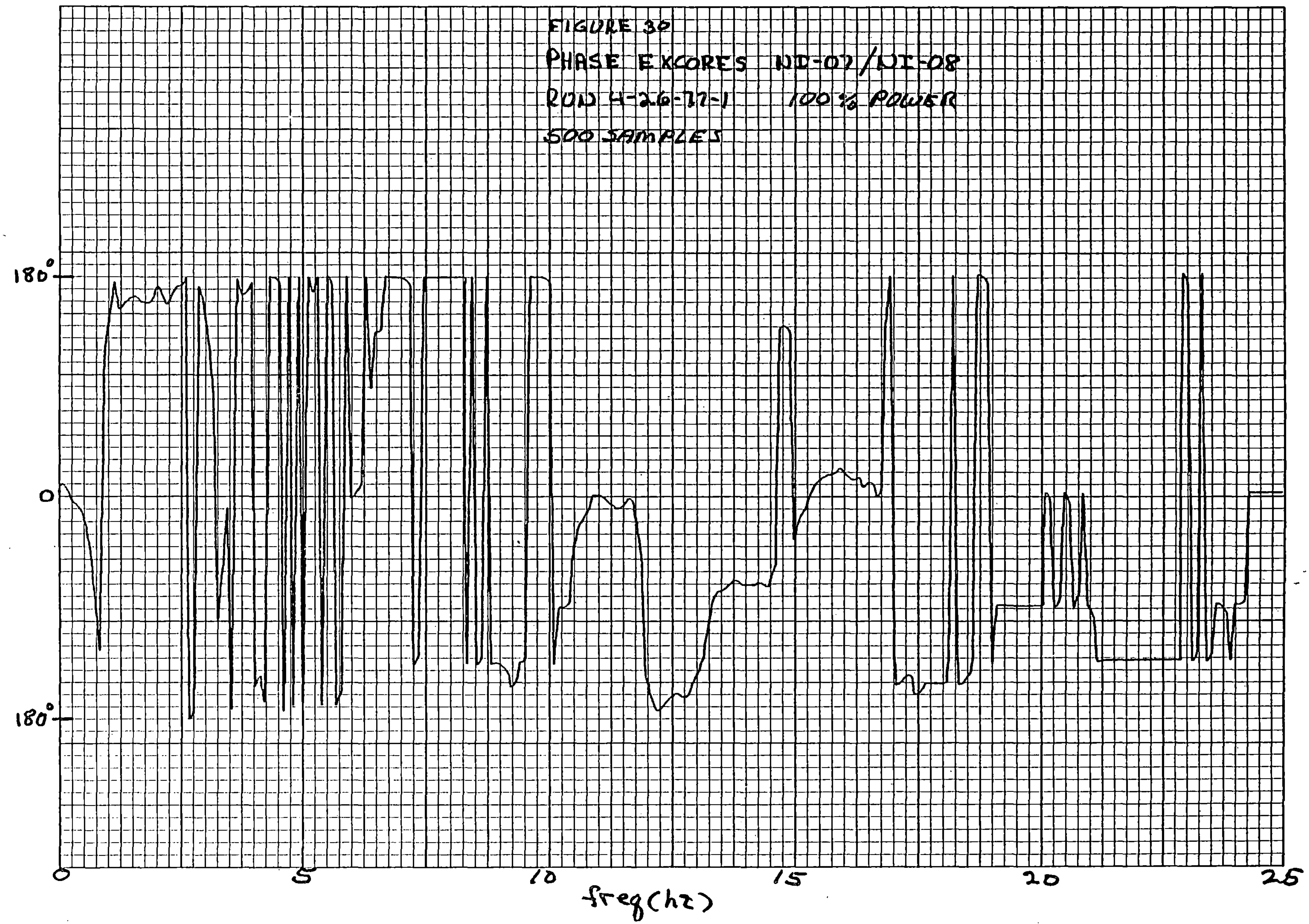

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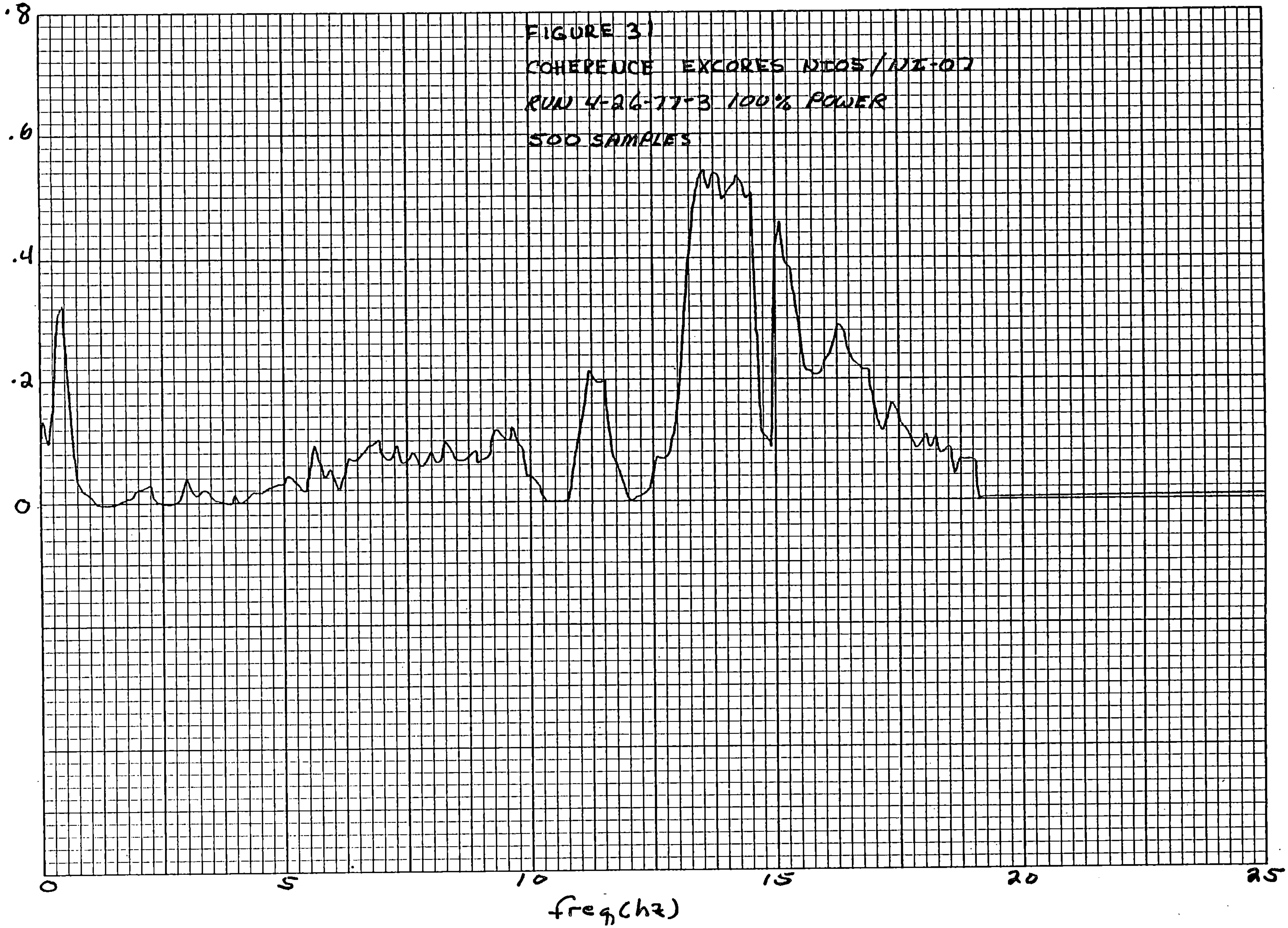

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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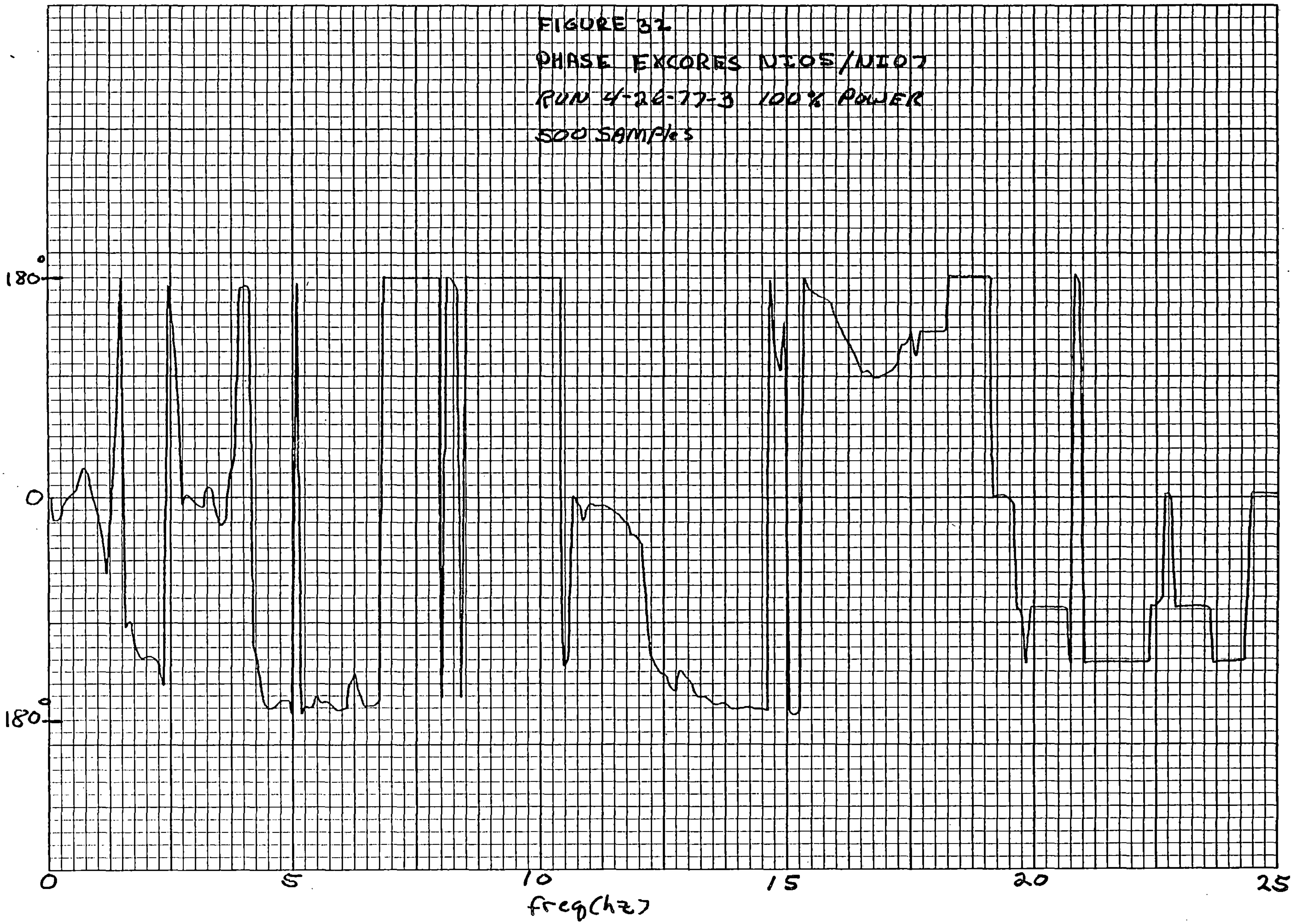

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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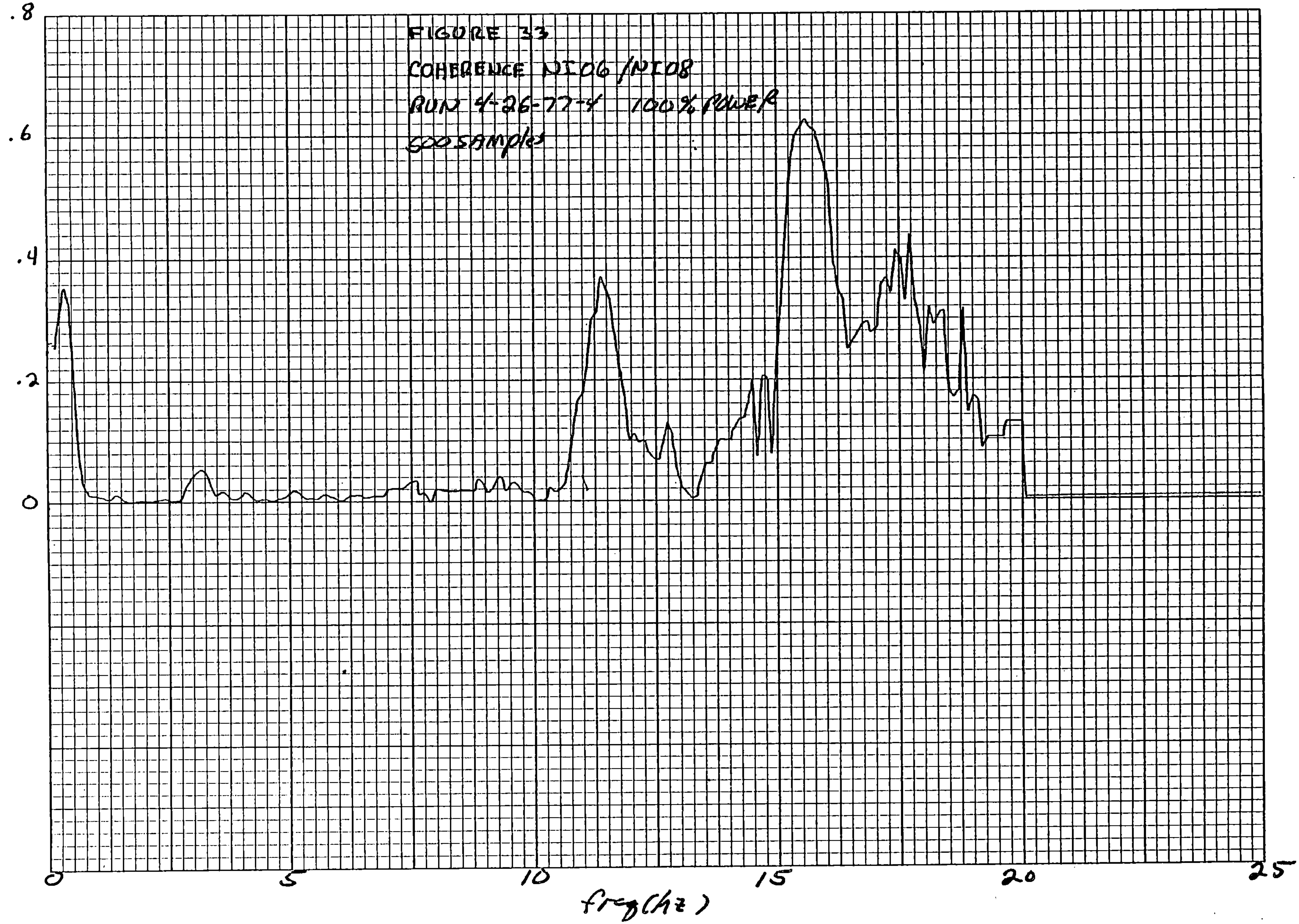

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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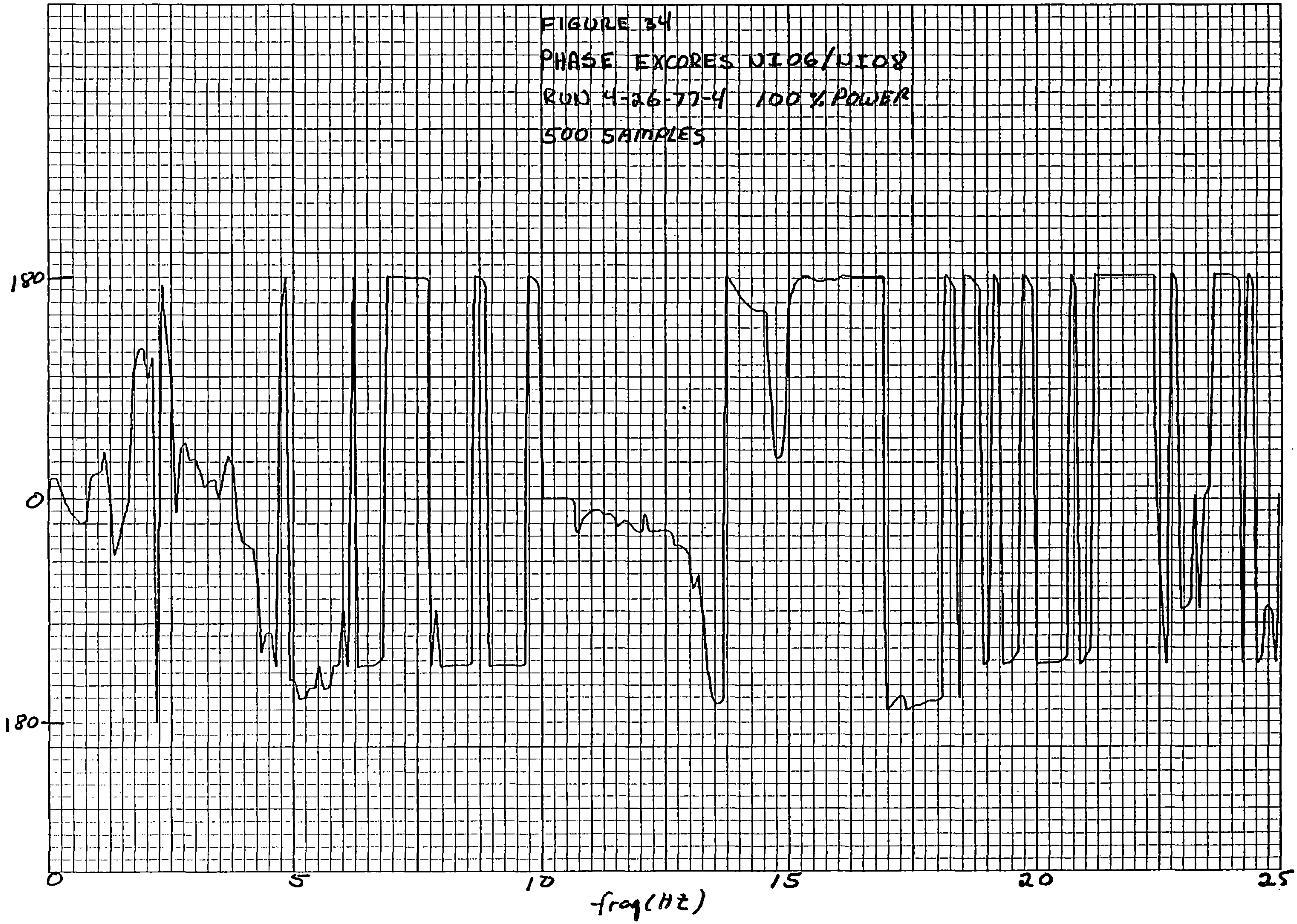

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
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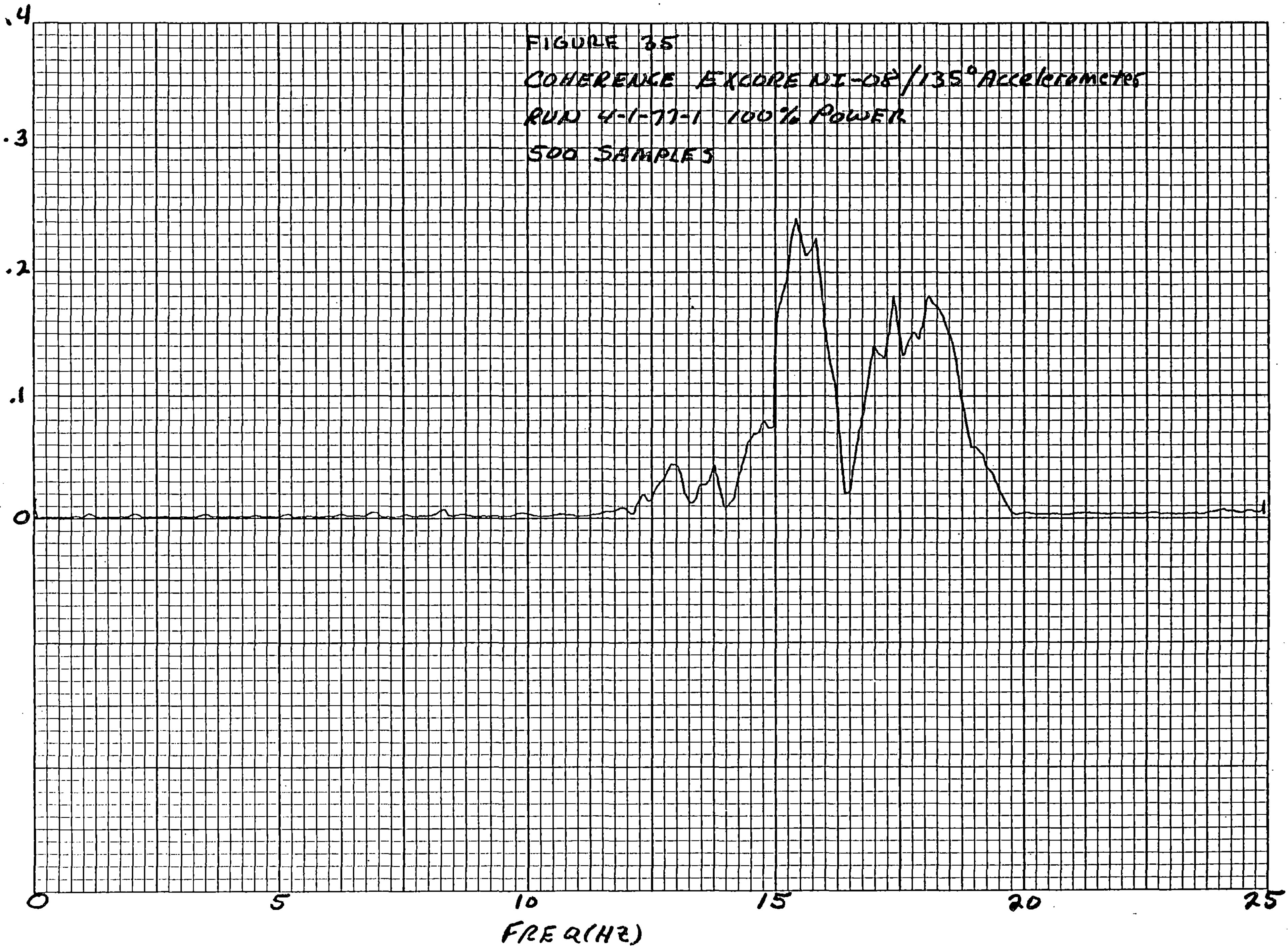

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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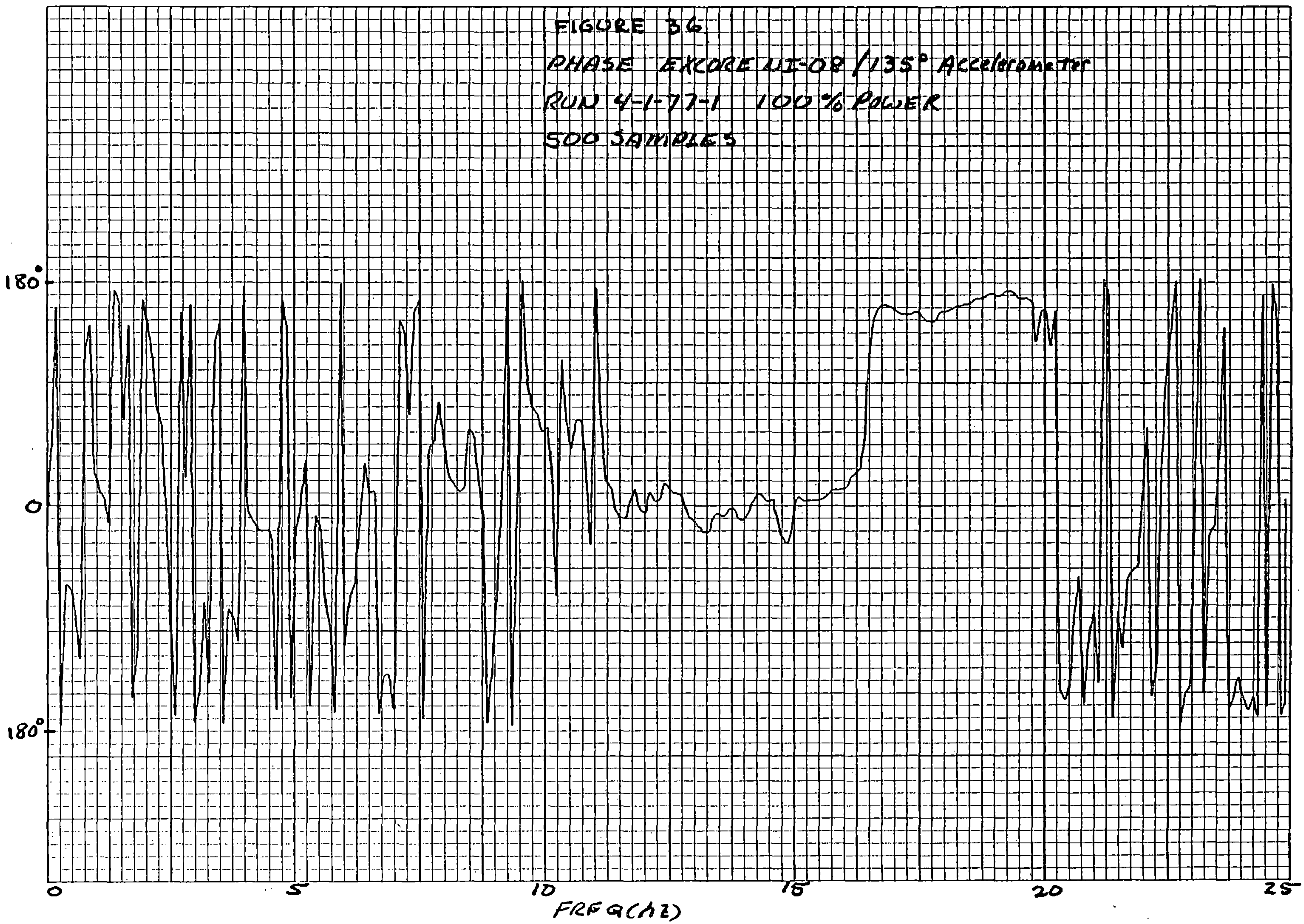

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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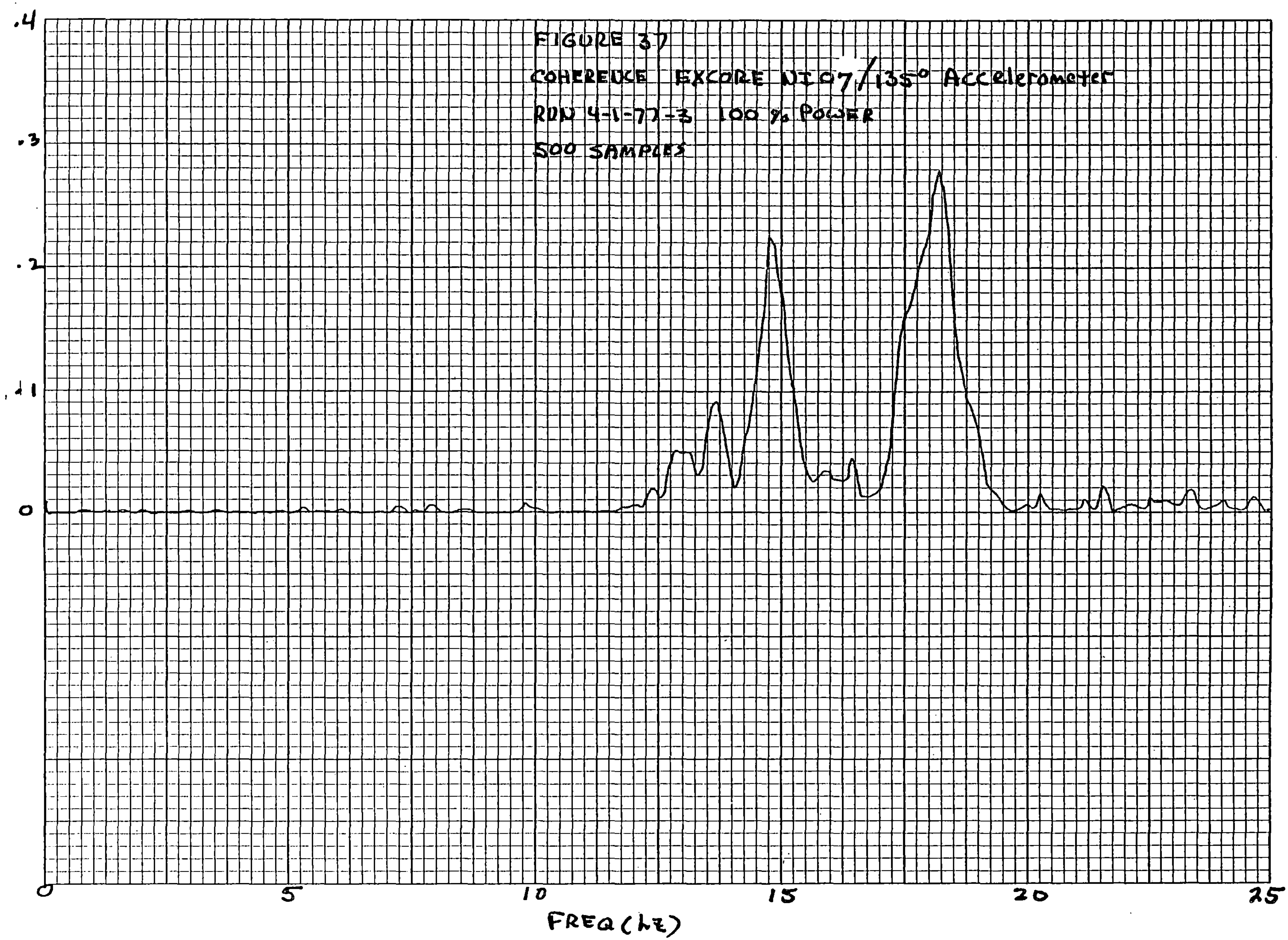
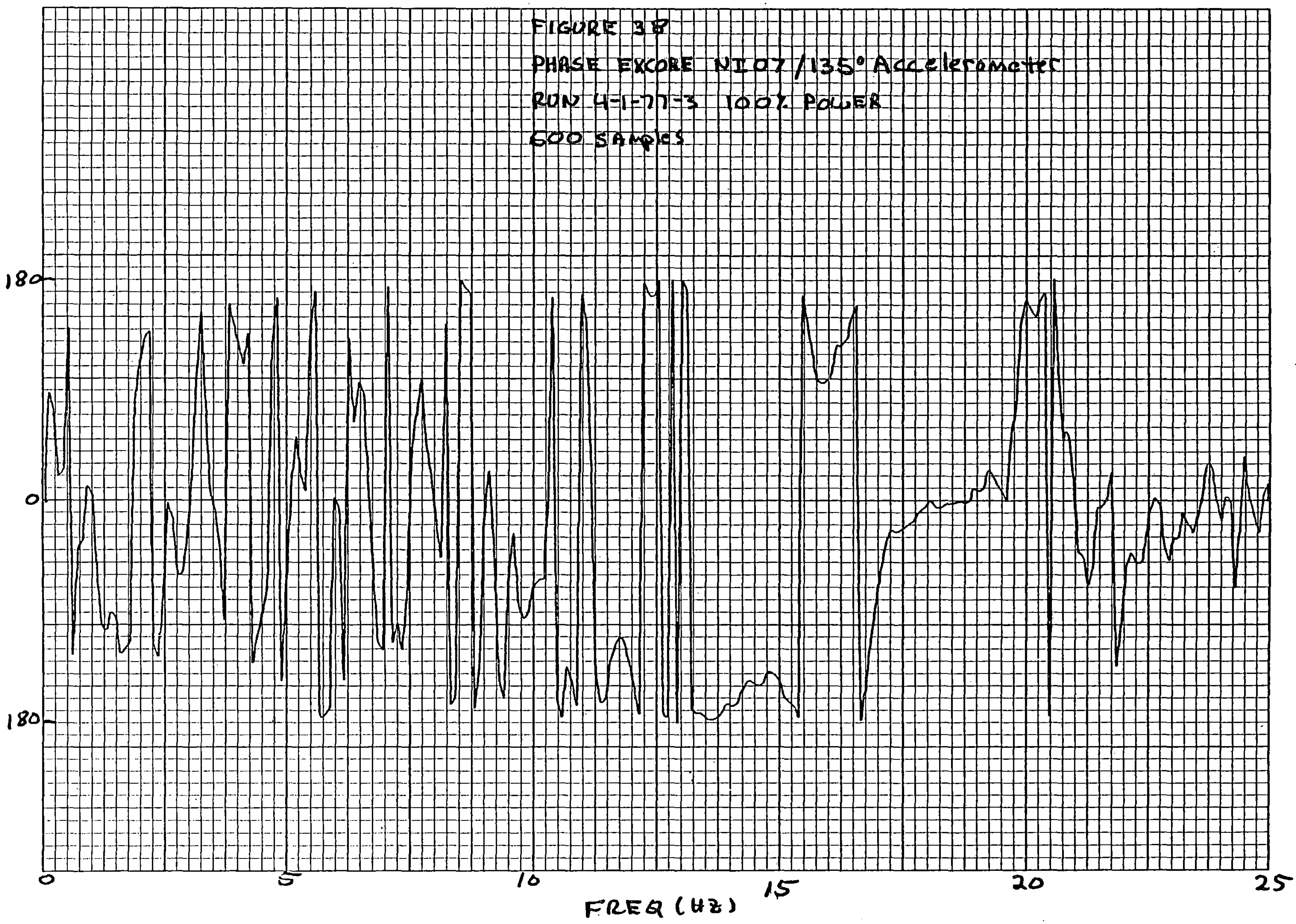


K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 0782



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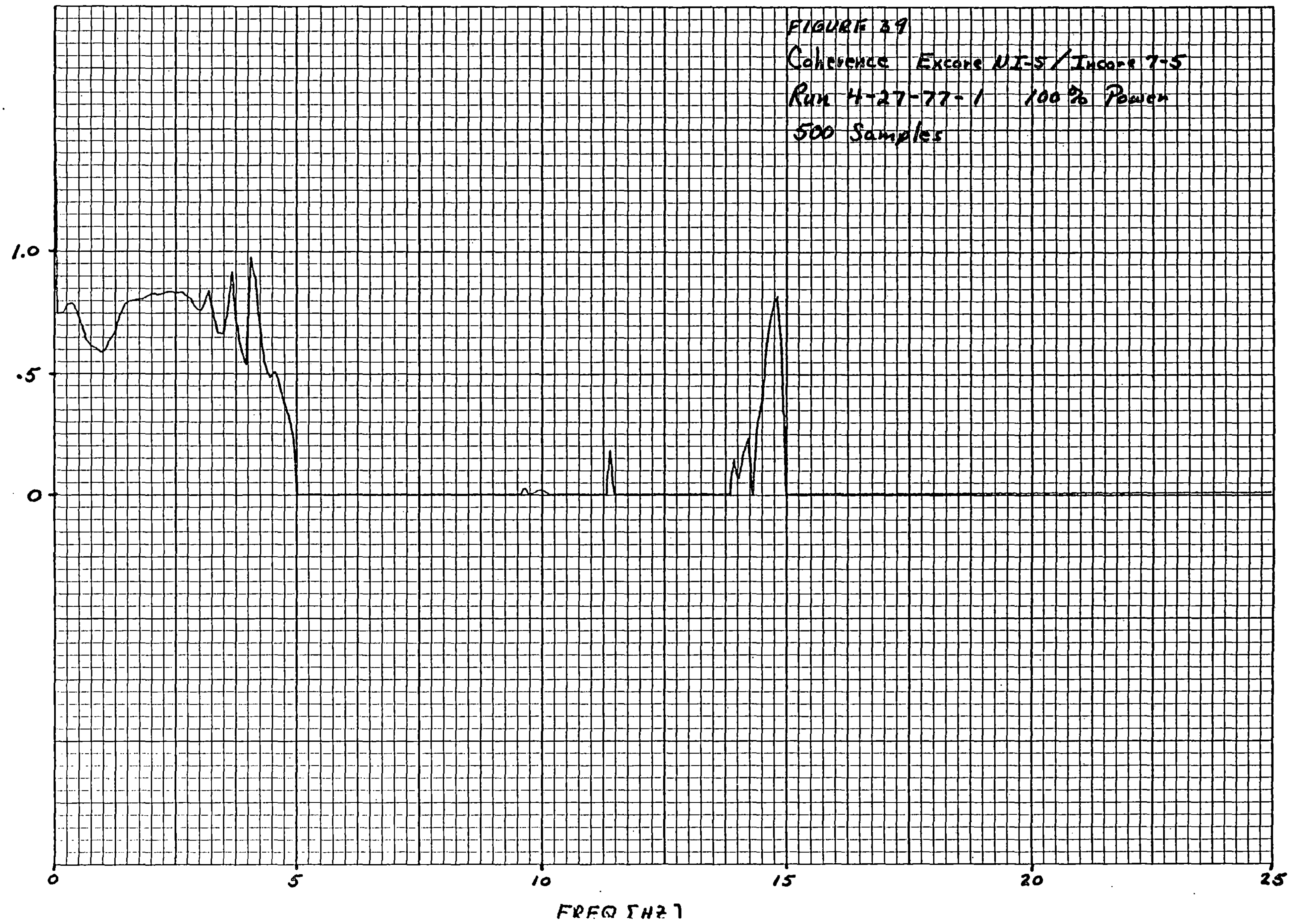

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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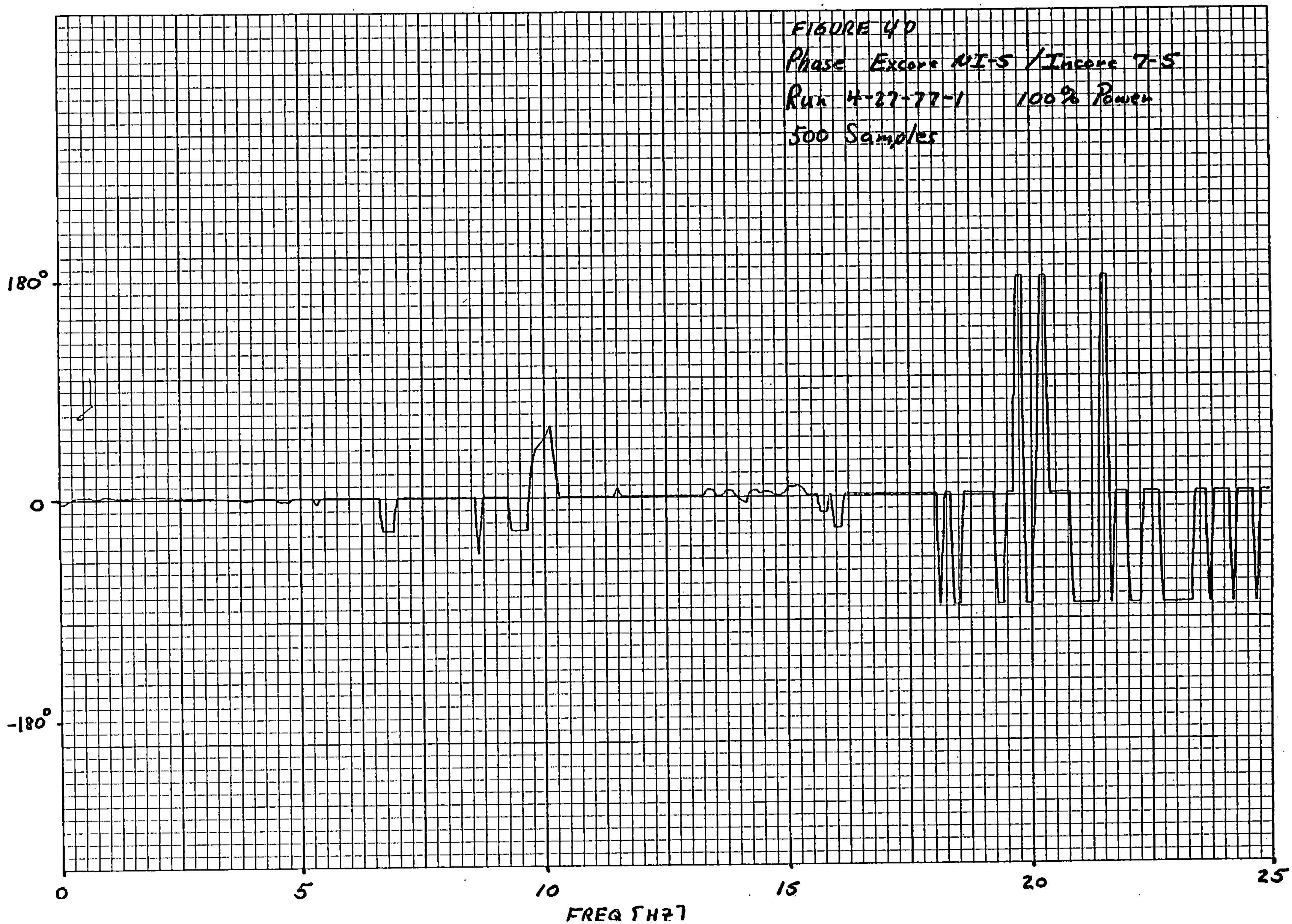

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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KEUFFEL & ESSER CO. MADE IN U.S.A.
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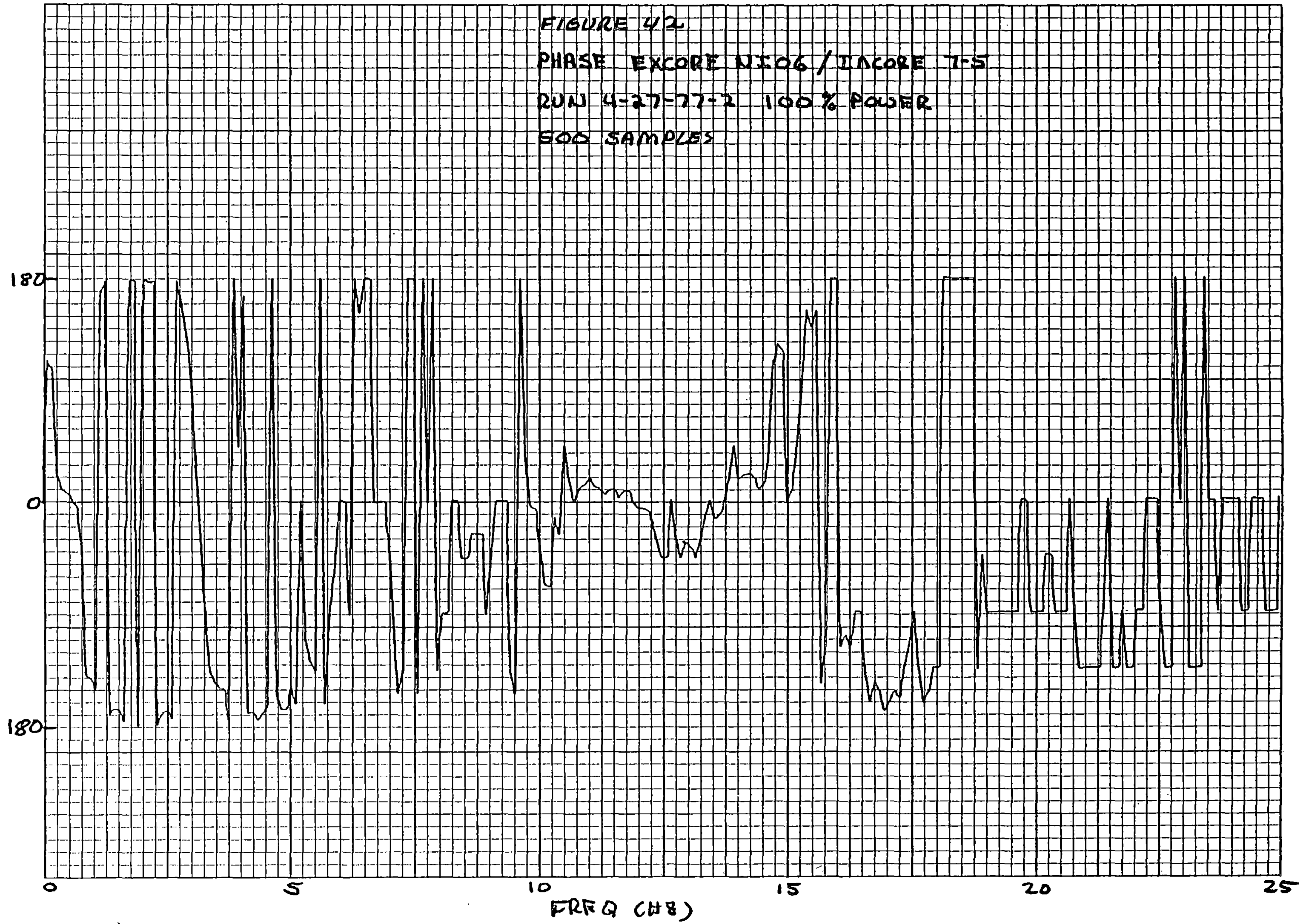

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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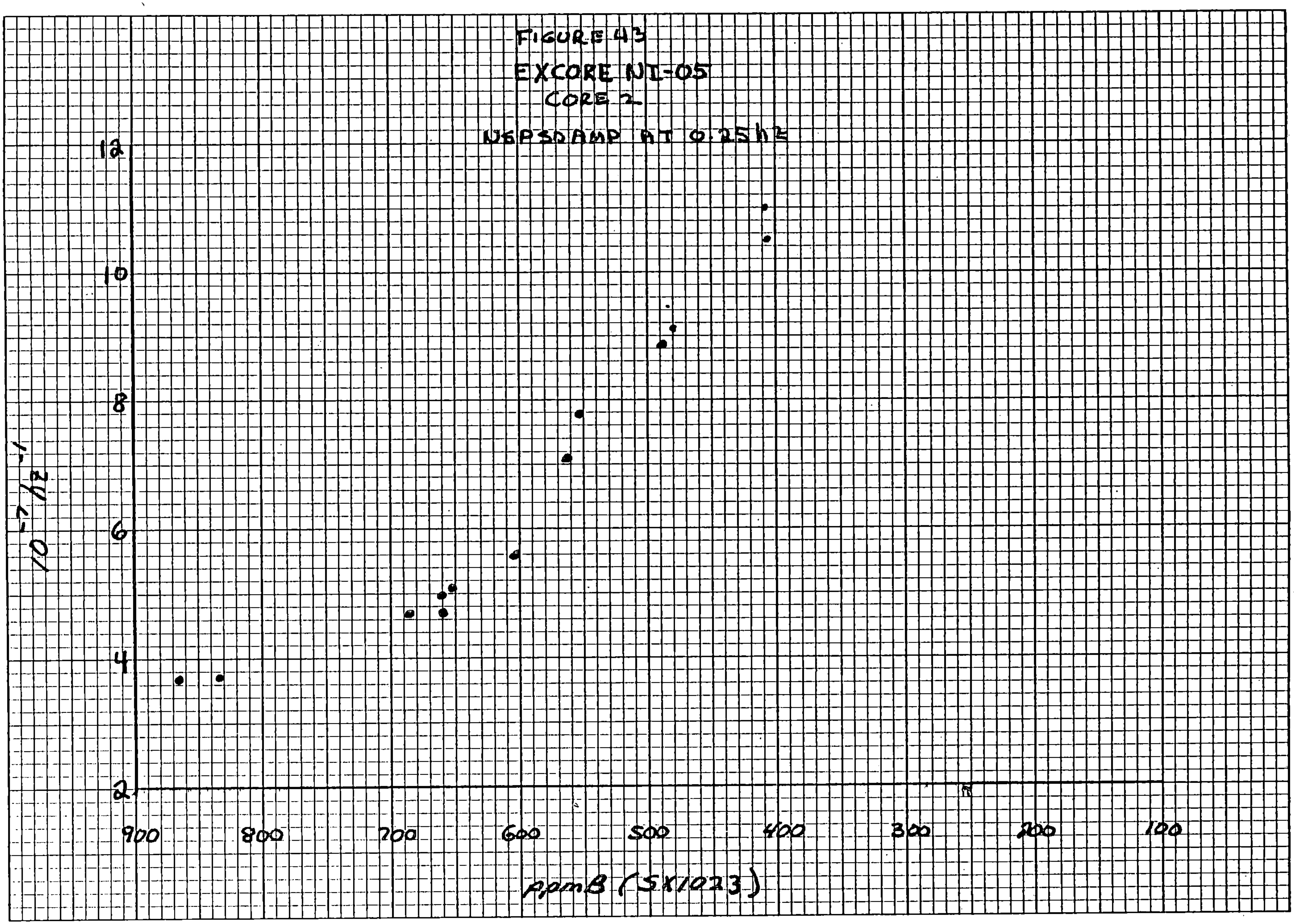

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
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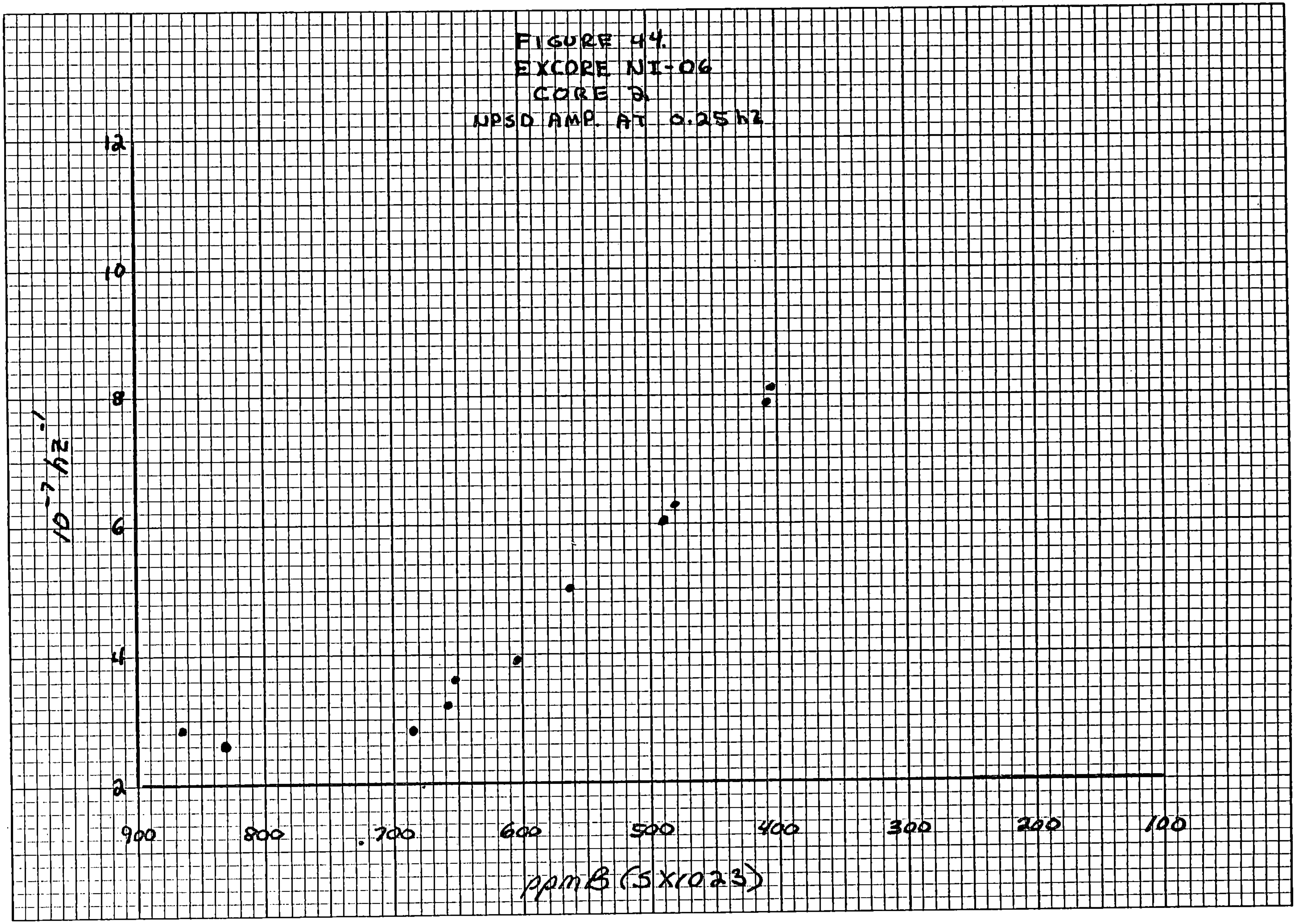

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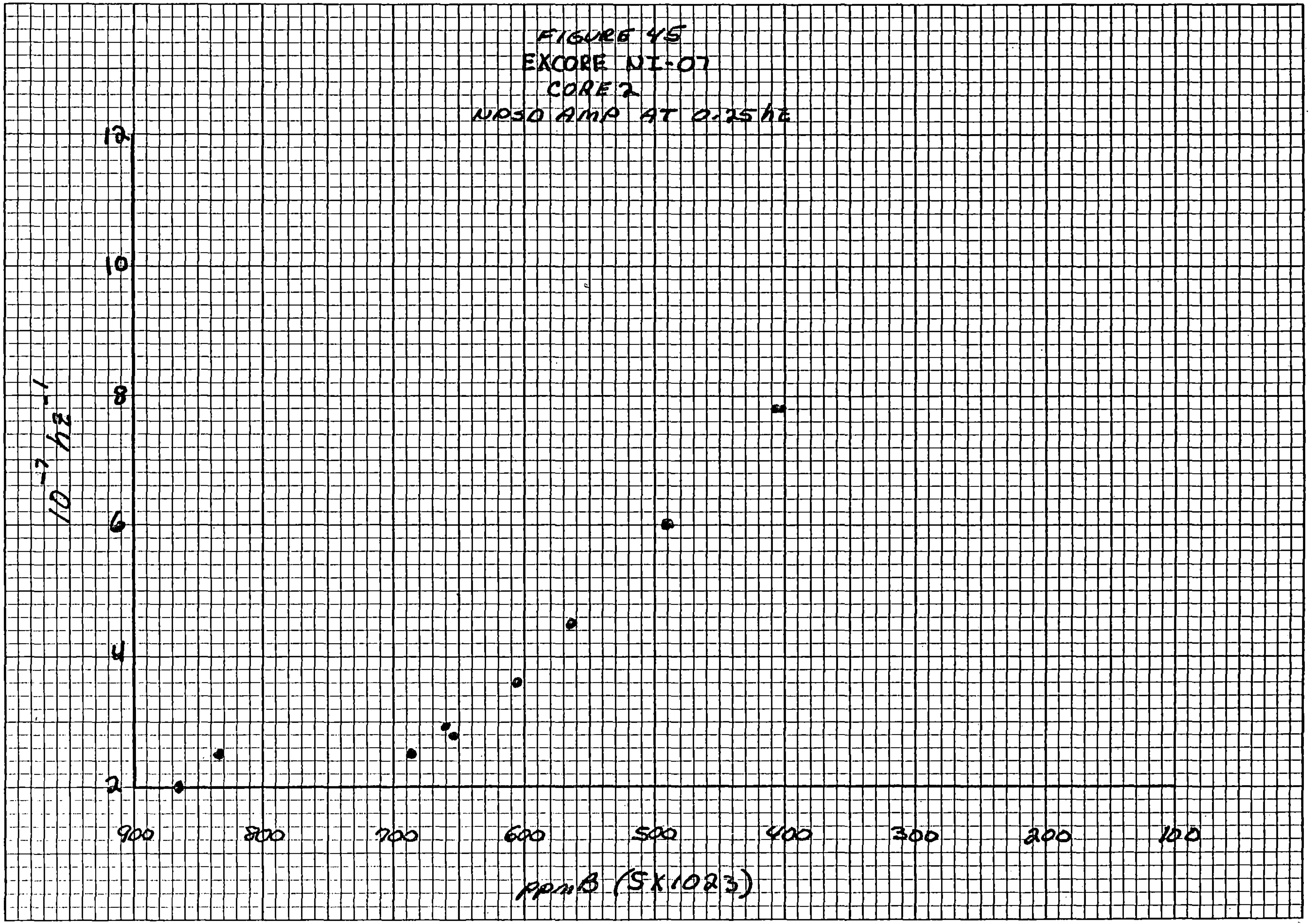

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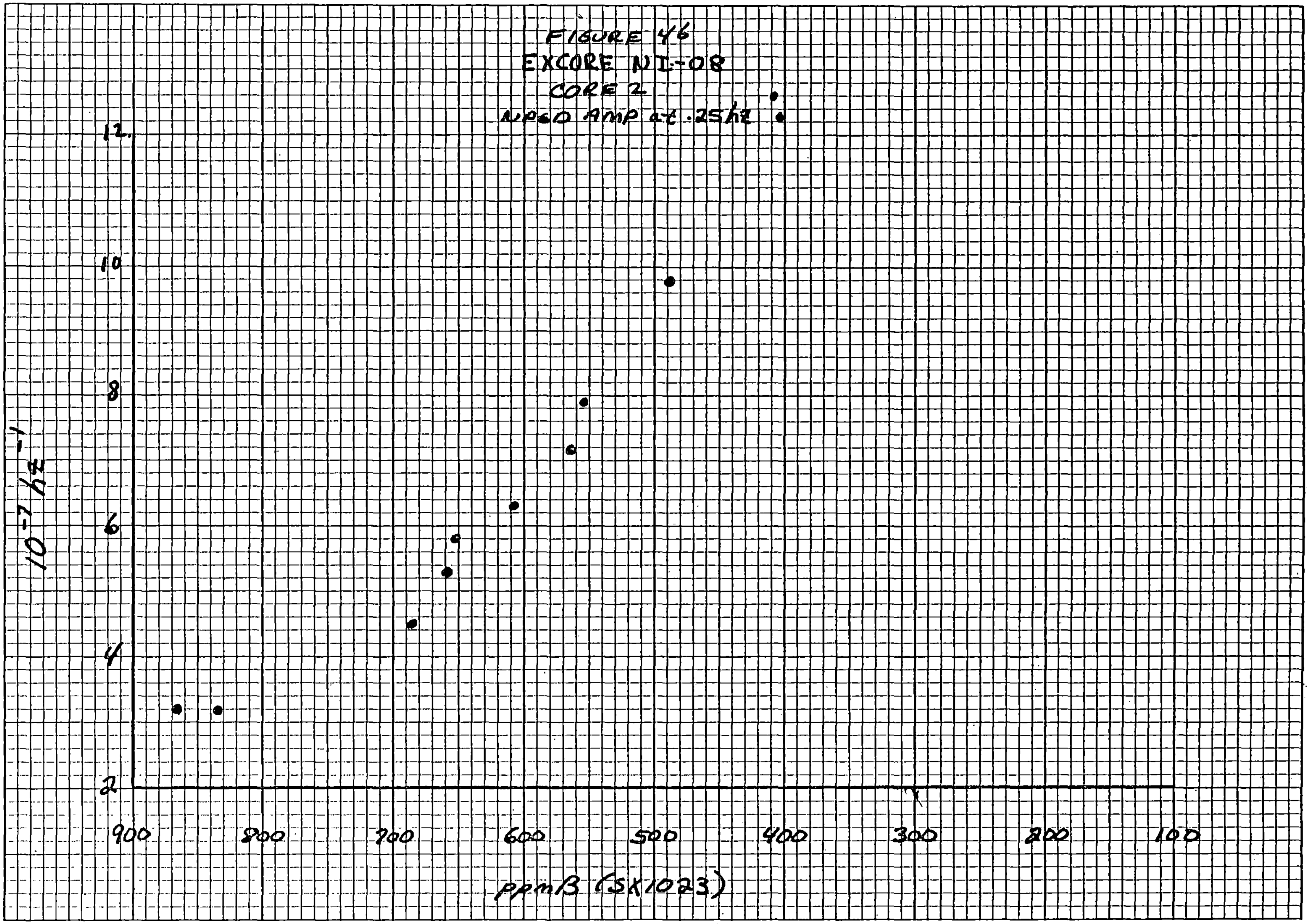
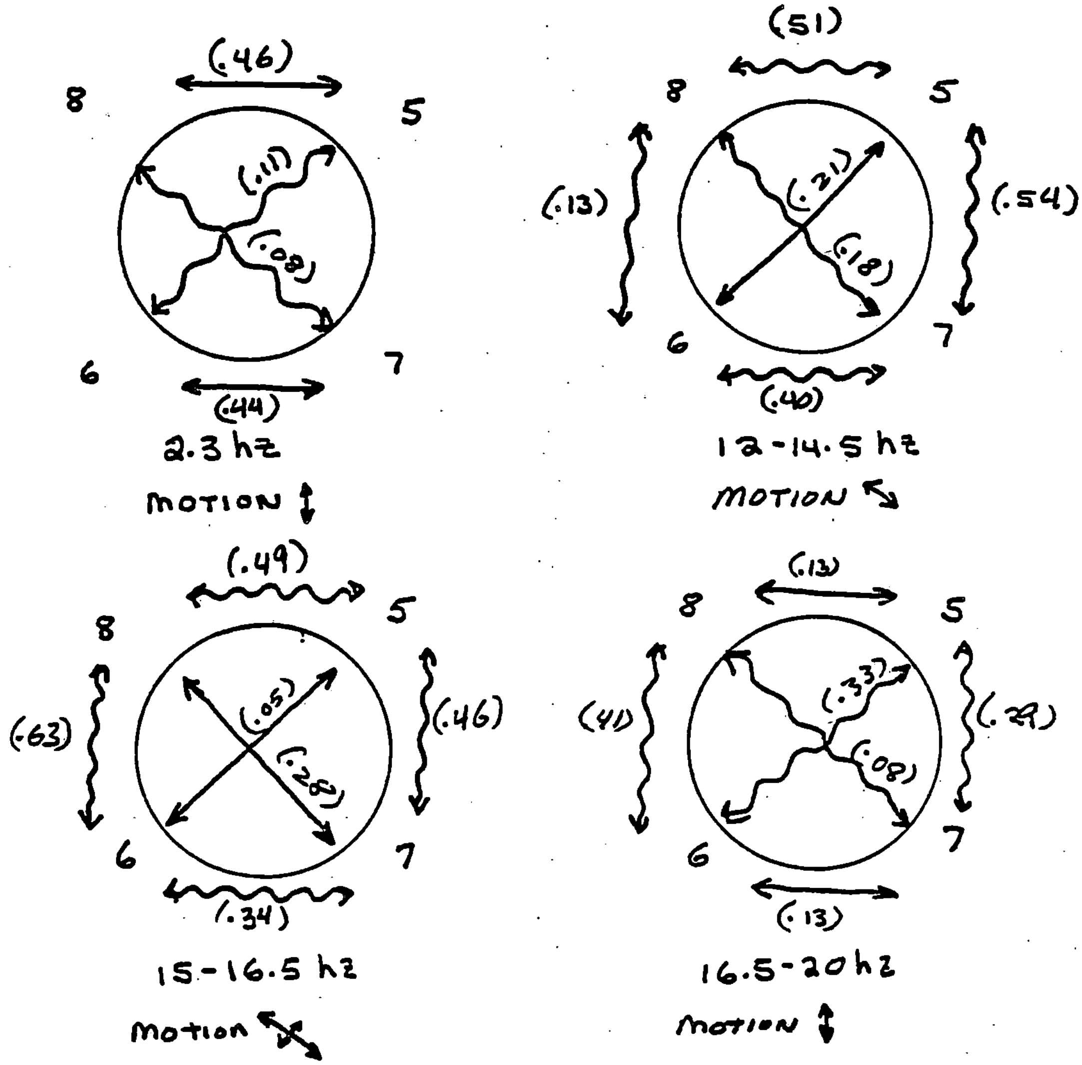


FIGURE 47: COHERENCE AND PHASE DIAGRAMS



Legend:

∼∼ 180° phase

⟷ 0° phase

( ) Coherence