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WYLE LABORATORIES - SOUTHEAST TEST DIVISION

RESEARCH STAFF

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ACOUSTIC TESTS ON TYPICAL SATURN SHROUD STRUCTURE

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WYLE LABORATORIES, Inc., /Huntsville, Alabama

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ACOUSTIC TESTS ON TYPICAL SATURN SHROUD STRUCTURE

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SUMMARY

A

The response to acoustic excitation, of typical structural panels from the Saturn engine shroud has been investigated experimentally and theoretically. The experimental results of the study are presented in this report. The development of the prediction technique is separately reported.

After obtaining the response data the tests under broad-band excitation were continued until structural failures occurred.

The tests of three similar complex panel specimens arrived at a common result. All three panels failed in similar fashion and exhibited lifetimes of approximately 27 minutes which were roughly 5 to 10 times the duration of anticipated lifetime requirements, including static firings, aborts, and launch.

AUTHOR

SECTION I. INTRODUCTION

Tests were conducted on three similar complex panel specimens as a part of a study to investigate the response of typical Saturn booster structure to acoustic excitation. Concurrently, the structure was analyzed theoretically with a view to predicting the response and subsequently ascertain the degree of correlation. The tests were performed in the Acoustic Facility of Wyle Laboratories under contract No. NAS8-5113, Task II, originating in the M-P and VE Division, NASA, MSFC.

The panels were subjected to both discrete frequency and broad-band excitation at overall sound pressure levels up to 160 db.* After throughly measuring the response of each panel the tests were continued until failure occurred. The tests on the first panel were previously reported in Wyle Report No. WR-63-3[1]**.

The theoretical portion of this investigation is reported in Wyle Report No. WR-63-9[2].

*The reference pressure of 0.0002 dynes/cm^2 is used throughout this report.
**Superscripts, where applicable, refer to REFERENCES throughout this report.

SECTION II. EXPERIMENTAL INVESTIGATION

A. ACOUSTIC FACILITY

The present investigation was conducted in the parallel incidence test section of the acoustic facility shown in Figure 1. The facility is equipped with two sound sources, one of which is used for discrete frequency and broad-band excitation, while the other is a broad-band source capable of considerably higher levels. The low level source operates on the electro-pneumatic principle and employs a voice coil the armature of which forms a slide valve modulating the exit orifices of the air flow. The high level source operates on the multi-rotor principle in which four contra-rotating rotors modulate the flow of air through an orifice. Overall levels up to 164 db* are obtainable in the 6.5 square foot cross-section of the parallel test section with the latter device.

B. DESCRIPTION OF SPECIMENS

Three test panels were supplied for test. These panels are representative of the Saturn booster engine shroud structure, as shown in Figure 2. The general arrangement of a typical panel specimen is illustrated in Figures 3,4, and 5. Construction details are given in Figure 6.

The specimens were essentially shallow curved complex rectangular panels of aluminum skin and stringer construction. The thin skin was supported by four continuous longitudinal stiffeners of channel-section, one along each edge and two at intermediate positions. The panel contour was formed by bent Z-section intercostals arranged transversely. It was noted that the flanges of the latter members were not connected across the channels thus reducing both the rigidity and the paths for load transfer. All joints were formed by riveting.

The three supplied panel specimens were not identical because of construction differences. Two panels were essentially the same with only minor dimensional differences in stiffener spacing. The third panel, however, differed markedly in the box section beside the removable panel. The Z members had been assembled in the reverse direction. The overall dimensions were noticeably different also.

C. TEST FIXTURE AND PANEL MOUNTING

The general arrangement of the test fixture is illustrated in Figure 7. A photograph showing the panel mounted in the test fixture is given in Figure 8. Since the panel curvature results in a slight protrusion of the panel into the horn,

wooden fairings are provided at each end of the panel to avoid sharp discontinuities. Figure 9 shows the downstream fairing.

The panel mounting attachments to the fixture are shown in Figures 7 and 10. Two heavy section aluminum angles (see A-A and B-B of Figure 10) were bolted by closely spaced 3/16 inch diameter bolts to the webs of the longitudinal panel edge members. Three angle brackets shown in detail C of Figure 10 were located at each end of the intermediate stiffeners which terminated at the transverse edges of the specimen and were bolted to the channel beams with 3/16 inch diameter bolts. Both the angle section beams and angle brackets were attached to the test fixture.

The attachments provided bending and torsional restraint along the edges of the specimen, at the same time permitting skin flexure as controlled by the channel section flanges of the edge members.

The assembly described above was in turn bolted into a massive concrete frame twelve inches thick. The frame was bolted to the test section as illustrated in Figure 8.

D. MEASUREMENTS, INSTRUMENTATION AND CALIBRATIONS

Resonant frequencies, mode shapes, strain response spectra and test sound pressure spectra were required from the tests.

The discrete frequency source, operating at low sound pressure levels, was used to excite the specimen at its resonant frequencies for the purpose of determining mode shapes. The panel motion was studied visually with a stroboscope while a hand-held probe transducer was used to determine the phase distribution over the panel in relation to a reference accelerometer. A block diagram of the instrumentation used for this study is given in Figure 11.

Discrete frequency sweeps at a constant sound pressure level were used to excite the panel. Panel excitation was also induced with broad-band random noise. Response spectra of the strain amplitudes were detected with electrical resistance strain gauges located at the stations indicated in Figures 12, 13, and 14 for the three panels, respectively. During the discrete frequency sweeps the gauge outputs were recorded on an oscillograph and/or an X-Y plotter. The microphone and strain gauge outputs were recorded on magnetic tape during the broad-band tests for later reduction into power spectral density plots. Diagrams of the instrumentation used to measure and record the strain gauge outputs are shown in Figure 15A for discrete frequency sweeps and in Figure 15B for the broad-band tests. Figure 16 illustrates the microphone system instrumentation.

The strain gauges were the foil type fastened to the specimen with contact cement. Each gauge was connected into a bridge network. The calibration of the gauges was accomplished with resistors of known value connected across each gauge in turn.

The sound pressure levels were measured with Photocon condenser microphone systems located on the center line of the test section at the upstream edge, center and downstream edge of the panel. These microphones were calibrated with a Photocon PC-120 calibrator.

E. TEST CONDITIONS

The acoustic test conditions were predicted by the Vibrations and Acoustics Group of NASA for the particular area of the shroud structure occupied by the panel specimen. The predicted overall sound pressure level was 162-163 db and the predicted one-third octave band test spectrum is shown in Figure 155A.

The sinusoidal sweep response spectra were used to determine the frequency bands of maximum panel response. The broad-band excitation spectra were then shaped relative to these maximum response bands in order to provide the best possible agreement with the predicted spectrum.

The broad-band tests began at lower levels than required to provide strain response data and the levels increased in increments until the test level was reached. Data were taken at each level increment.

SECTION III. EXPERIMENTAL RESULTS

A. DISCRETE FREQUENCY TEST DATA

1. Resonant Frequencies and Mode Shapes. The phase distribution of the panel motion at its resonant frequencies was investigated with a stroboscope and a hand-held acceleration probe. The discrete frequency excitation was supplied at low levels by the air modulator. A few of the modal distributions identified are illustrated in Figure 17, 18, and 19 for panel No. 1. These results are strictly qualitative.

2. Discrete Frequency Sweeps. Sinusoidal frequency sweeps at a constant low sound pressure level over a frequency range from 30 cps to 1000 cps, at a 25 degree per minute sweep rate, were made for each specimen to determine its response characteristics. Several sweeps were made at various sound pressure levels to permit an evaluation of the linearity of the panel response. The maximum strain levels were limited to around 500 microinches per inch such that the accumulated test time would result in negligible strain levels at the resonant peaks.

The results of the sinusoidal sweeps are presented as strain amplitude versus frequency in Figures 20 through 51 for the three specimens.

B. BROAD BAND TEST DATA

1. Low-Level Broad-Band Noise. Panels No. 2 and No. 3 were subjected to low level broad-band acoustic excitation supplied by the air modulator. Strain gauge and microphone outputs were recorded on magnetic tape for different overall sound pressure levels. Power spectral density (PSD) plots of the microphone and strain gauge data were made from an analysis of the magnetic tape data. The filter sweep rate was determined such that the averaging time was about twice the sample length per bandwidth of the scanning filter, i.e. a twenty second averaging time for a 2 cps bandwidth filter on a ten second sample loop length. A few representative PSD curves are contained in Figures 54 through 154 for the two specimens.

2. High-Level Broad-Band Noise. All three panels were excited by the multi-rotor random siren at high sound pressure levels. The overall test sound pressure level predicted by NASA of 162 db along with the predicted sound pressure level frequency spectrum were to be used in conducting fatigue life tests on the panel specimens.

Panel No. 1 was subjected to a variety of sound pressure spectra at an overall level 6 db down from the test level (156 db) during preliminary spectrum shaping. A spectrum close to the predicted spectrum was strived for, at least

in those frequency bands of maximum panel response. Figure 155 shows the variance of these preliminary spectra relative to the desired predicted spectrum.

The strain gauges were lost almost immediately at this level (156 db) due to excessive vibration levels. Therefore, no data were obtained to indicate strain levels. Panel No. 1 failed before a satisfactory spectrum was obtained. The following summary reviews the test history of panel No. 1:

Run 1. Overall sound pressure level 156 db, duration 5 minutes. The specimen was examined visually but no damage was found.

Run 2. Overall sound pressure level 156 db, duration 3 minutes. No damage to panel.

Run 3. Overall sound pressure level 156 db, duration 1 minute. Visual examination of specimen revealed cracks in the intercostals, see Figure 156.

Run 4. Overall sound pressure level 156 db, duration 7 minutes. Visual examination of panel showed that previously noted cracks had increased in length.

Run 5. Overall sound pressure level 156 db, duration 2 minutes. No change in damage.

Run 6. Overall sound pressure level 156 db, duration 1 minute. No significant change in damage.

Run 7. Overall sound pressure level 156 db, duration 8 minutes. A 4" crack was found in the facing sheet along a rivet row after this run and operations were discontinued. The failure is shown in Figures 157, 158, and 159.

The total time at 156 db was therefore 27 minutes.

Panel No. 2 was tested at a few lower levels in an attempt to gain strain measurements. The PSD curves are plotted in Figures 54 through 99. The test level was raised and a search for a suitable spectrum begun. The panel lost strain gauges, developed cracks and finally failed. A summary of the test history of Panel No. 2 follows:

Run 1. Overall sound pressure level 160 db, duration 7 minutes. Cracks developed in intercostals after two minutes of run time.

Run 2. Overall sound pressure level 160 db, duration 4 minutes. Crack developed in skin at rivet line. (Figures 160 and 161) Cracks in intercostals increased 50 per cent. The total time at 160 db was 11 minutes. Figure 162 shows fatigued panel after a few more minutes at 160 db.

Strain data was obtained from Panel No. 3 at quite low levels ($<$ 150 db). The PSD plots are contained in Figures 100 through 154. A spectrum was shaped at

an over-all level of 156 db. Panel No. 3's test history at the 156 db level was as follows:

Run 1.	Overall sound pressure level 156 db. Duration 7 minutes. No evidence of cracks.
Run 2.	Overall sound pressure level 156 db. Duration 16 minutes. Evidence of fatigue around a rivet head between gauges 11 and 12.
Run 3.	Overall sound pressure level 156 db. Duration 4.5 minutes. Crack 5 inches long noted between gauges 11 and 12 (Figure 163) No cracks in intercostal.

The total time at 156 db was 27.5 minutes. Figure 164 shows fatigued panel after a few more minutes at 161 db. Note that panel No. 3 had finger strap shear ties included at intercostal joints, thereby increasing the intercostal fatigue life.

SECTION IV. DISCUSSION OF RESULTS

The modal frequency grouping phenomenon described by Lin[3,4] for regular (periodic) systems is exhibited in a somewhat limited fashion by the response spectra of the non-regular shroud panel system as shown by the sinusoidal sweep data in Figures 20 through 51 and the random acoustic force data in Figures 59 through 154. Of course, panel curvatures, irregular spans and a finite number of panels will cause wide departures from the regular span spectra.

The strain amplitude spectra of Figures 20 through 38 for the strain gauge responses of panels Number 1 and Number 2 to a constant amplitude sinusoidal frequency sweep indicate some clustering of the resonant response peaks into frequency bands (groups). There appear to be many narrow bands the highest of which occurs around 100 cps and 110 cps for panels Number 1 and Number 2, respectively.

However, the strain response amplitude spectra (Figures 39 through 51) for panel Number 3 were obtained in a slightly different manner and the many apparent frequency bands noted above are seen to broaden and hence, become fewer. The differences between Figures 20 through 38 and Figures 39 through 51 are that the latter data were not squared before plotting.

A "soft spring" characteristic appears when amplitudes at different sound pressures are plotted versus frequency. Figure 52 illustrates a few examples of this phenomenon. However, when the amplitudes are plotted versus the forcing pressure (Figure 53) an apparent "hard spring" characteristic is noted. Further research needs to be directed toward an explanation of this anomaly.

Figures 54 through 154 contain the spectra of the data taken from the outputs of both microphones and strain gauges on panels Number 2 and Number 3 when excited with random acoustic energy. The data is presented as Power Spectral Density (PSD) in units of $(\text{psi(rms)})^2$ per cps for the sound pressures and in units of $(\text{strain (peak)})^2$ per cps for the strains. The noise source is identified on all of the graphs.

The aperture (bandwidth) of the scanning filter used in the PSD analyses is important, especially, in its effect on the fine structure of the low frequency portions of the spectra. Figure 68 and Figures 75 and 76 illustrate the differences existing between a 10 cps filter bandwidth and a 2 cps filter bandwidth for analyzing the outputs of microphone Number 2 and strain gauge Number 12, respectively. Little new information is gained above 150 cps, however, much is gained below that frequency.

Figures 81, 88, 92, and Figures 93 and 99 show the effects of the 10 cps filter, respectively, for microphone Number 1's response to the broad-band siren field.

Figures 87 and 96 and Figure 97 illustrate the effect of the 10 cps filter and the 2 cps filter, respectively, on strain gauge No. 12's output.

For a lot of closely spaced peaks the narrower filter yields more distinct information about the low frequency ($<$150 cps) end of both microphone and strain gauge response spectra. A sand filled stiffened box was substituted for the specimen to obtain microphone data to eliminate any questions about the microphone spectra possibly containing panel response peaks. Figures 98 and 99 contain these spectra, which appear much the same as the previous microphone data as seen in comparing Figures 98 and 99 with Figures 92 and 93, respectively.

Figures 100 through 154 comprise that data taken from the random noise excited responses of panel Number 3. Both the air modulater and siren noise sources were used. A 2 cps bandwidth filter furnished the sampling aperture for analyzing the data from both microphone and strain gauge outputs.

Figures 155 through 164 review the structural damage done to the three panel specimens and the comparisons of the input sound pressure spectra with the NASA predicted spectrum. Note that the spectra in the Figures 155A, 155B and 155C had higher sound pressure levels in the 100-150 cps band. This coincides with the high response band of the panel specimens. These failures indicate high stress concentrations at the rivet attachment to the beam between Plates I and II of Figure 5.

The fatigue life of approximately 27 minutes of all three panel specimens was roughly 5 to 10 times the useful life of the shroud structure for all forseeable missions. Hence, the structure is well qualified for the predicted acoustic environment.

The effects of the dissimilarities of the three panels are noted by examining Figures 165 through 168. These figures contain the superimposed response spectra of the strain gauges, which are common to two or three of the panels, to a constant 136 db SPL discrete frequency sweep. The strain amplitudes are quite different as are the peak frequencies. The subsequent lack of consistency in the data makes the above fatigue explanation difficult, since all three panels failed in similar times and fashion.

SECTION V. CONCLUSIONS AND RECOMMENDATIONS

In general, the results of the program were satisfactory and have demonstrated the plausibility of the analysis procedures proposed by Lin[3,4]. These experimental results are among the first to demonstrate the theory of clustered modes. However, the data are somewhat confused because of the dissimilar configuration of the stiffeners.

The narrow-band analyses of the microphone data indicate the inadequacies of the multi-rotor siren in its present form and suggest areas in need of improvement. Currently, the following modifications are in process: 1) random modulation of the siren rotor speeds 2) addition of a plenum chamber to reduce upstream radiation and 3) design of high-speed rotors to move the spectrum into the higher frequency regimes.

These changes are directed towards making the spectral density uniform and widening the frequency range over which spectrum shaping is possible.

The fatigue fractures that occurred at the cut-outs in the inter-costals (see Figure 156) emphasize the importance of careful detail design. Such failures are typical of the damage sustained by sub-structure in high-intensity environments. Had the design been representative of the actual structure, in that respect, the strength would have been marginal.

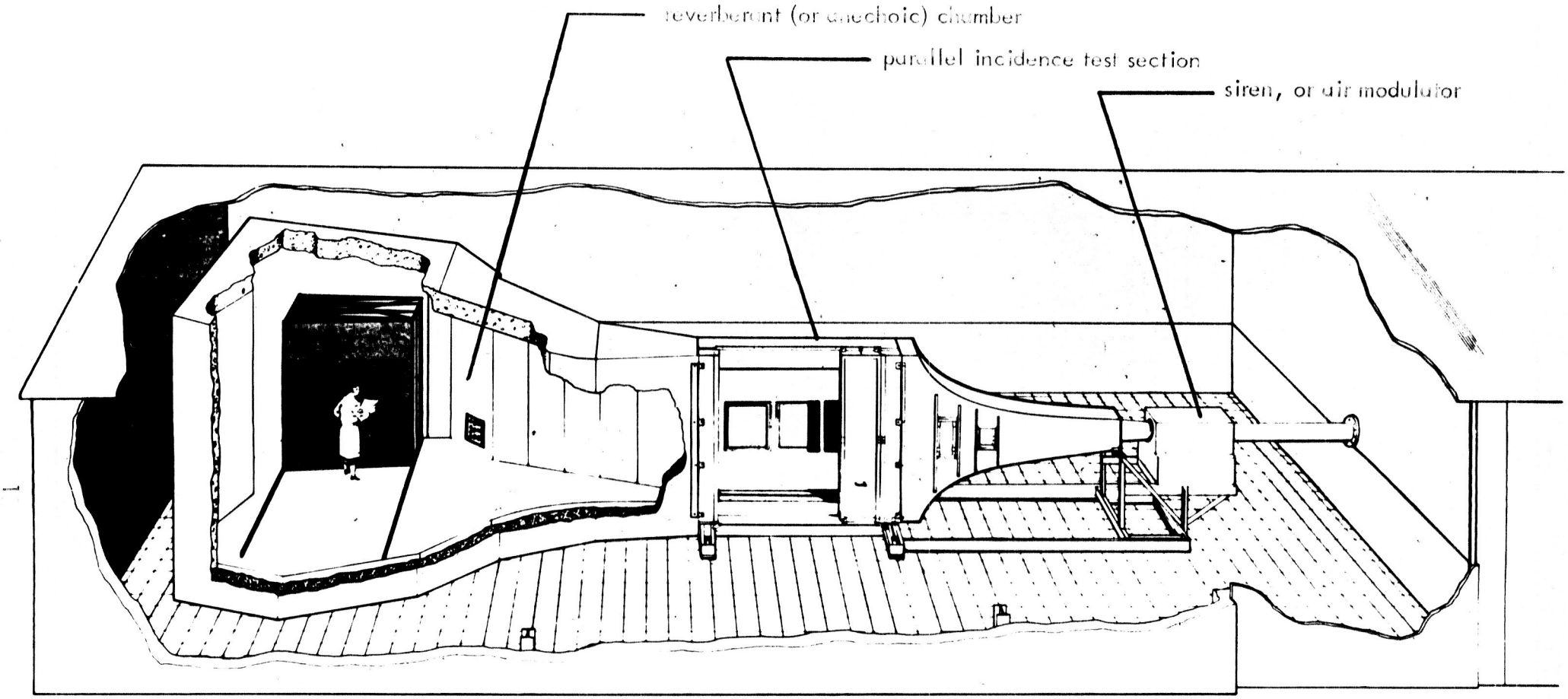
REFERENCES

1. B.J. Spice, "Acoustic Tests on a Satum Shroud Panel," (Wyle Laboratories Research Staff Report No. WR-63-3, February 1963).

2. D.J. Bozich, "Theoretical and Experimental Evaluation of the Response of Typical Saturn Shroud Structure to Acoustic Excitation," (Wyle Laboratories Research Staff Report No. WR-63-9, October 1963).

3. Y.K. Lin, "Free Vibration of Continuous Skin-Stringer Panels," (Journal of Applied Mechanics, December 1960). P. 669-676.

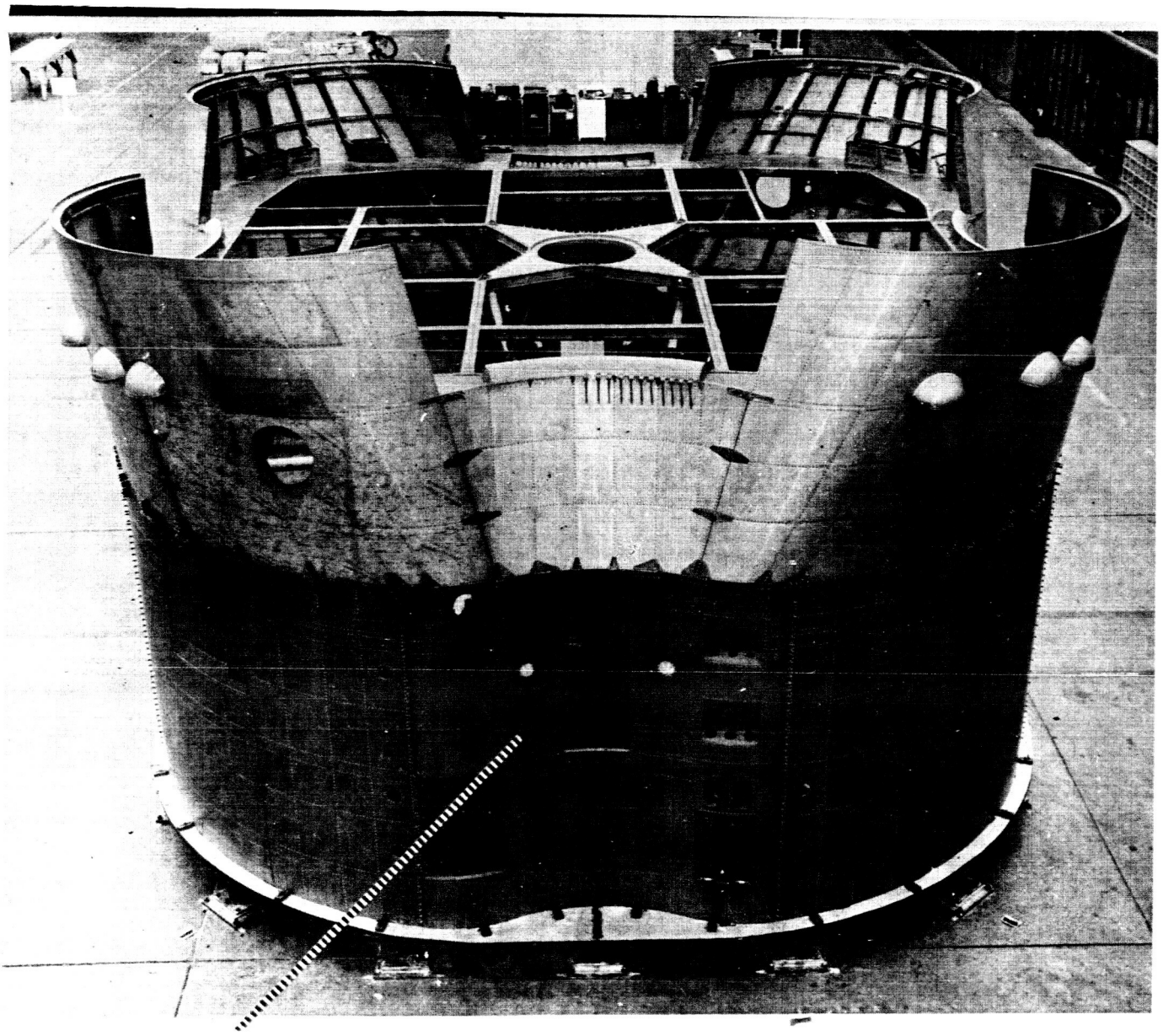
4. Y.K. Lin, "Stresses in Continuous Skin-Stringer Panels Under Random Loading," (Journal of the Aerospace Sciences, January 1962). P. 67-75.



HIGH-INTENSITY ACOUSTIC FATIGUE TEST FACILITY

Wyle Laboratories, Huntsville, Alabama

Figure 1: Acoustic Facility Horn, Showing Parallel Test Section and Reverberant Chamber.



Test Panel Section

Figure 2: Saturn C-1 Booster Engine Shroud Structure.

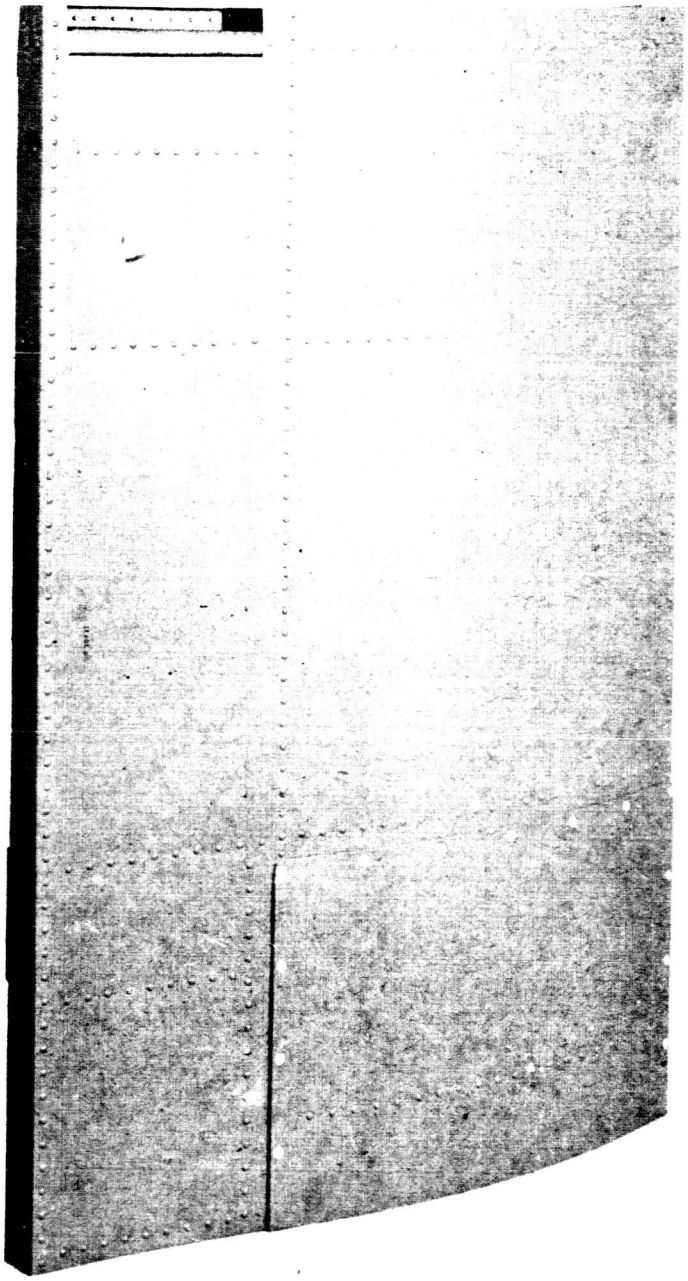


Figure 3: Typical Shroud Panel Specimen - Front View.

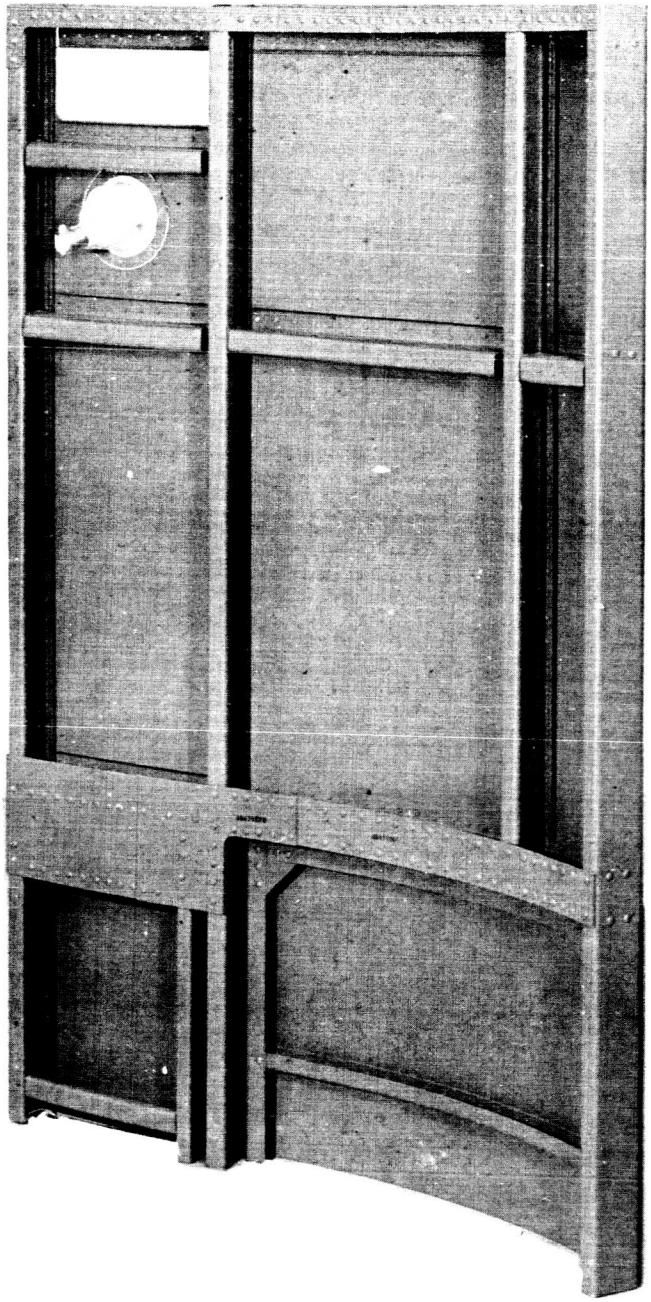


Figure 4: Typical Shroud Panel Specimen-Rear View.

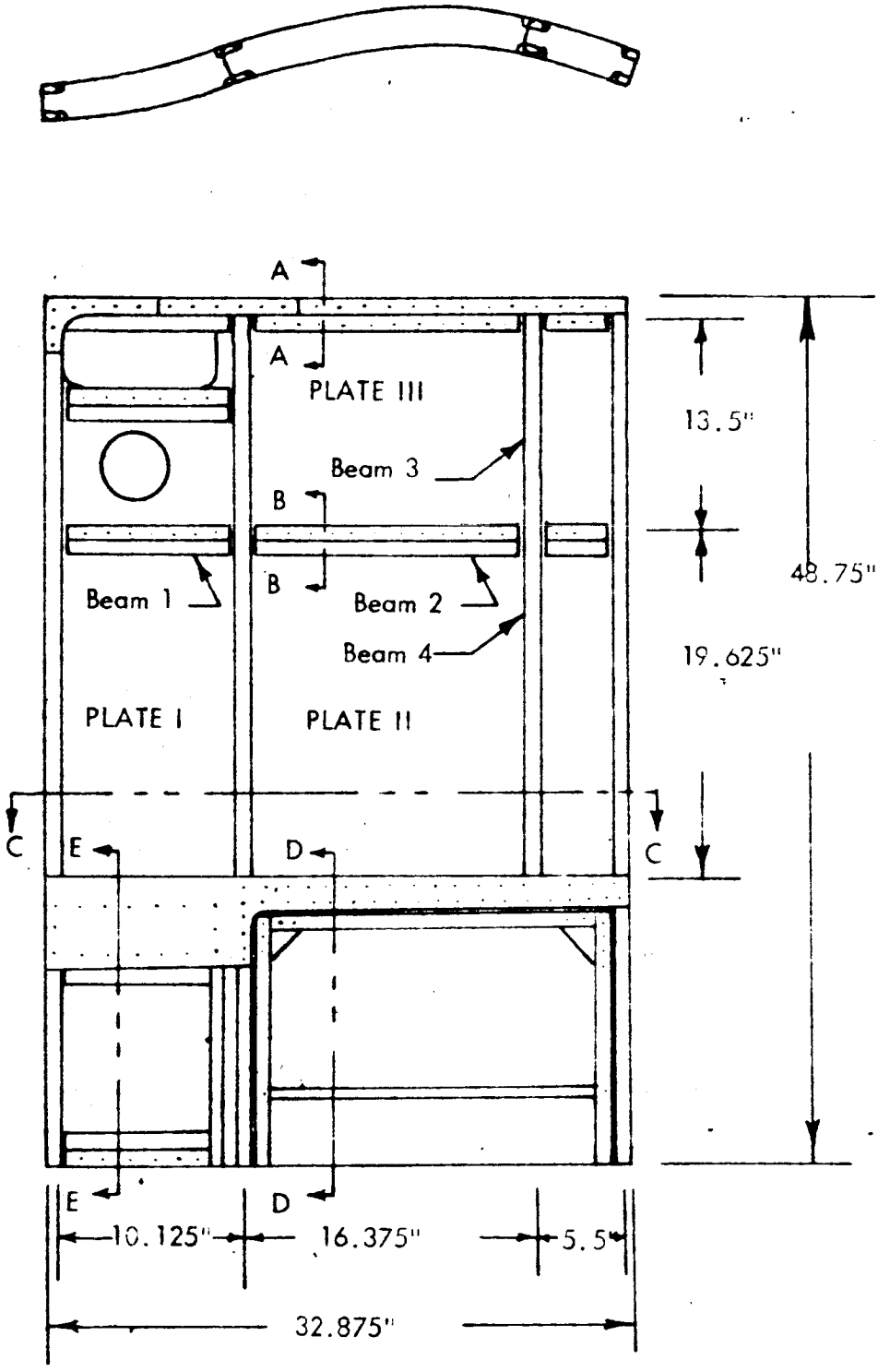


Figure 5: General Arrangement of Shroud Panel

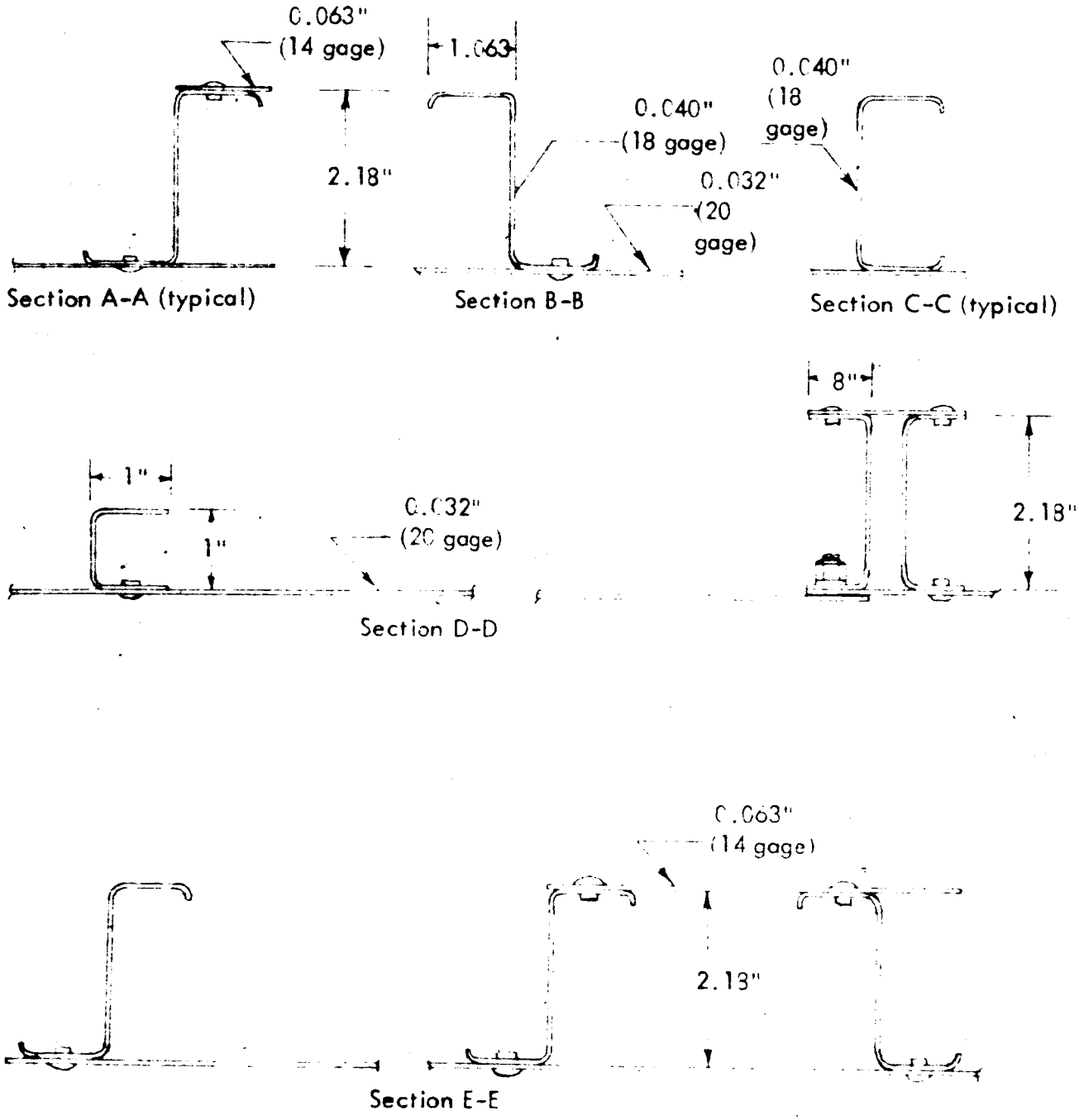
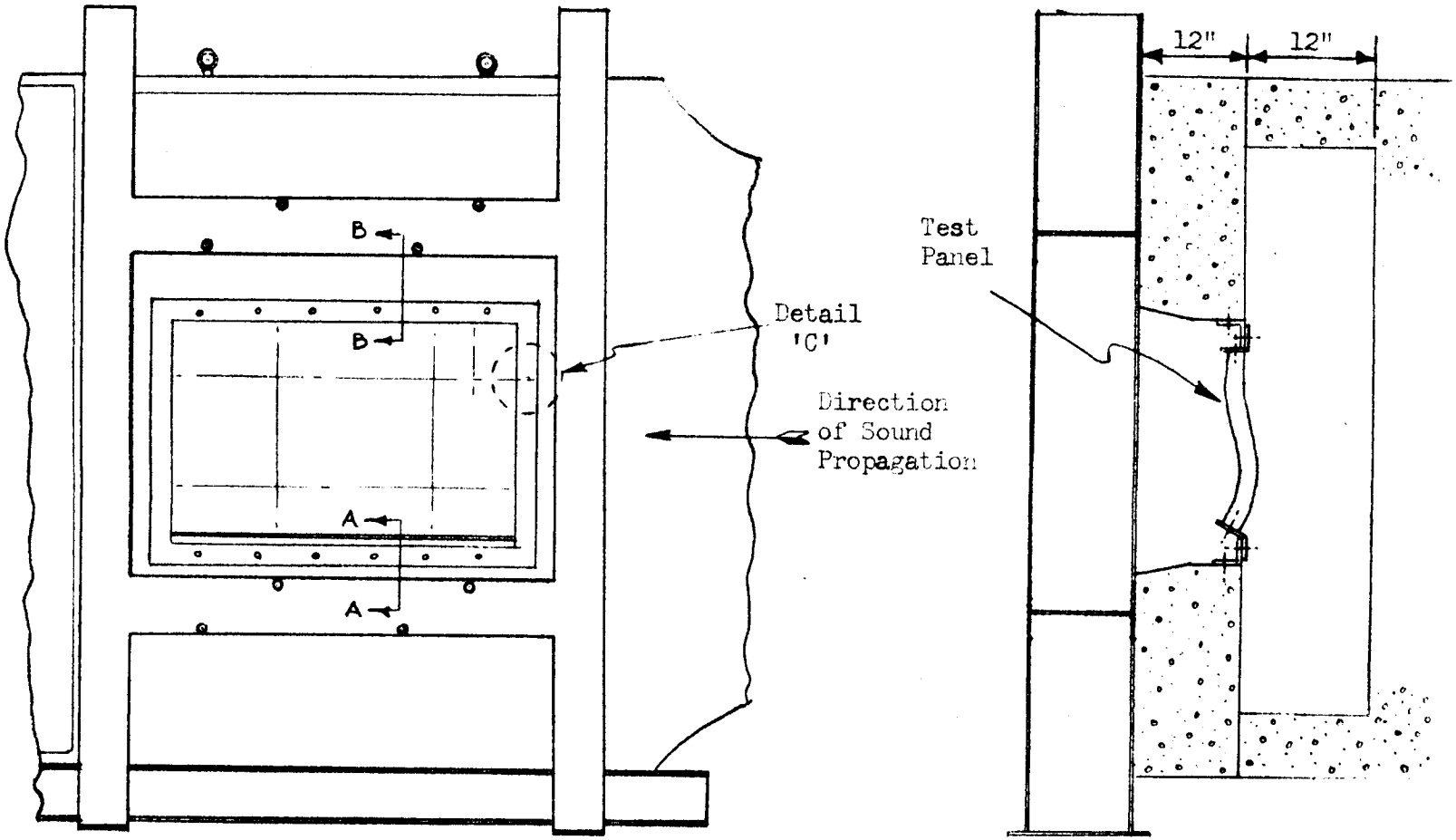


Figure 6: Details of Shroud Panel Construction.



For details of Sections AA & BB
and detail C, See Figure 8

Section looking from siren

Figure 7. General Arrangement of Test Setup for
Shroud Panel Grazing Incidence Tests

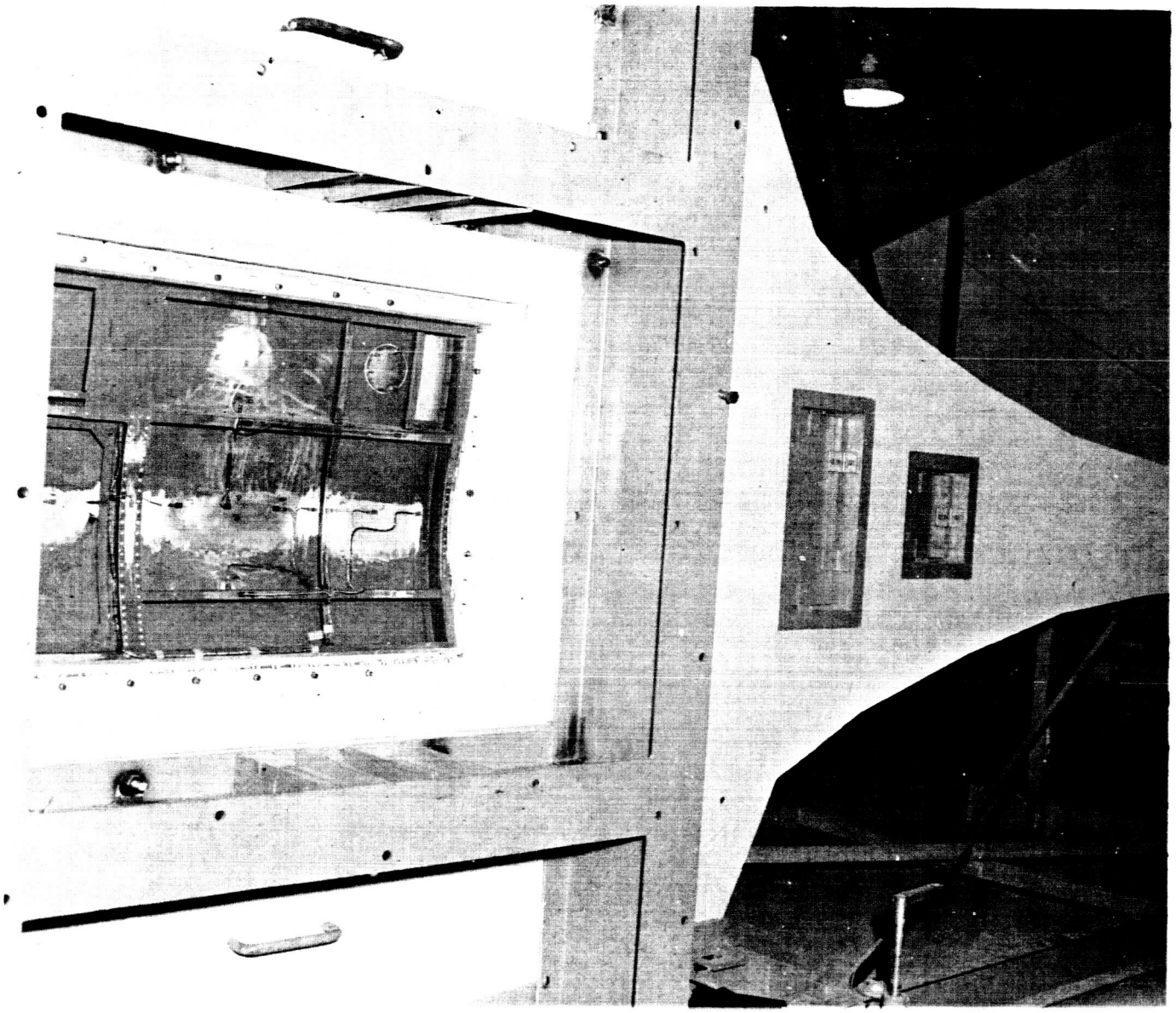


Figure 8: Shroud Panel Mounted in the Test Fixture.

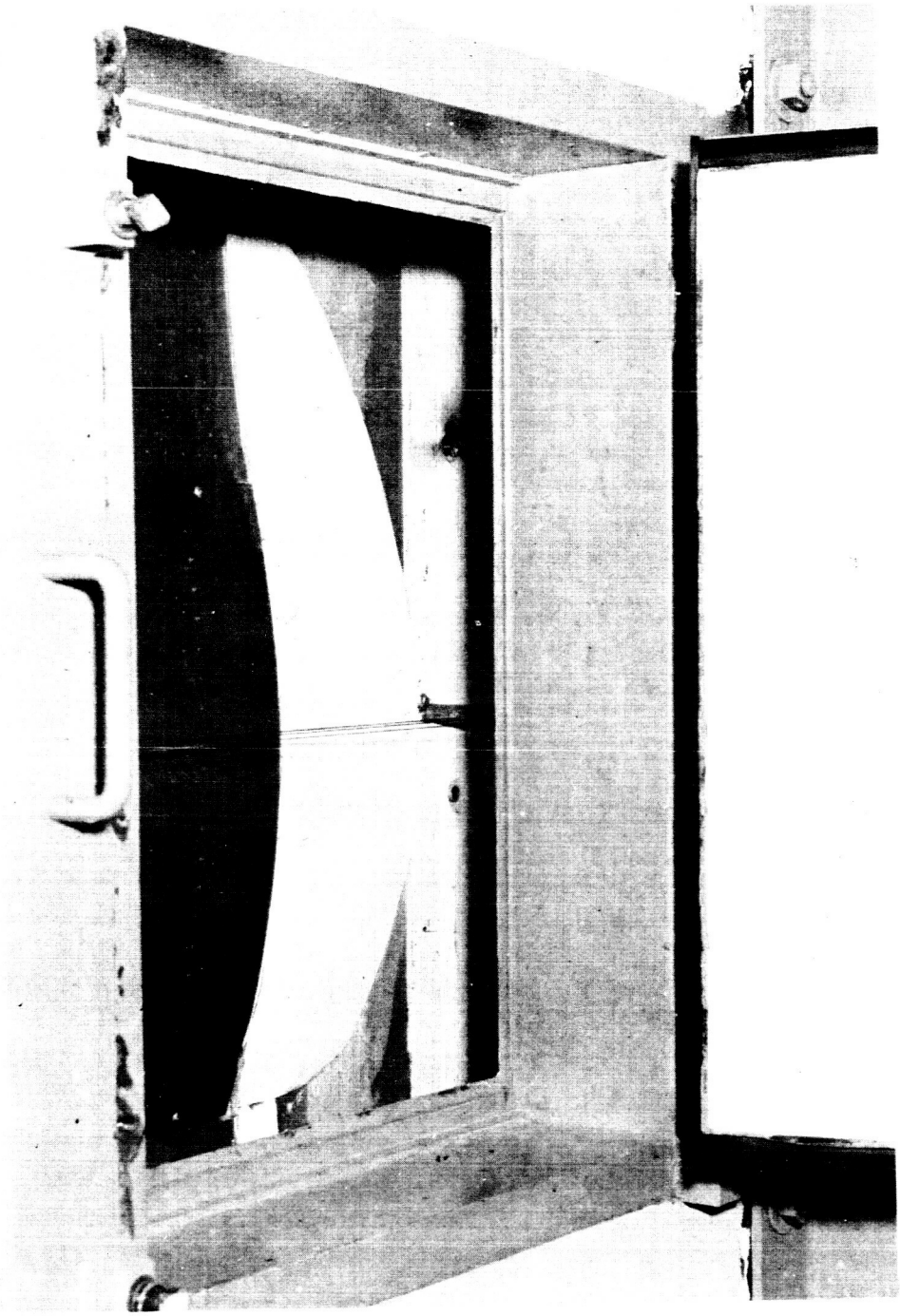
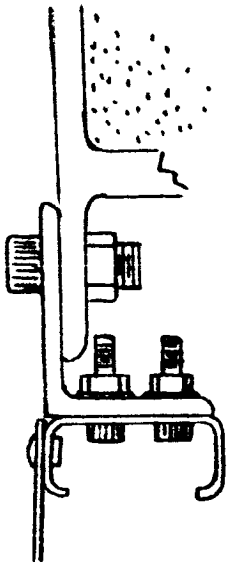
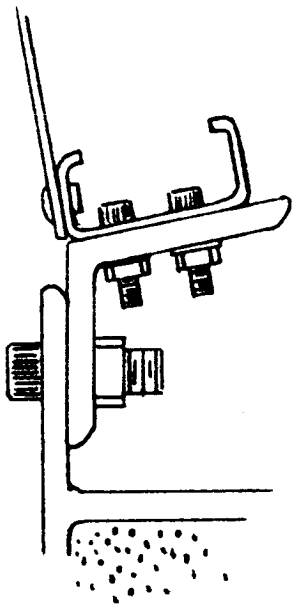


Figure 9: Downstream Fairing.



B-B



A-A

DETAIL 'C'

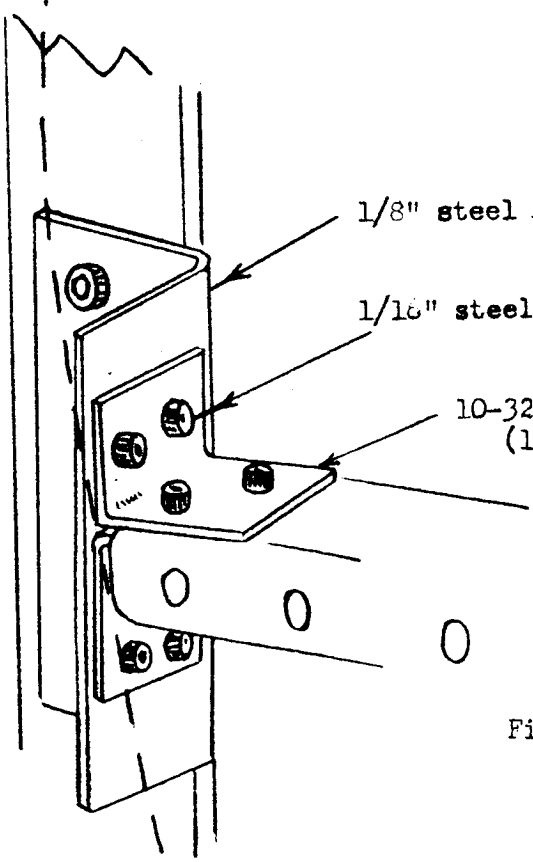


Figure [illegible] Sketches Showing Details of Test Fixture - Shroud Panel

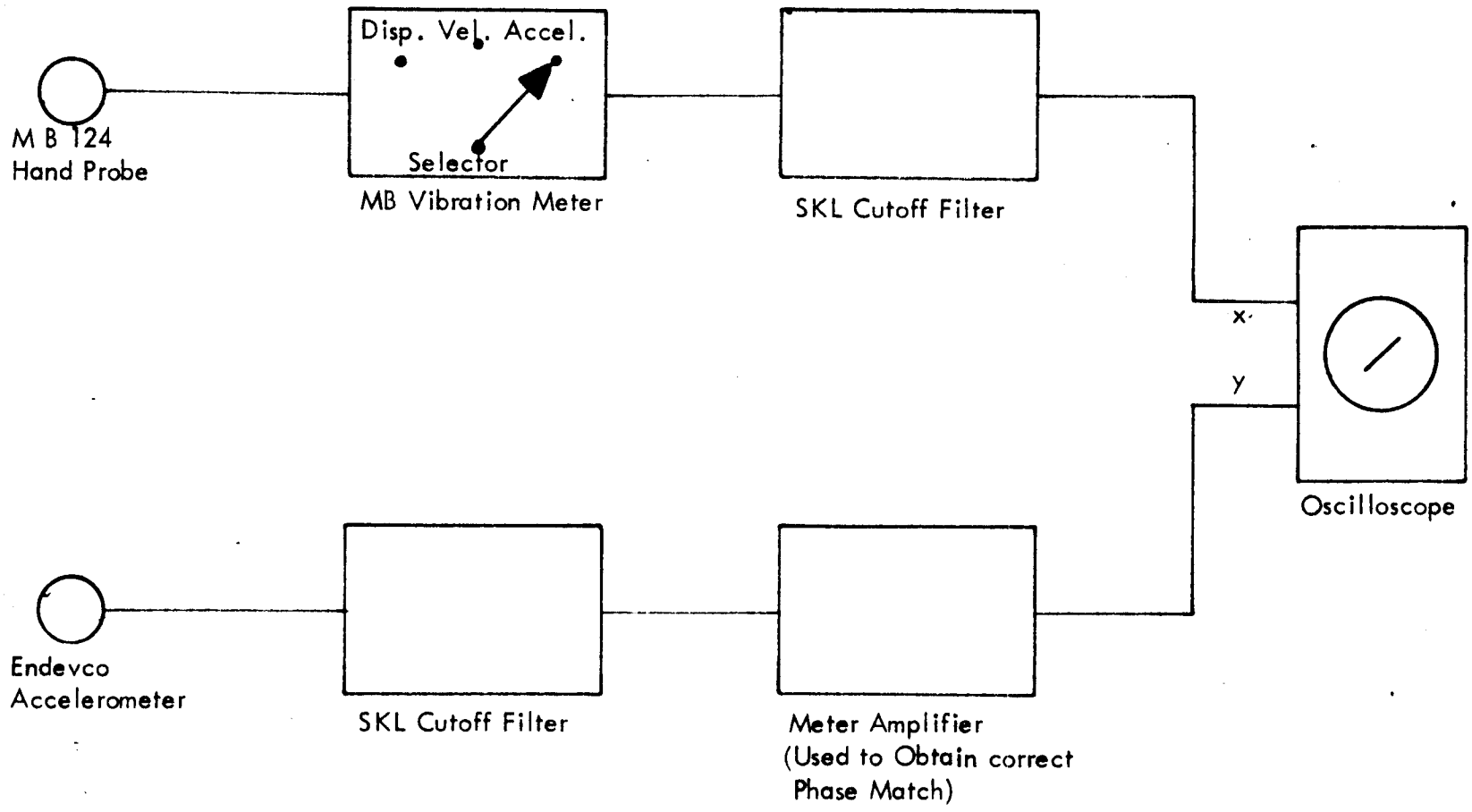
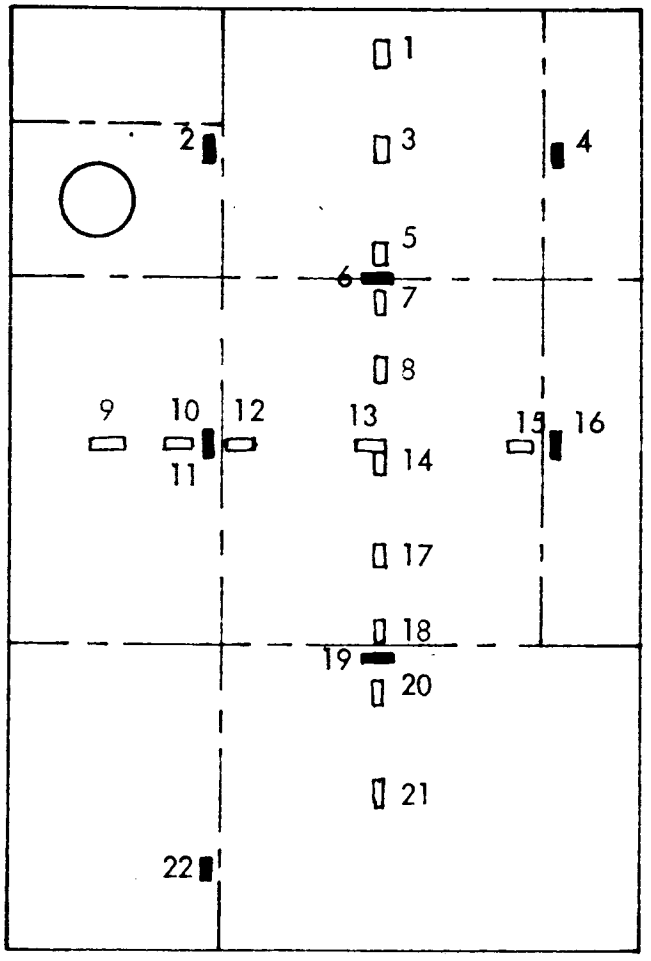


Figure 11: Mode Shape Study-Instrumentation Block Diagram.



Notes: 1. ▮ Gauges on Stiffener Flanges (Figure 4)

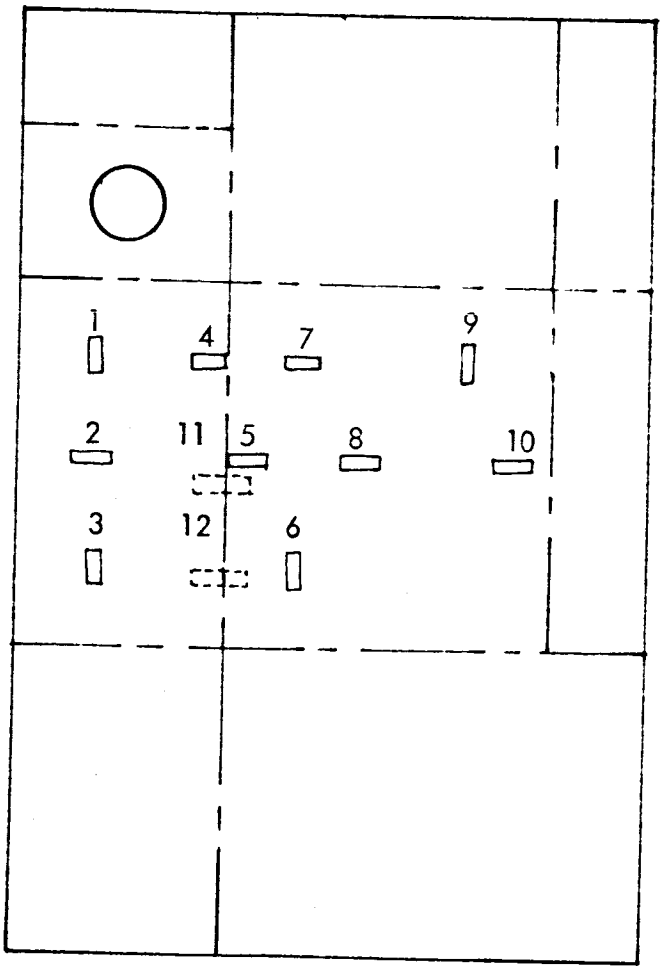
2. ▯ Gauges on Skin (back side, Figure 4)

3. All Gauges 120 ohm, Gauge Factor 2.06

Figure 12: Strain Gauge Locations
Panel No. 1.

Back panel side (Figure 4)

Front panel side (Figure 3)

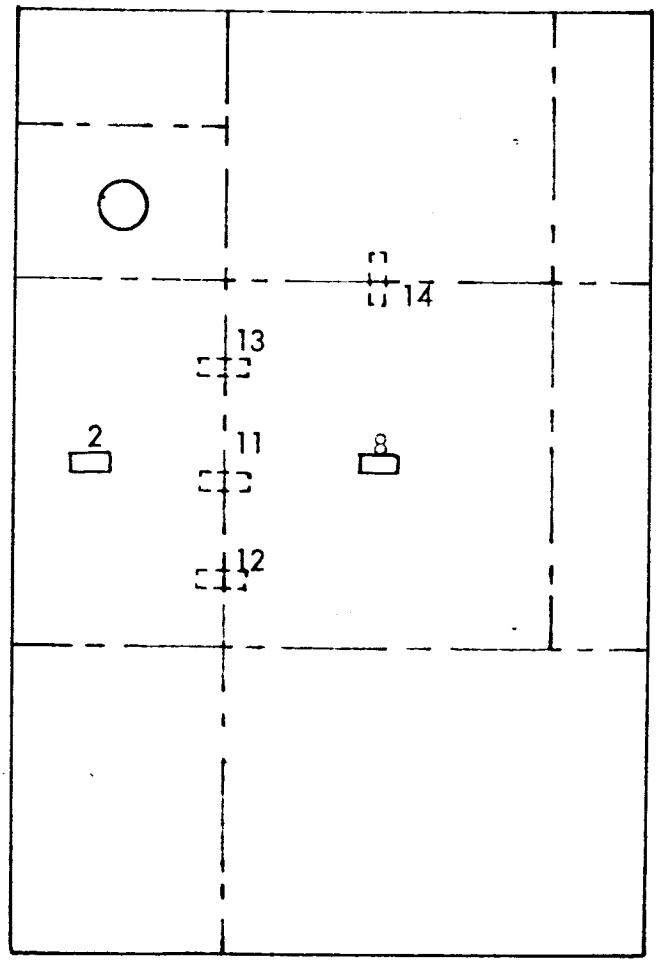


Notes: 1. Gauges 11 and 12 were on (Front) Outer Face of Panel.
2. All gauges 120Ω, Gauge Factor 2.06.

Figure 13: Strain Gauge Locations Panel No. 2.

Back panel side (Figure 4)

Front panel side (Figure 3)



Notes: 1. Gauges 11, 12, 13, and 14 were on (Front) Outer Face of Panel.

2. All gauges 120 Ω, Gauge Factor 2.06.

Figure 14: Strain Gauge Locations Panel No. 3.

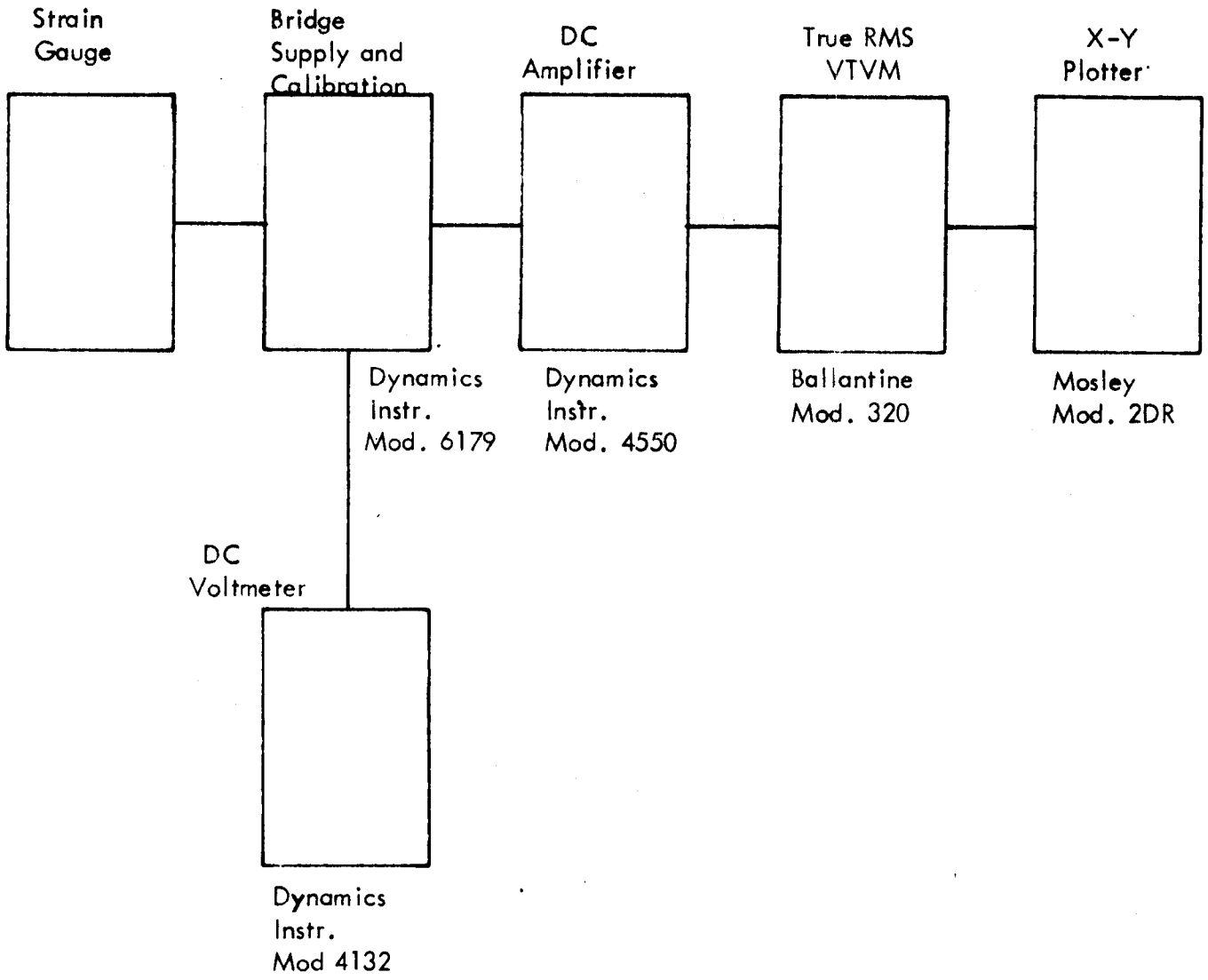


Figure 15A: Block Diagram of Strain Gauge Circuit for Frequency Sweeps.

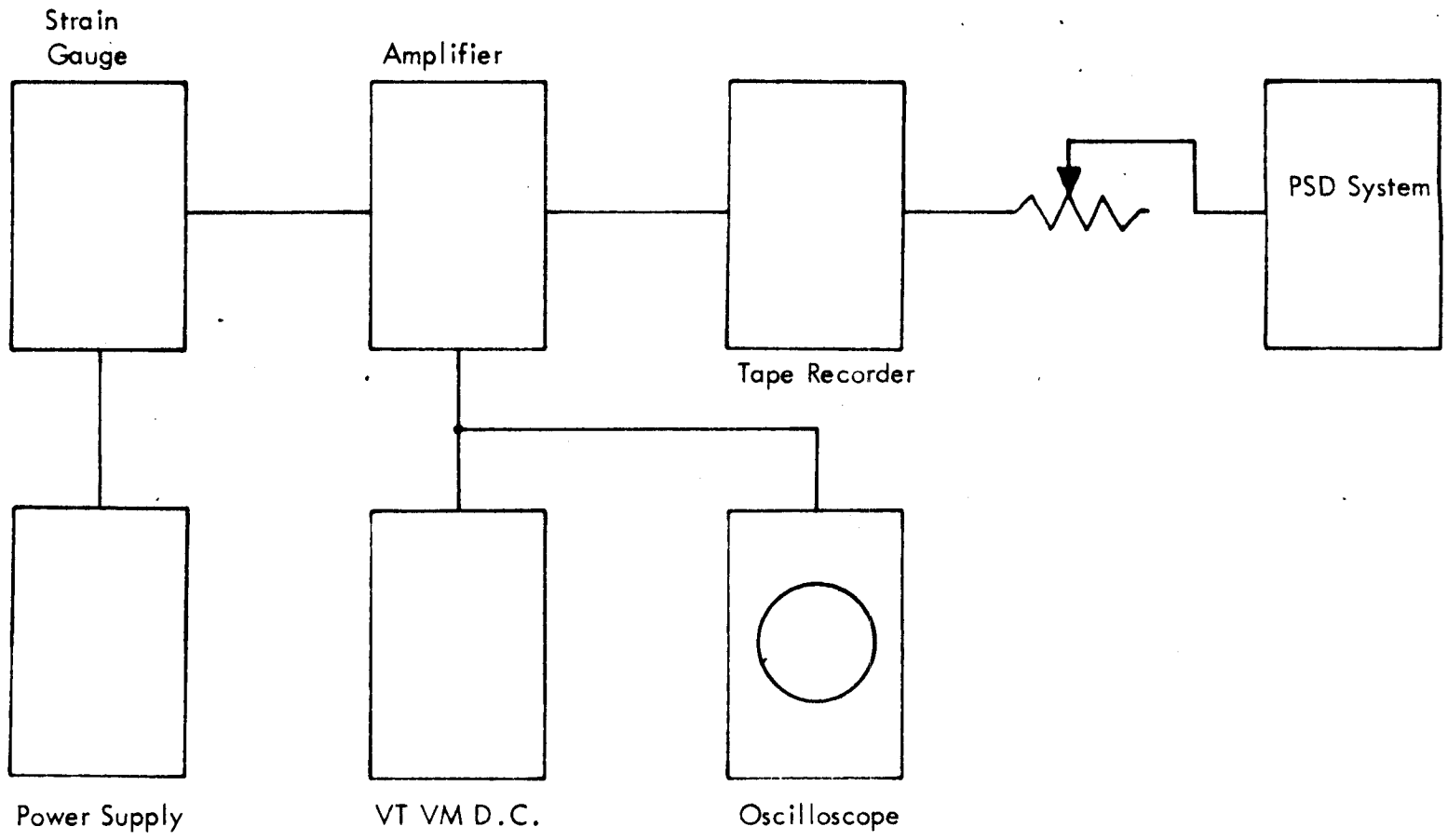


Figure 15B: Block Diagram of Strain Gauge Circuit for Broad Band Excitation.

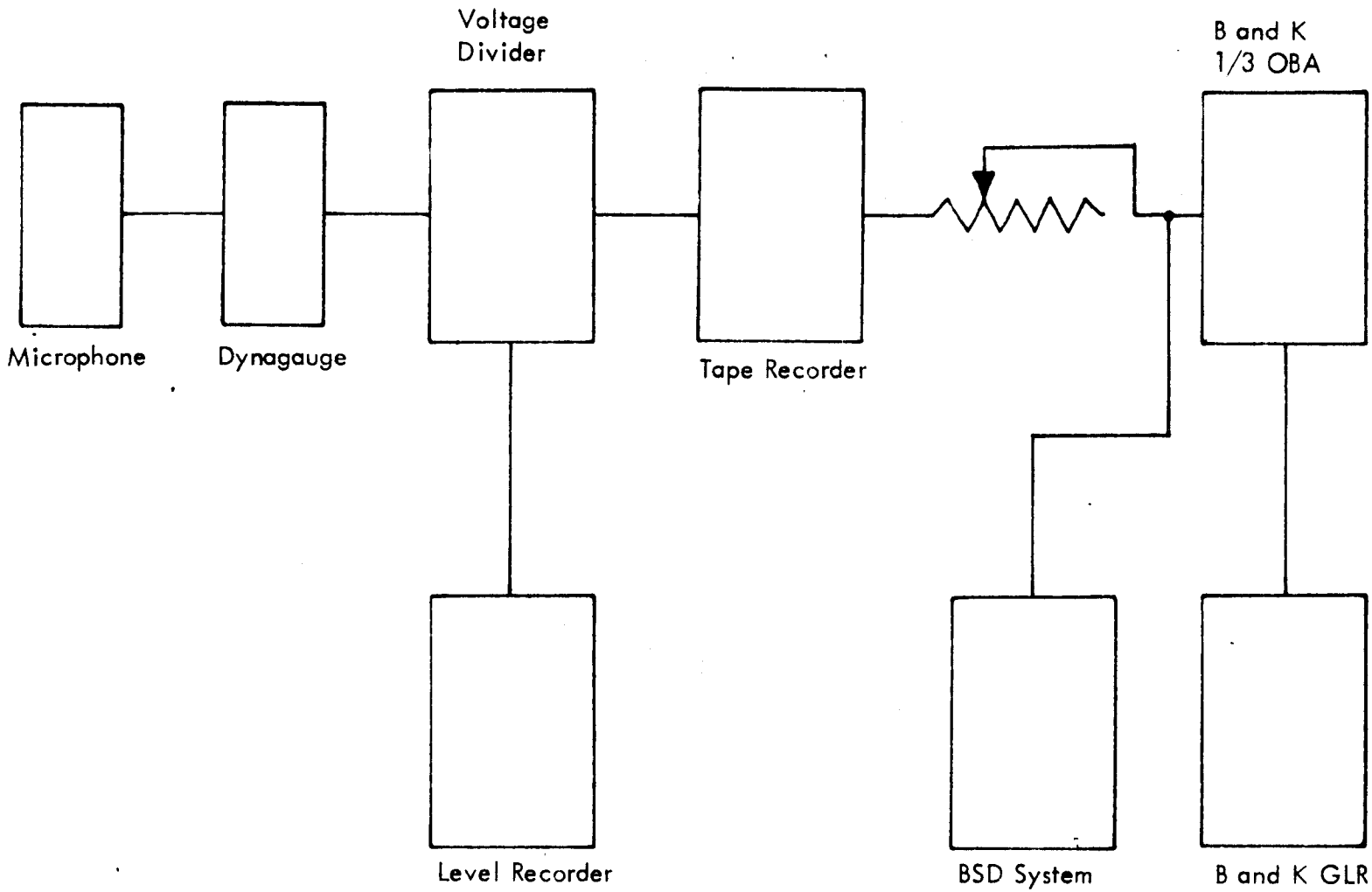
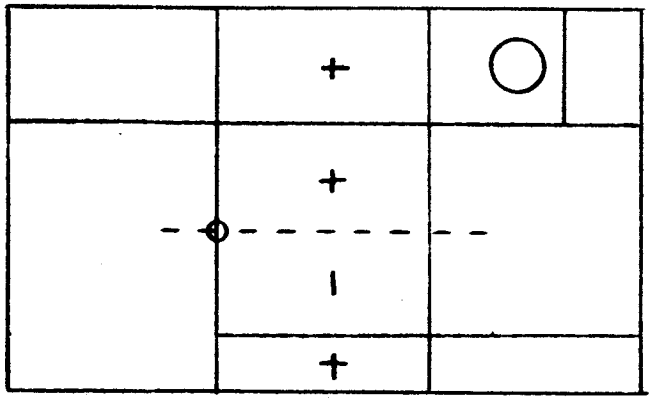


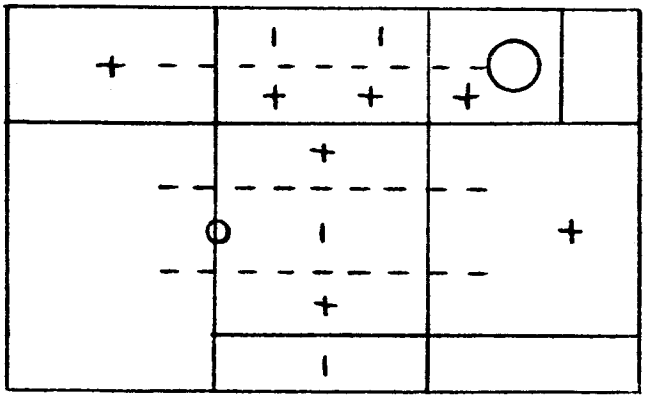
Figure 16: Microphone Output Measurement Instrumentation Block Diagram.



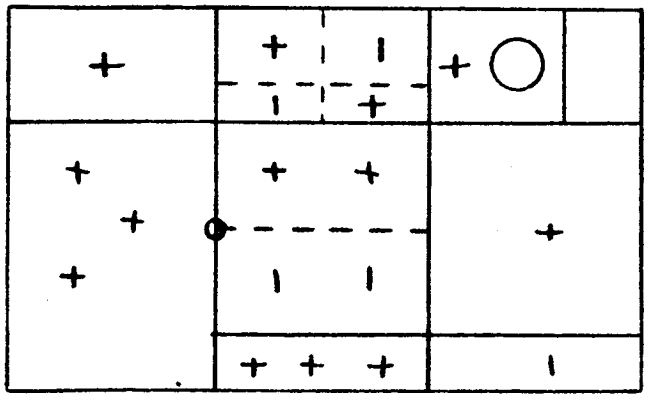
Frequency 100 cps
SPL 120 db

Legend;

----Node Lines
+ in phase
- out of phase

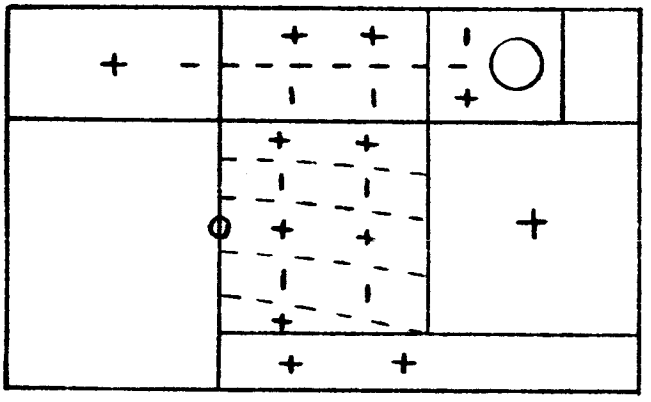


Frequency 152 cps
SPL 120 db

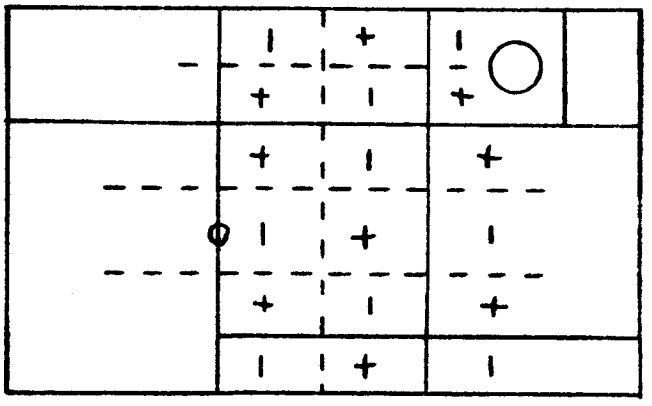


Frequency 169 cps
SPL 120 db

Figure 17: Panel Mode Shapes and Response Frequencies-Experimental.



Frequency 200 cps
SPL 120 db



Frequency 220 cps
SPL 120 db

Legend: ----- Node Lines
+ In phase
- out of phase

Figure 50: Panel Mode Shapes and Response Frequencies (Cont'd)
Experimental.

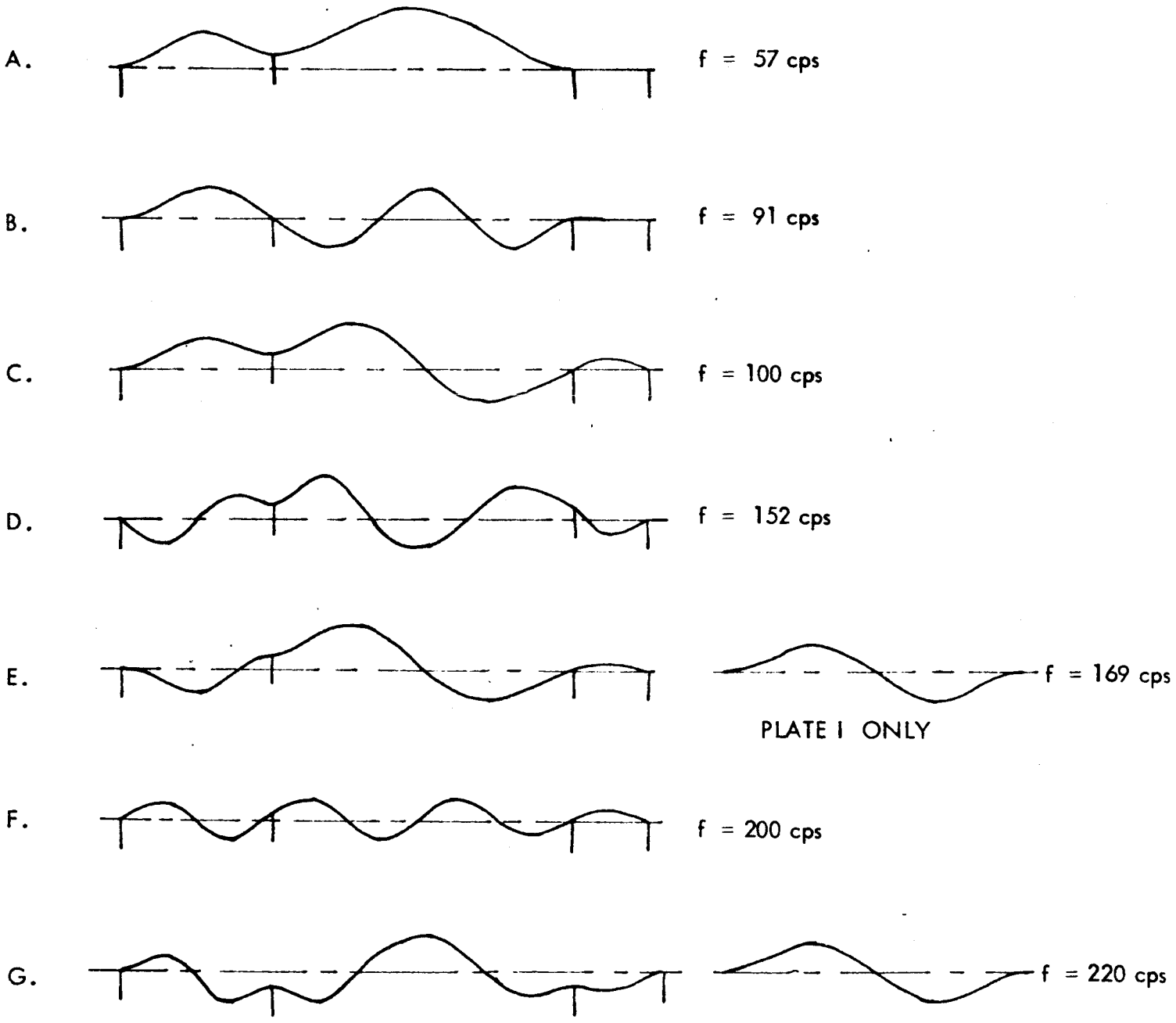


Figure 19: Experimental Mode Shapes (Qualitative)

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MILLIMETER 3 CYCLES X 10 DIVISIONS

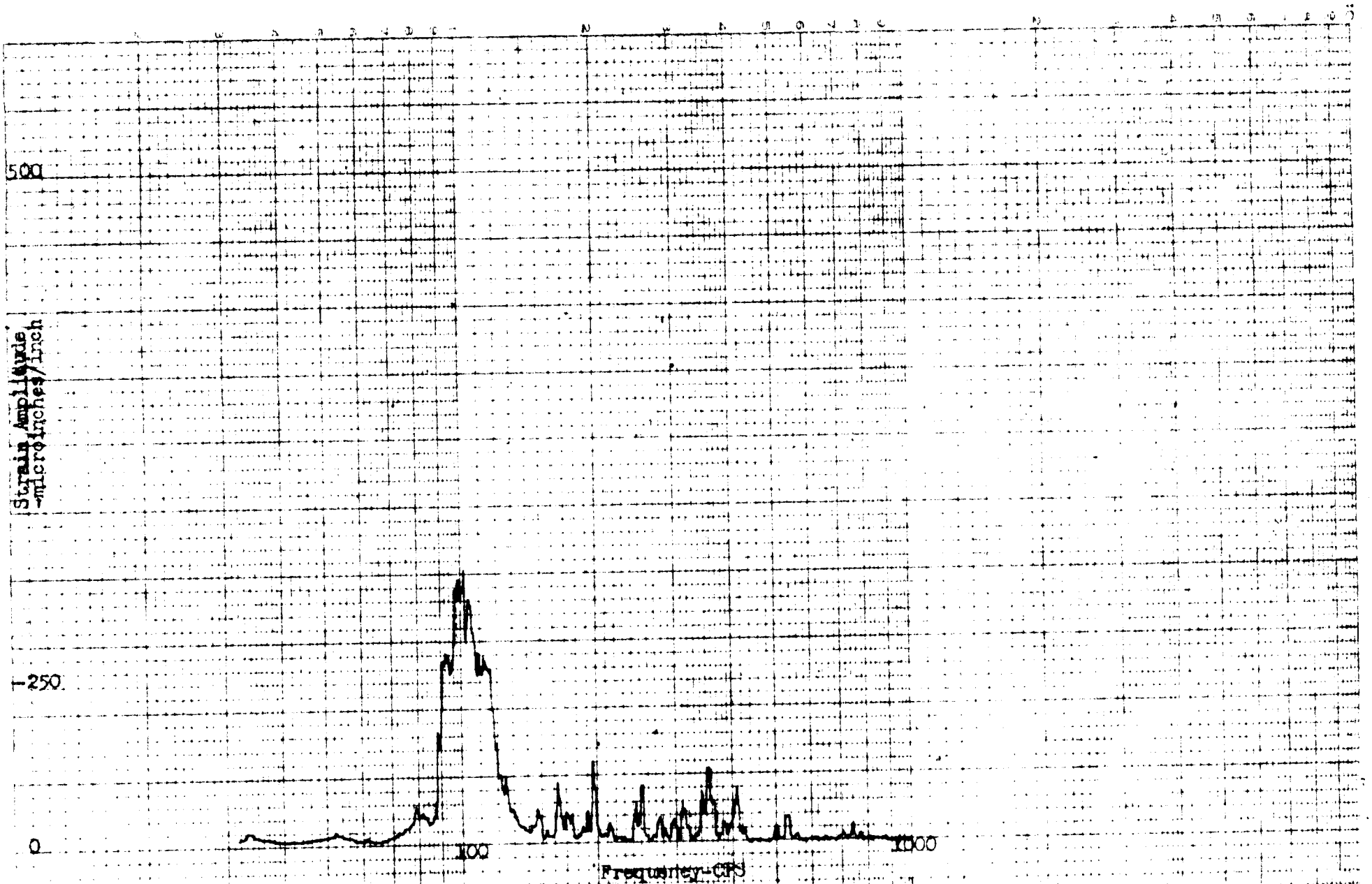

Figure 20. Shroud Panel No. 1 - Discrete Frequency Sweep at 139DB - Gage No. 9

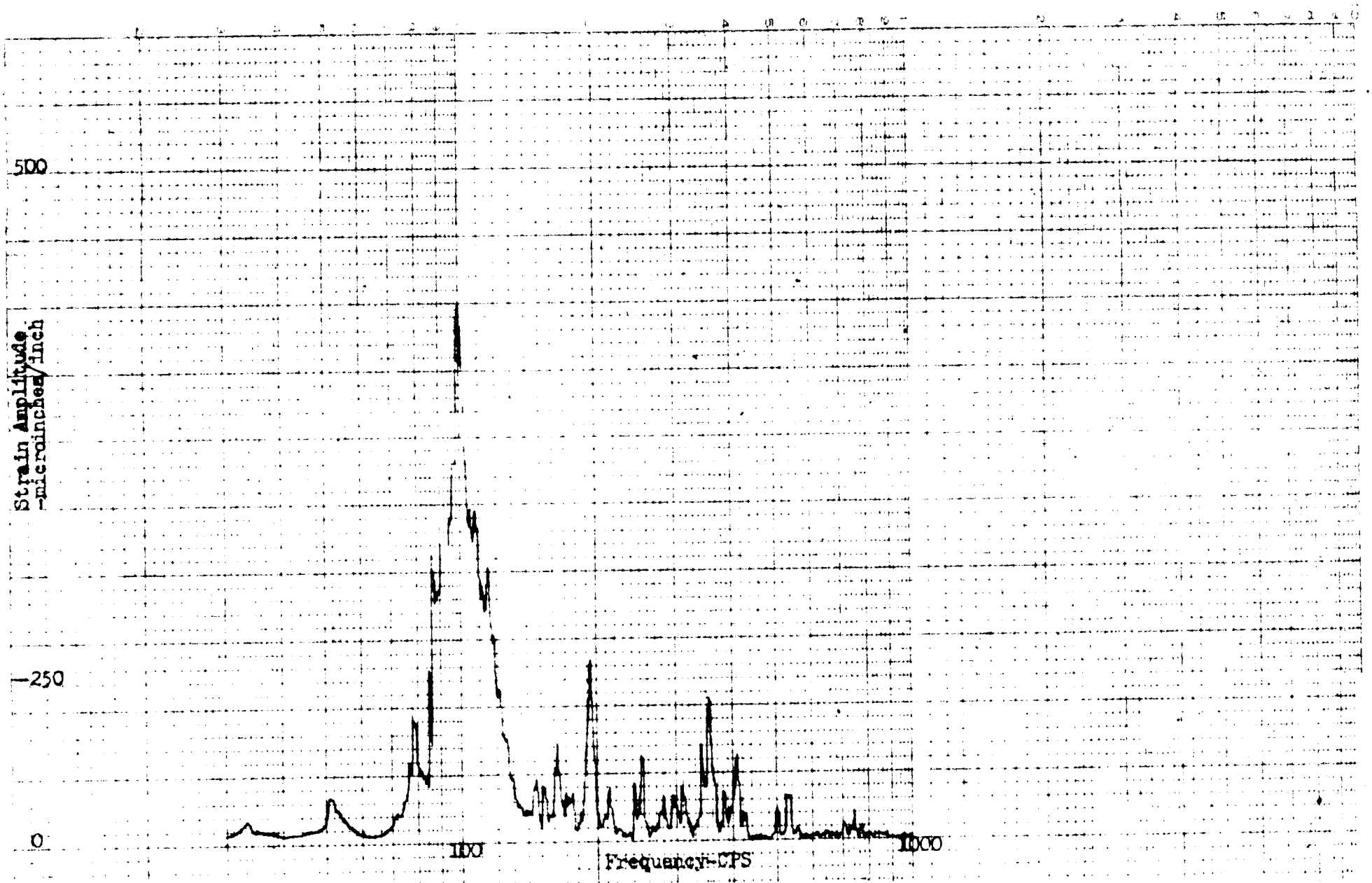

Figure 21 Shroud Panel No. 1 - Discrete Frequency Sweep at 142DB - Gage No. 9

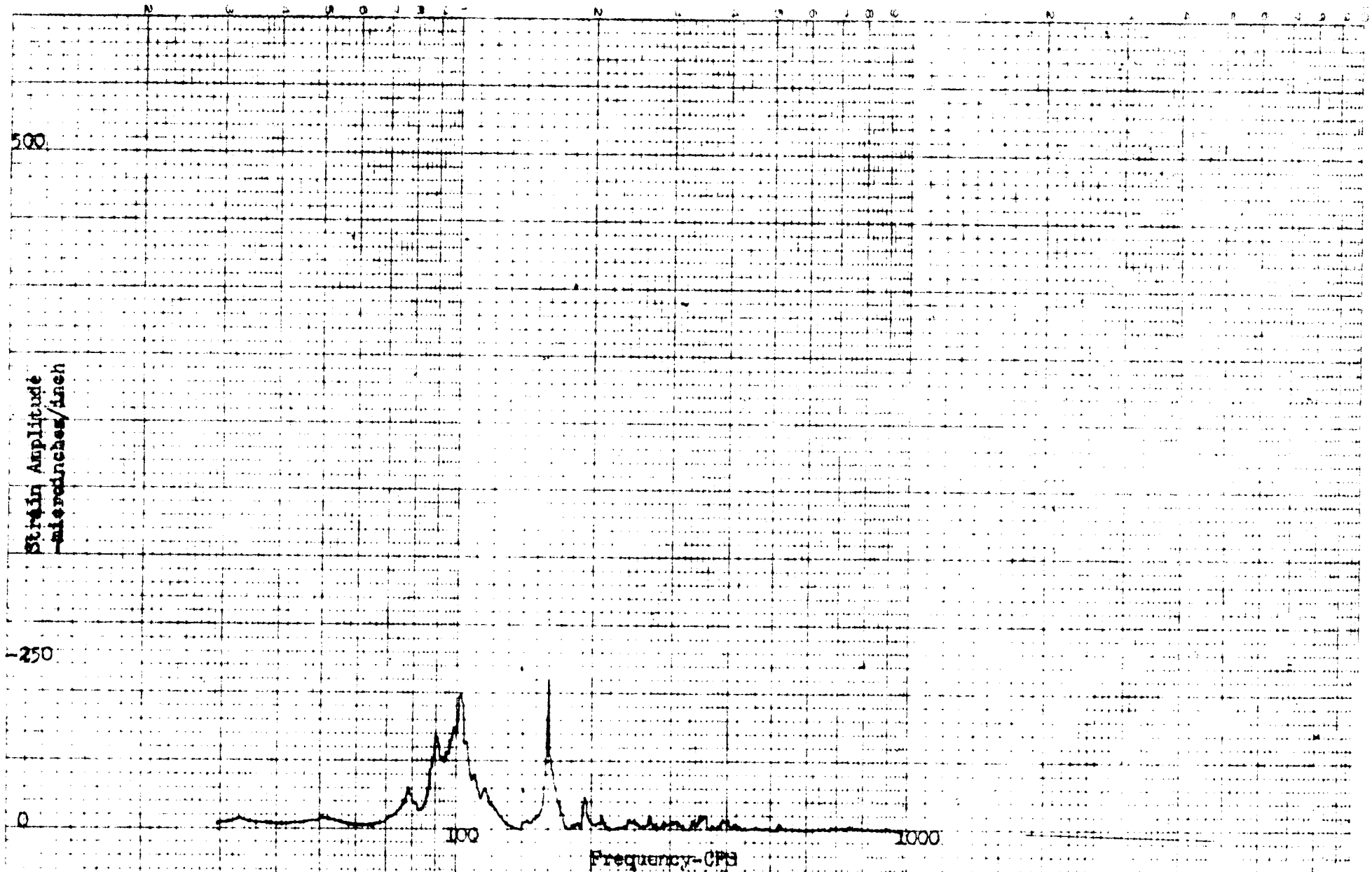

Figure 22 Shroud Panel No. 1 - Discrete Frequency Sweep at 136DB - Gage No. 10

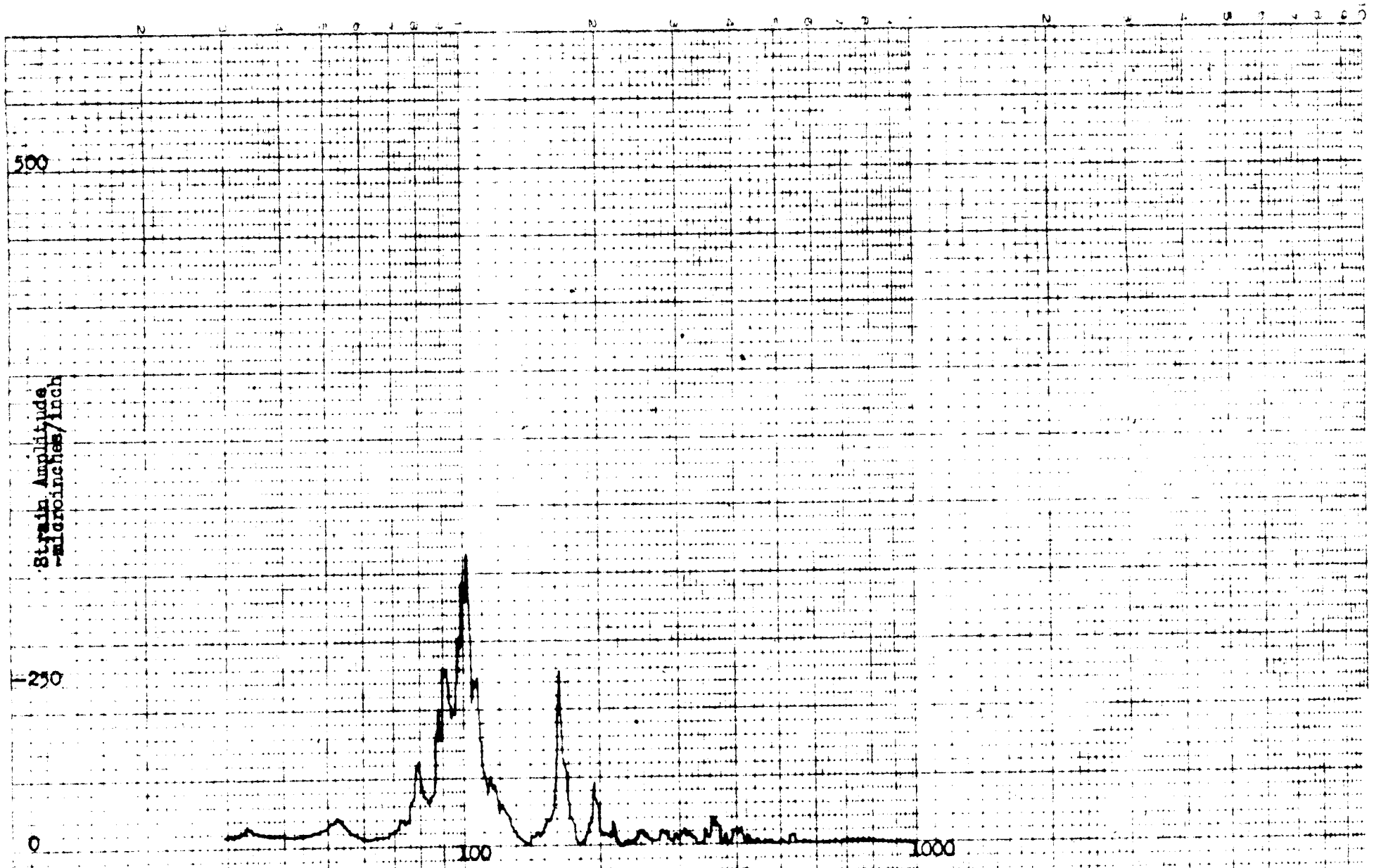

Figure 23 Shroud Panel No. I – Discrete Frequency Sweep at 139DB – Gage No. 10

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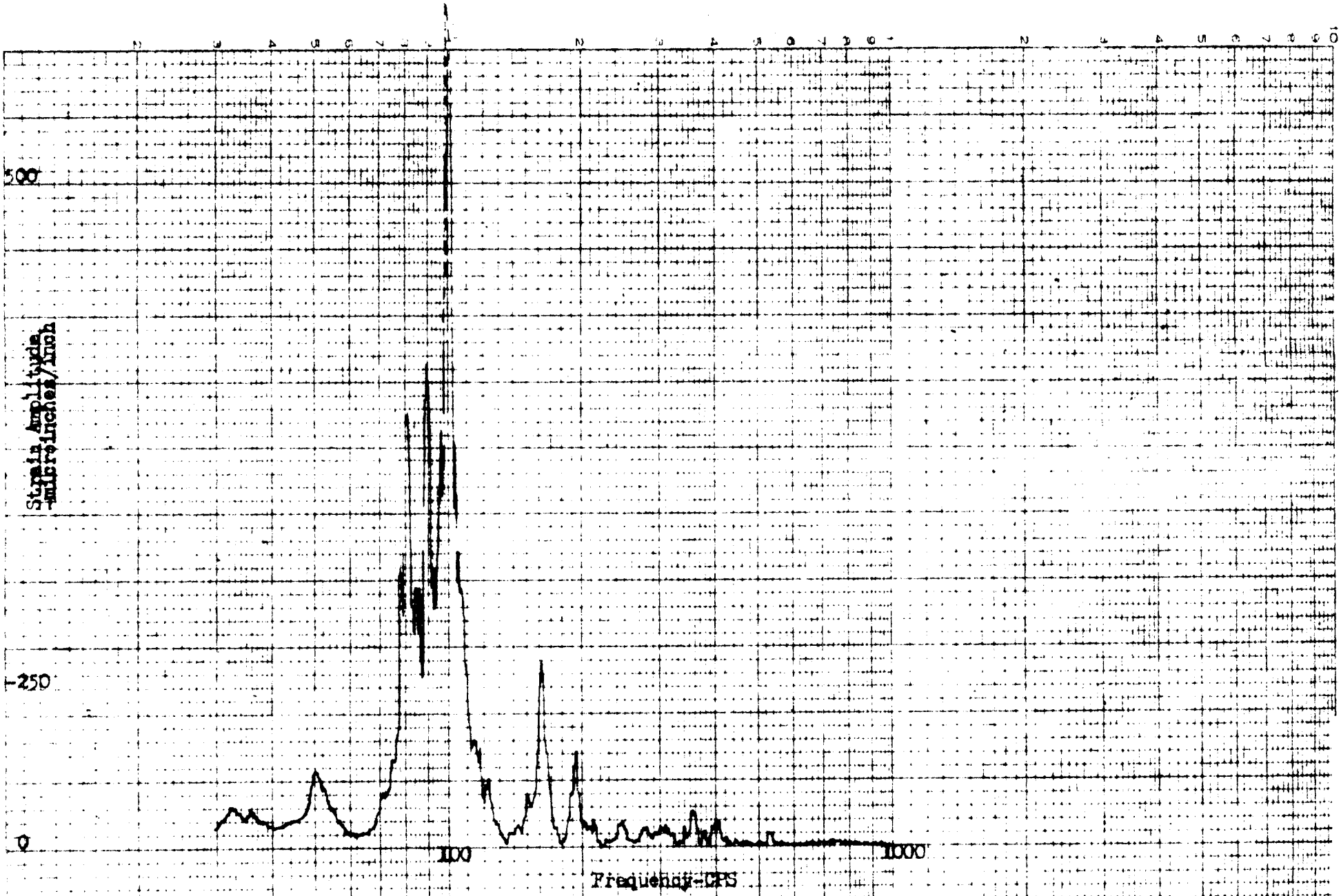

Figure 24 Shroud Panel No. 1 - Discrete Frequency Sweep at 14.2 DB - Gage No. 10

340R-L910 DIETZGEN GRAPH PAPER

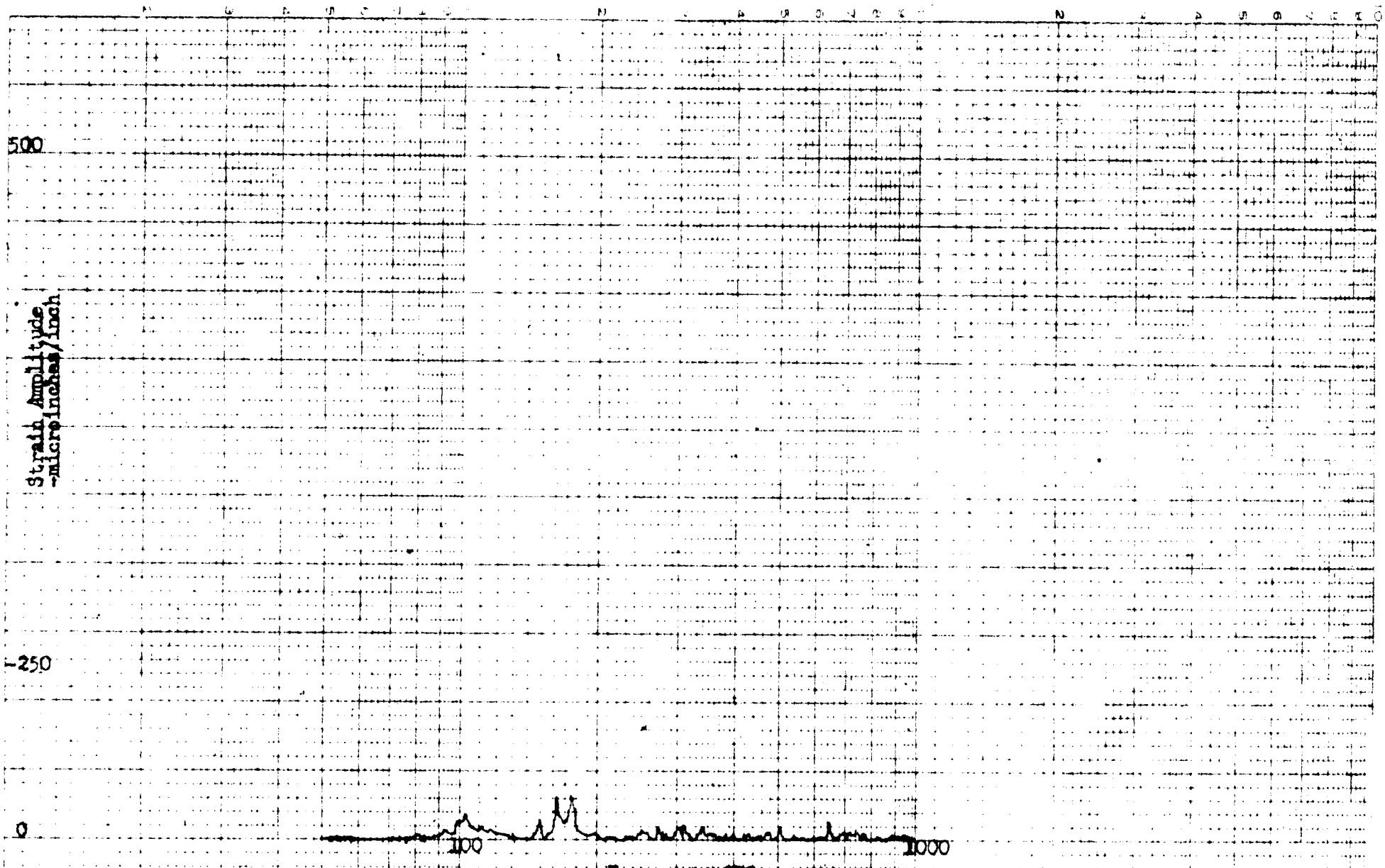

Figure 25 Shroud Panel No. 1 - Discrete Frequency Sweep at 136DB - Gage No. 12

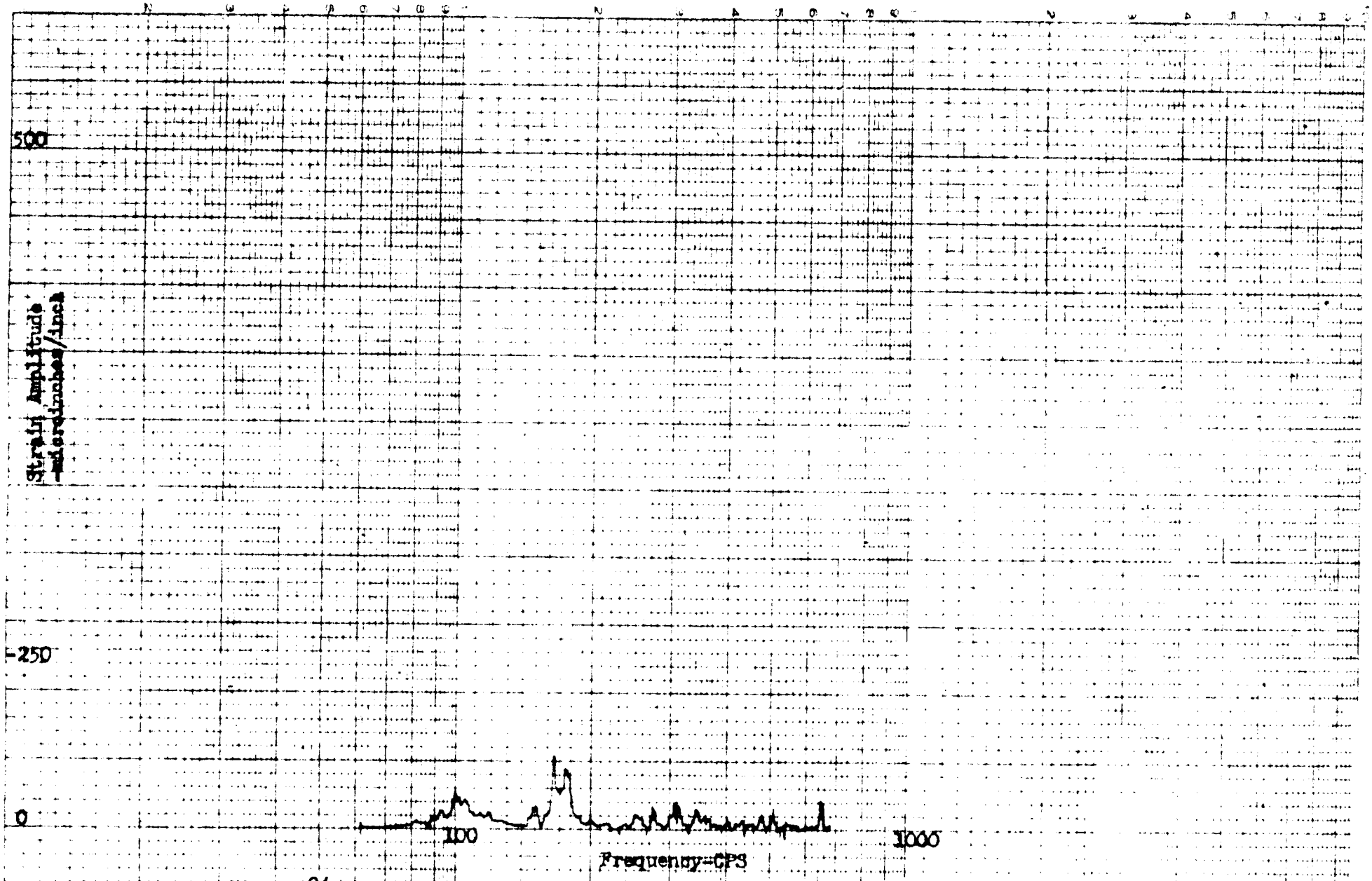

Figure 26 Shroud Panel No. 1 - Discrete Frequency Sweep at 139DB - Gage No. 12

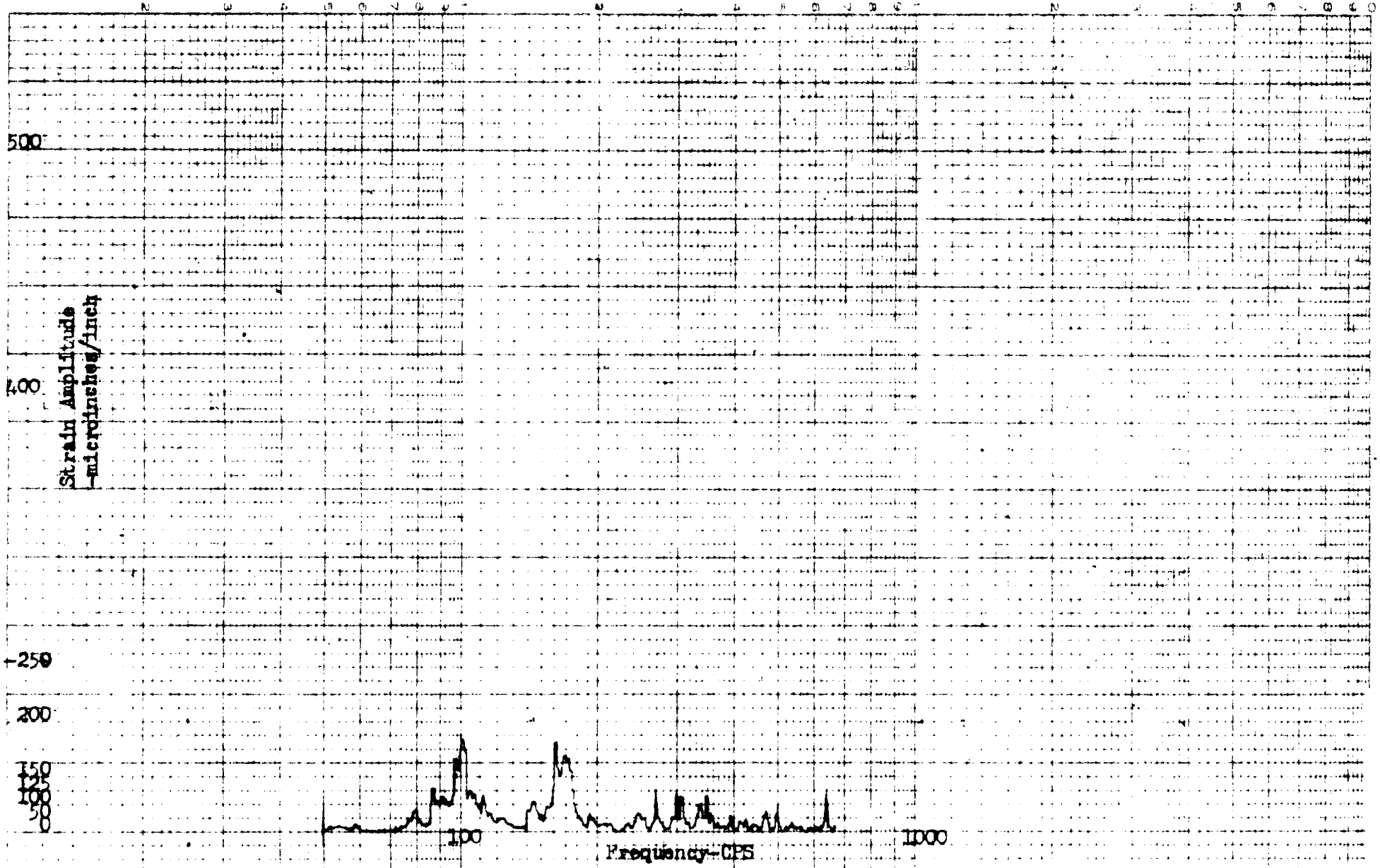

Figure 27 Shroud Panel No. 1 - Discrete Frequency Sweep at 142DB - Gage No. 12

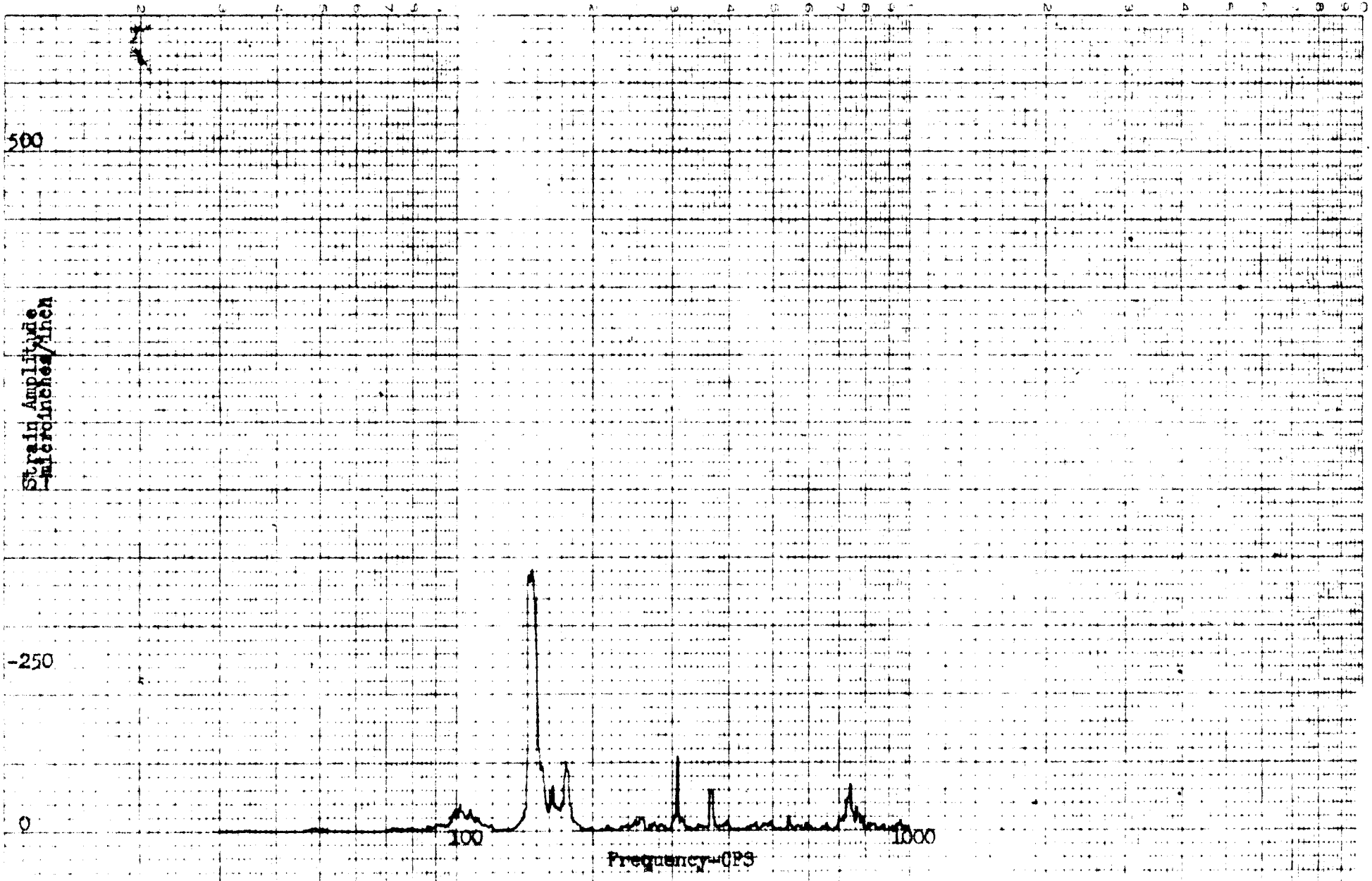

Figure 28 Shroud Panel No. 1 - Discrete Frequency Sweep at 136DB - Gage No. 13

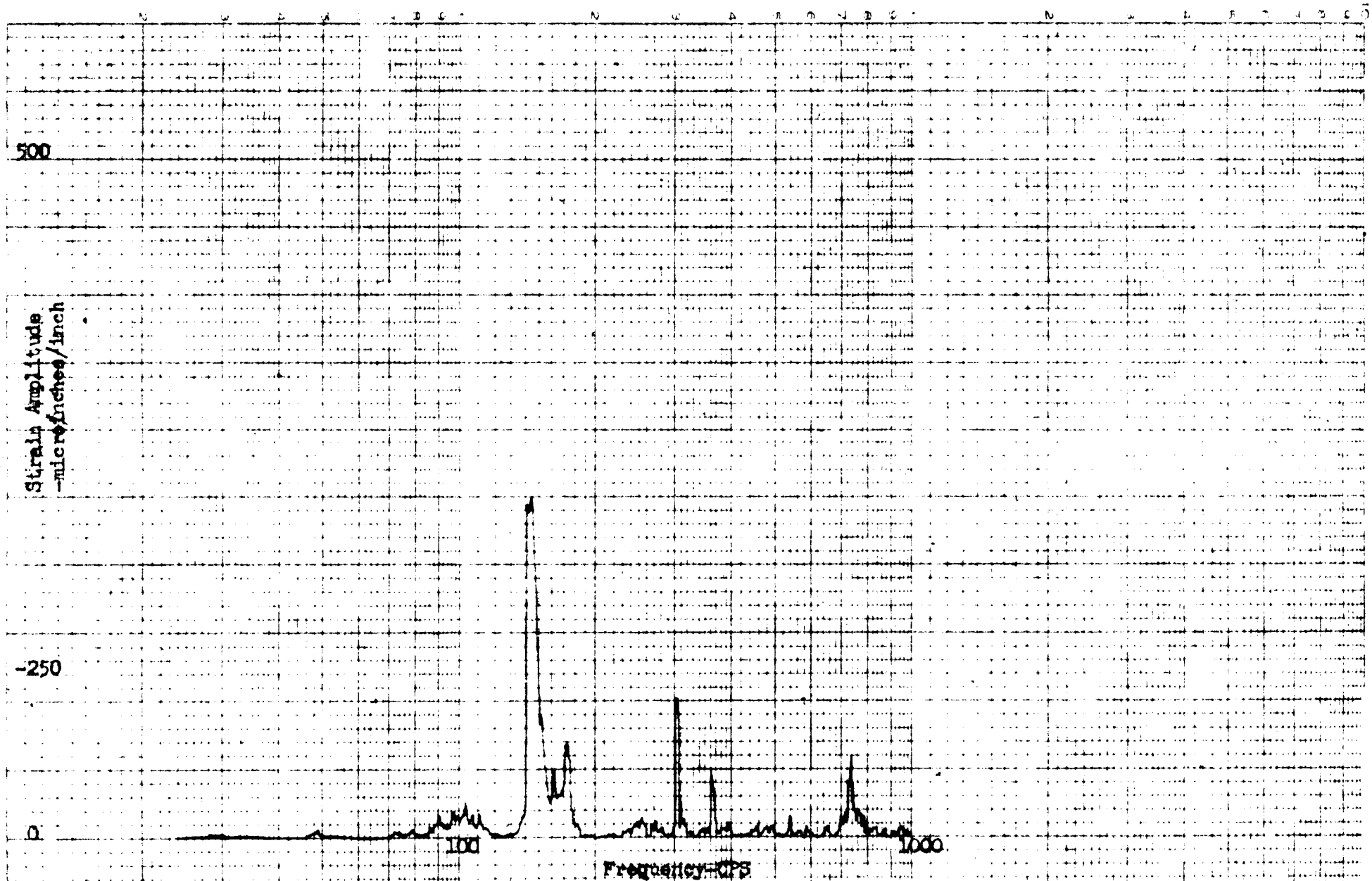

Figure 29 Shroud Panel No. 1 - Discrete Frequency Sweep at 139DB - Gage 13

LOGARITHMIC 3 CYCLES X 10 DIVISIONS

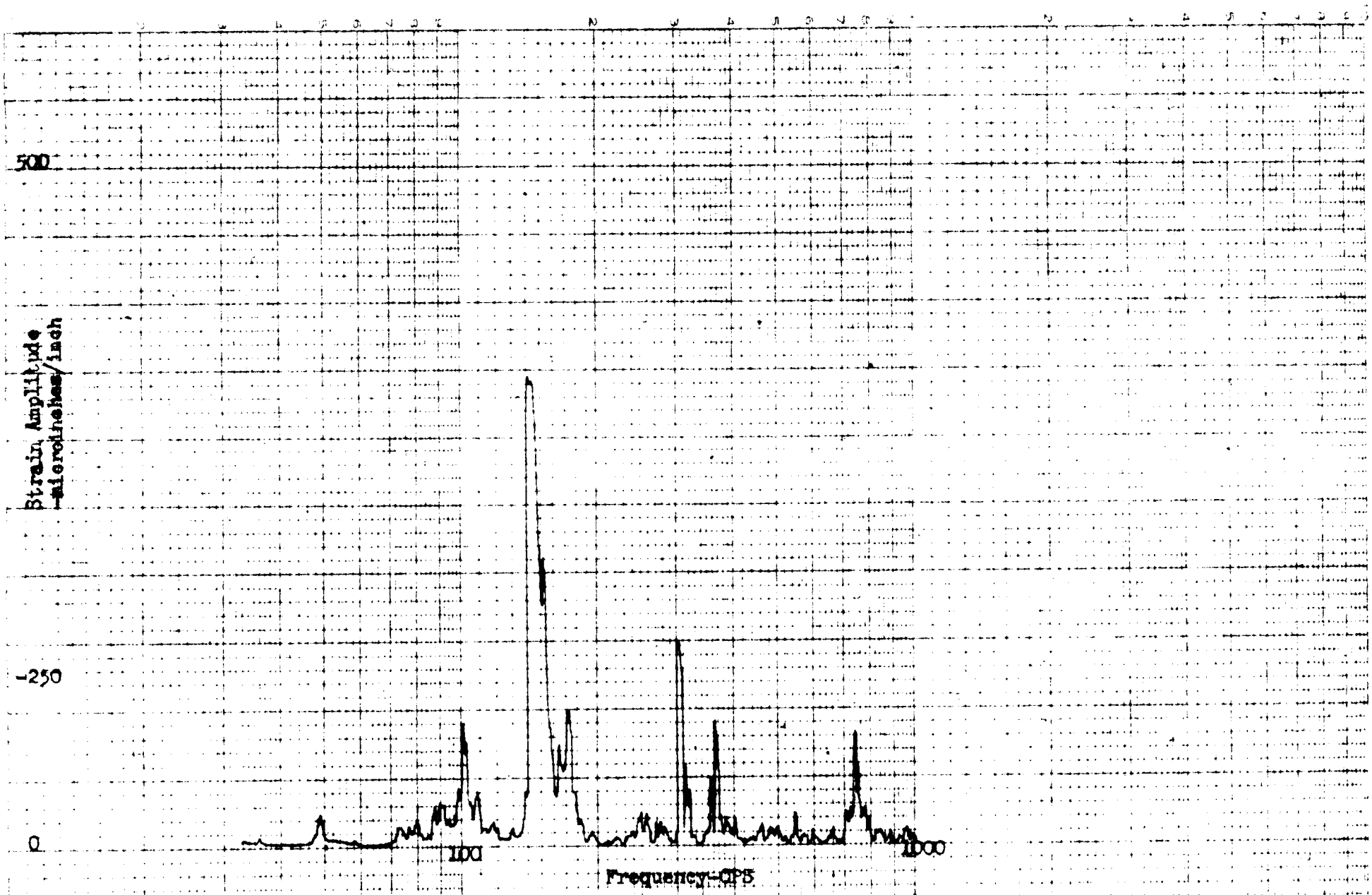

Figure 30 Shroud Panel No. 1 - Discrete Frequency Sweep at 143DB - Gage No. 13

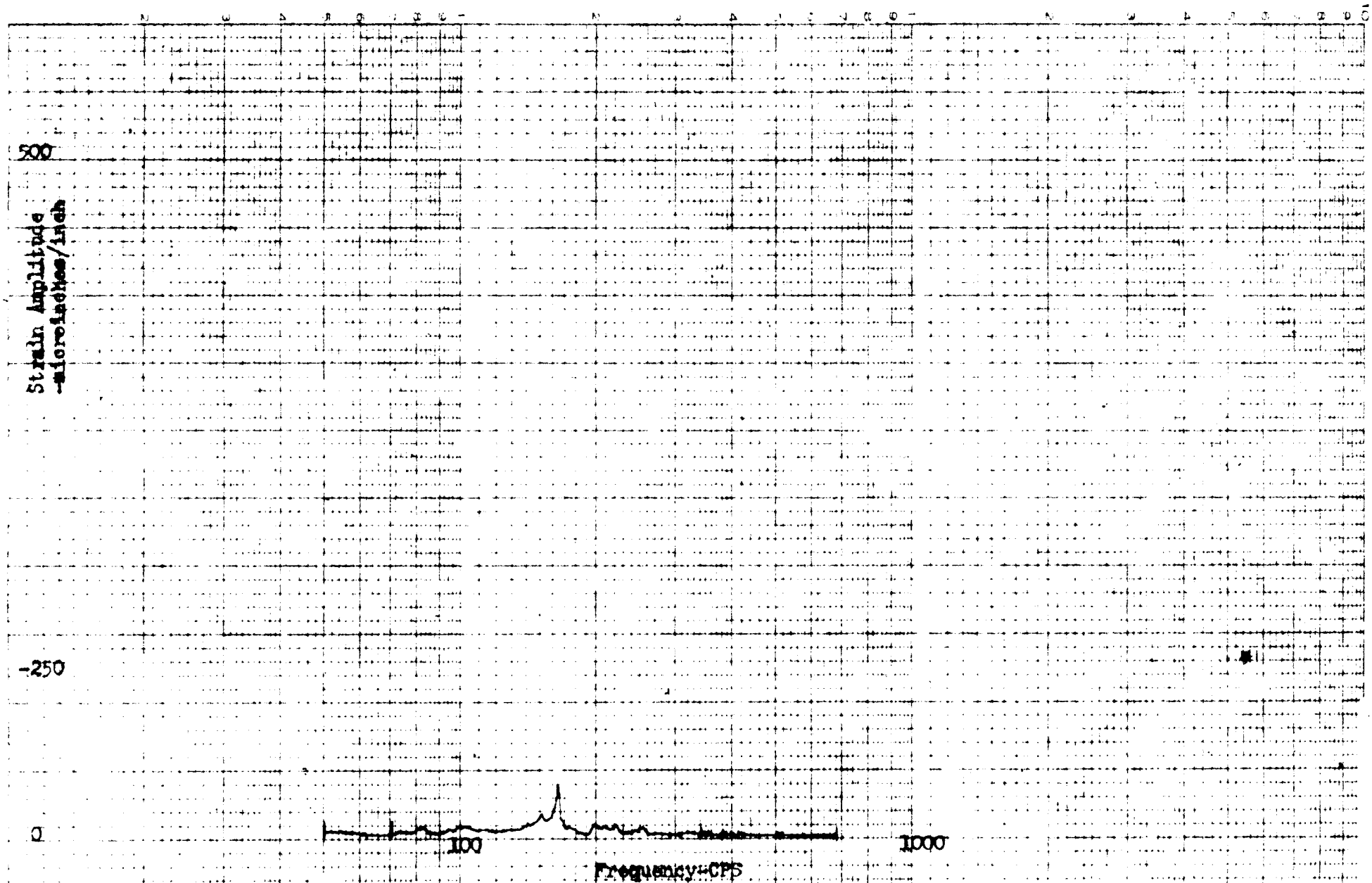

Figure 31 Shroud Panel No. 1 - Discrete Frequency Sweep at 14.2DB - Gage No. 19

OR-DIETZ GRAPH PAPER
41-LOGARITHMIC-3 CYCLES X 10 DIVISIONS
GENERAL
PRINTED IN U.S.A.

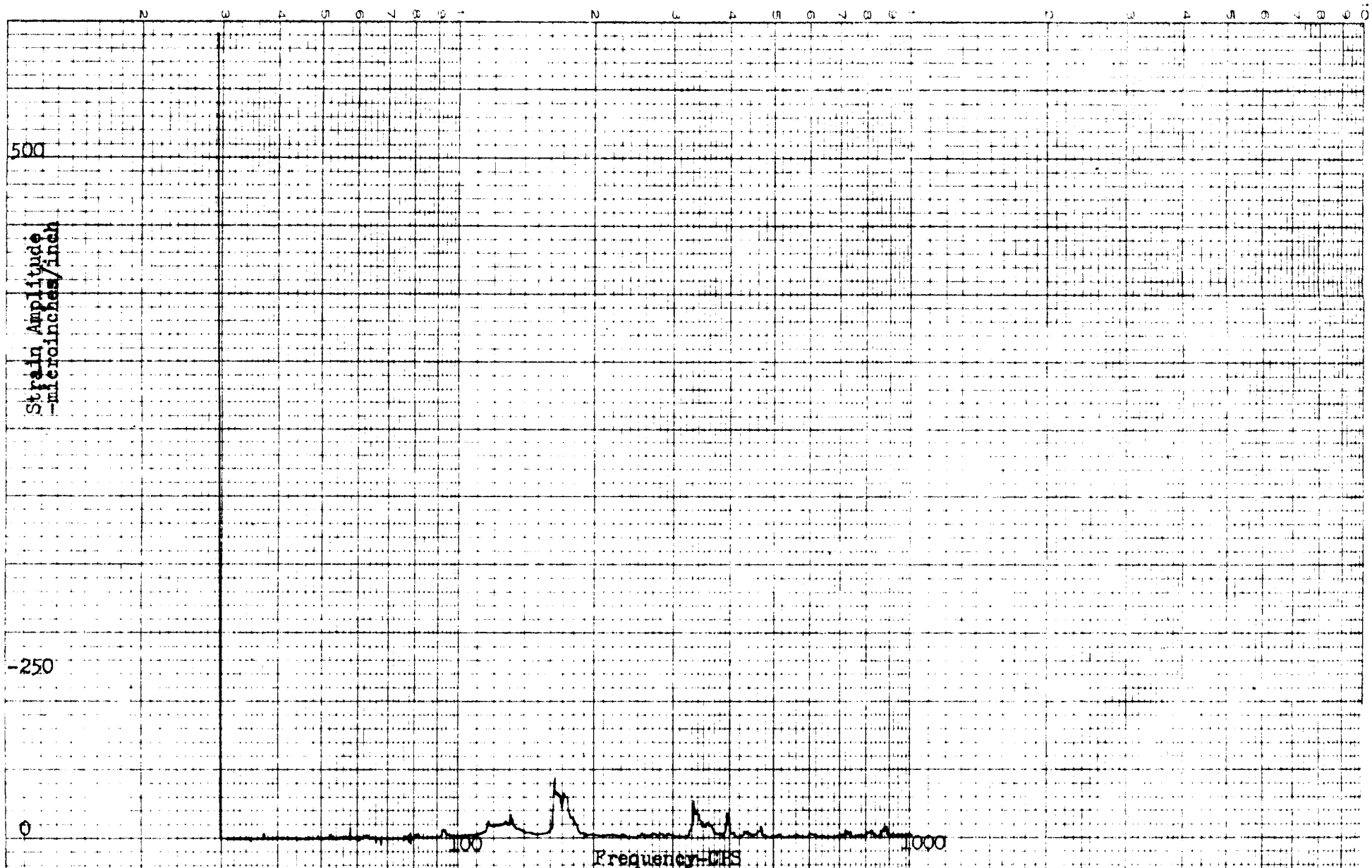

Figure 32 Shroud Panel No. 2 - Discrete Frequency Sweep at 136DB - Gage No. 8

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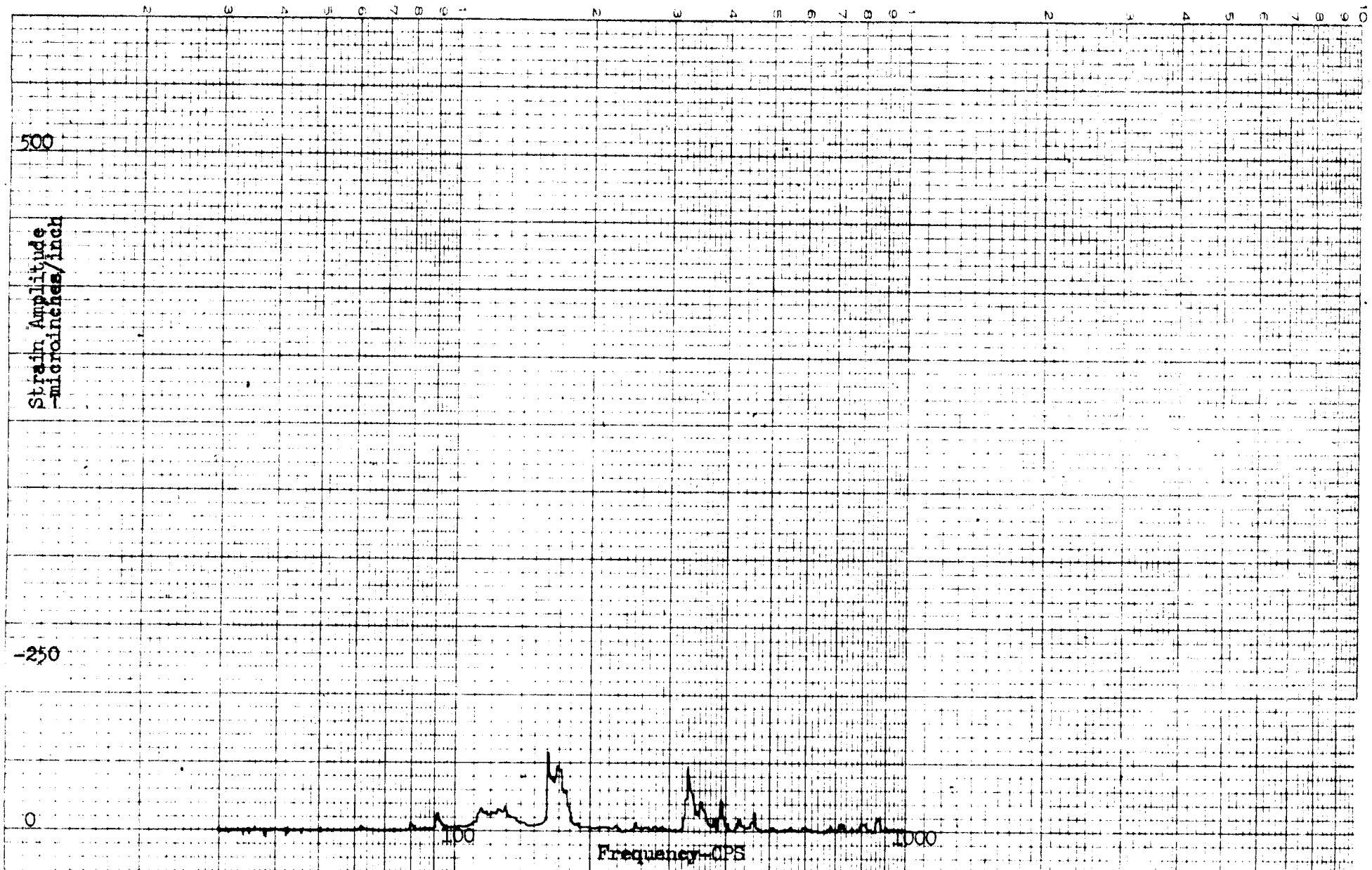


Figure 33 Shroud Panel No. 2 - Discrete Frequency Sweep at 139DB - Gage No. 8

2.340R-L310 DIETZGEN GRAPH PAPER
LOGARITHMIC-3 CYCLES X 10 DIVISIONS

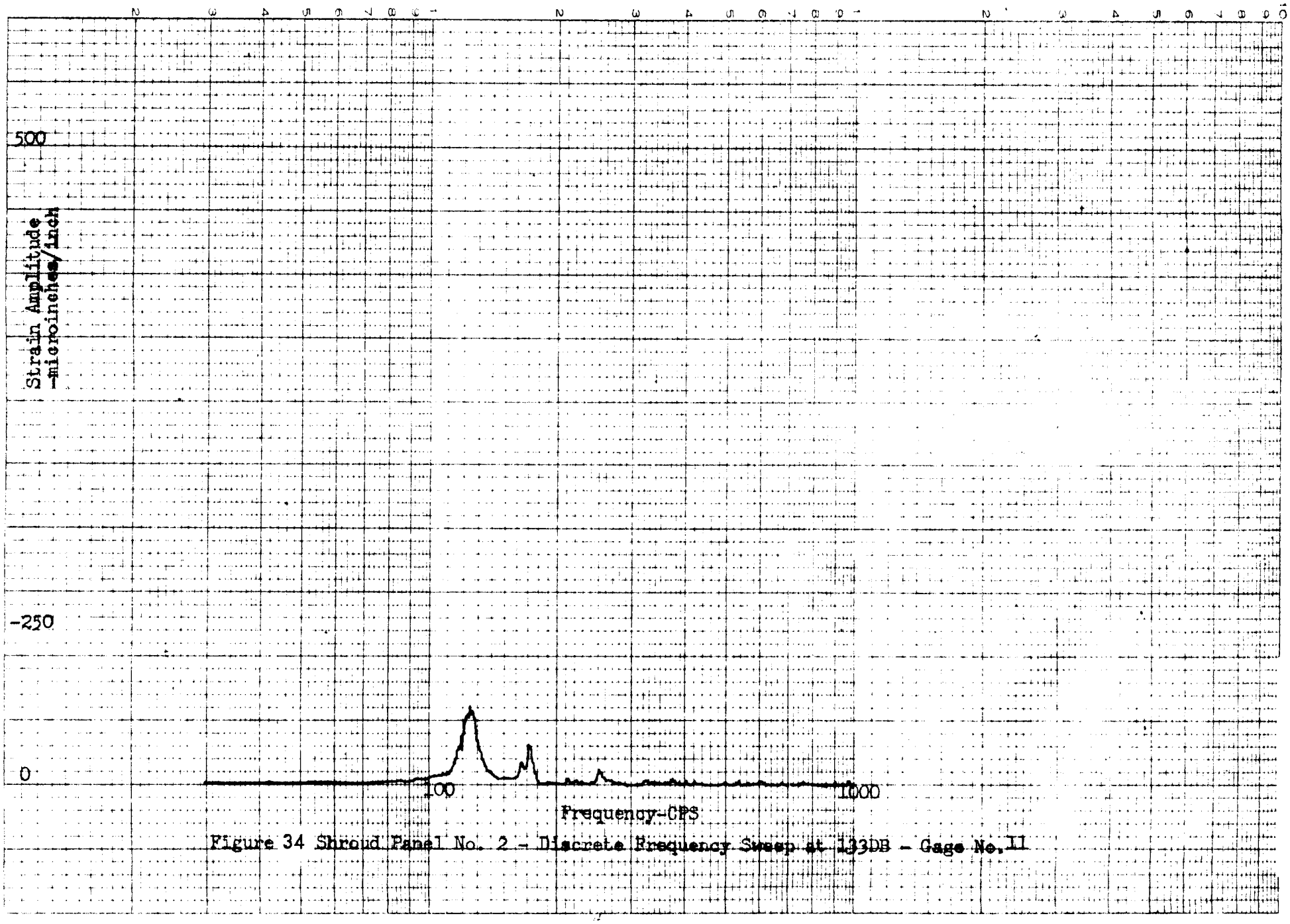


Figure 34 Shroud Panel No. 2 - Discrete Frequency Sweep at 133DB - Gage No. 11

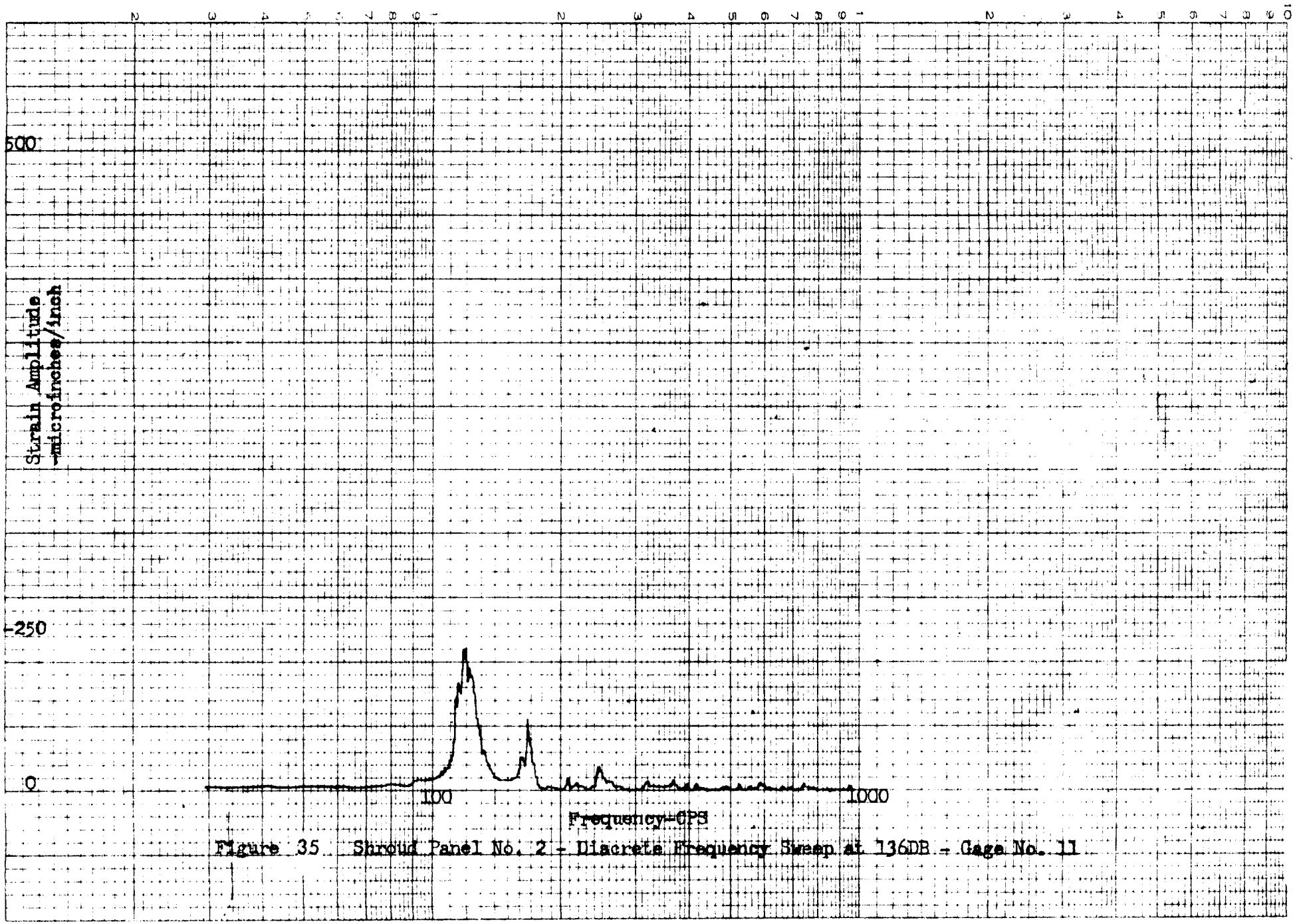


Figure 35 Shroud Panel No. 2 - Discrete Frequency Sweep at 136DB - Gage No. 11

MI-LOGARITHMIC-3 CYCLES X 10 DIVISIONS

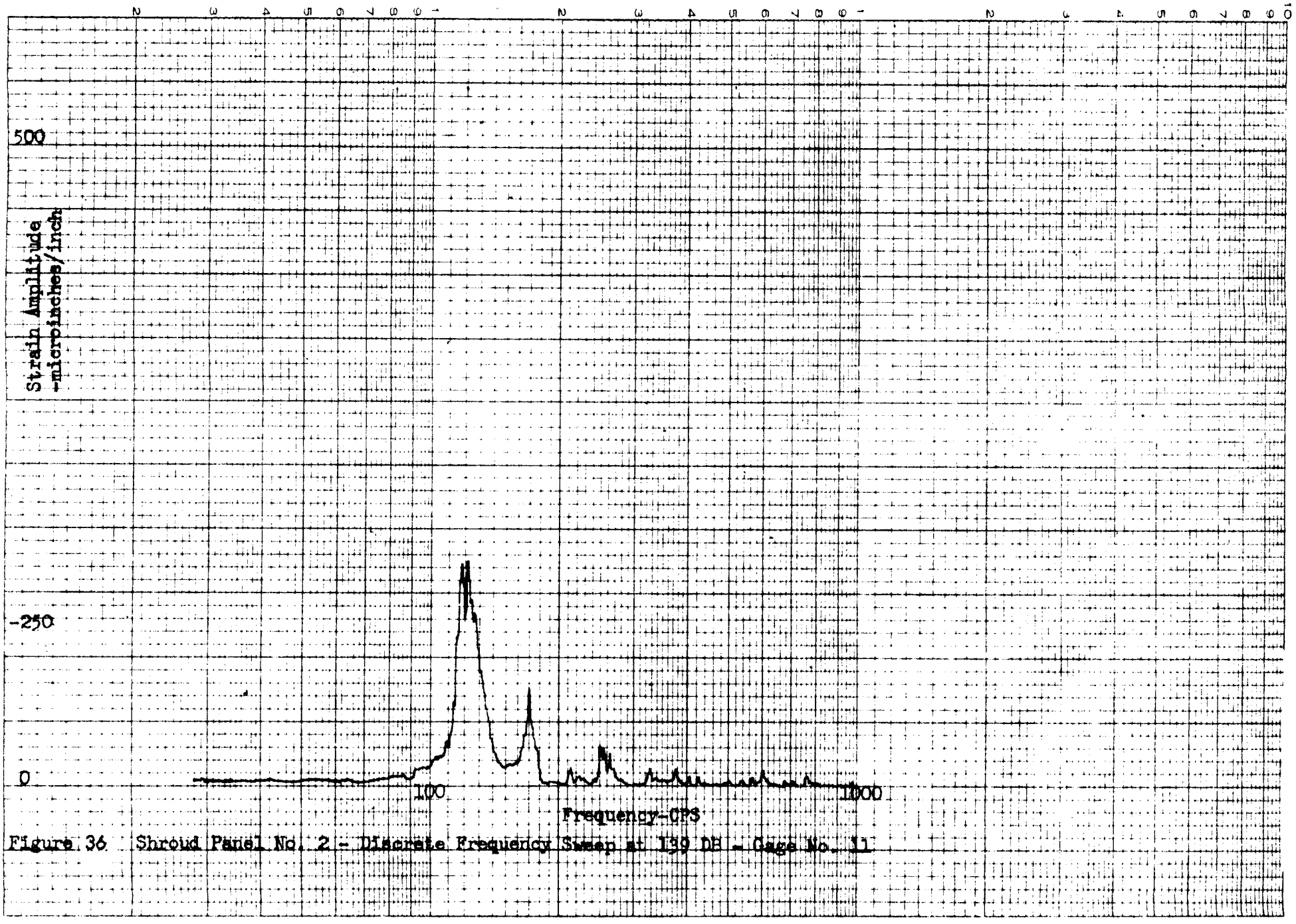


Figure 36 Shroud Panel No. 2 - Discrete Frequency Sweep at 139 DB - Gage No. 11

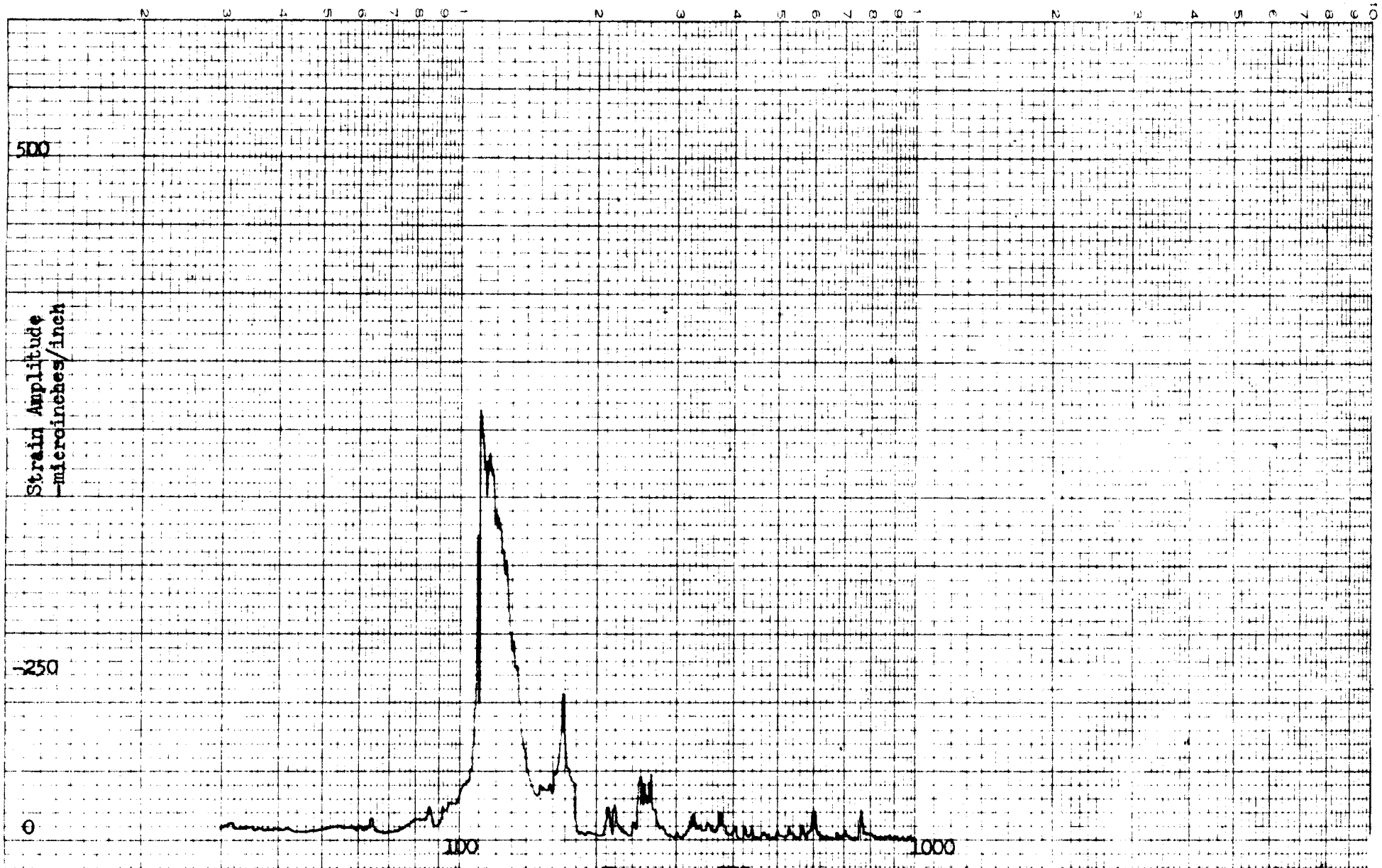


Figure 37 Shroud Panel No. 2 - Discrete Frequency Sweep at 142 DB - Gage No. 11

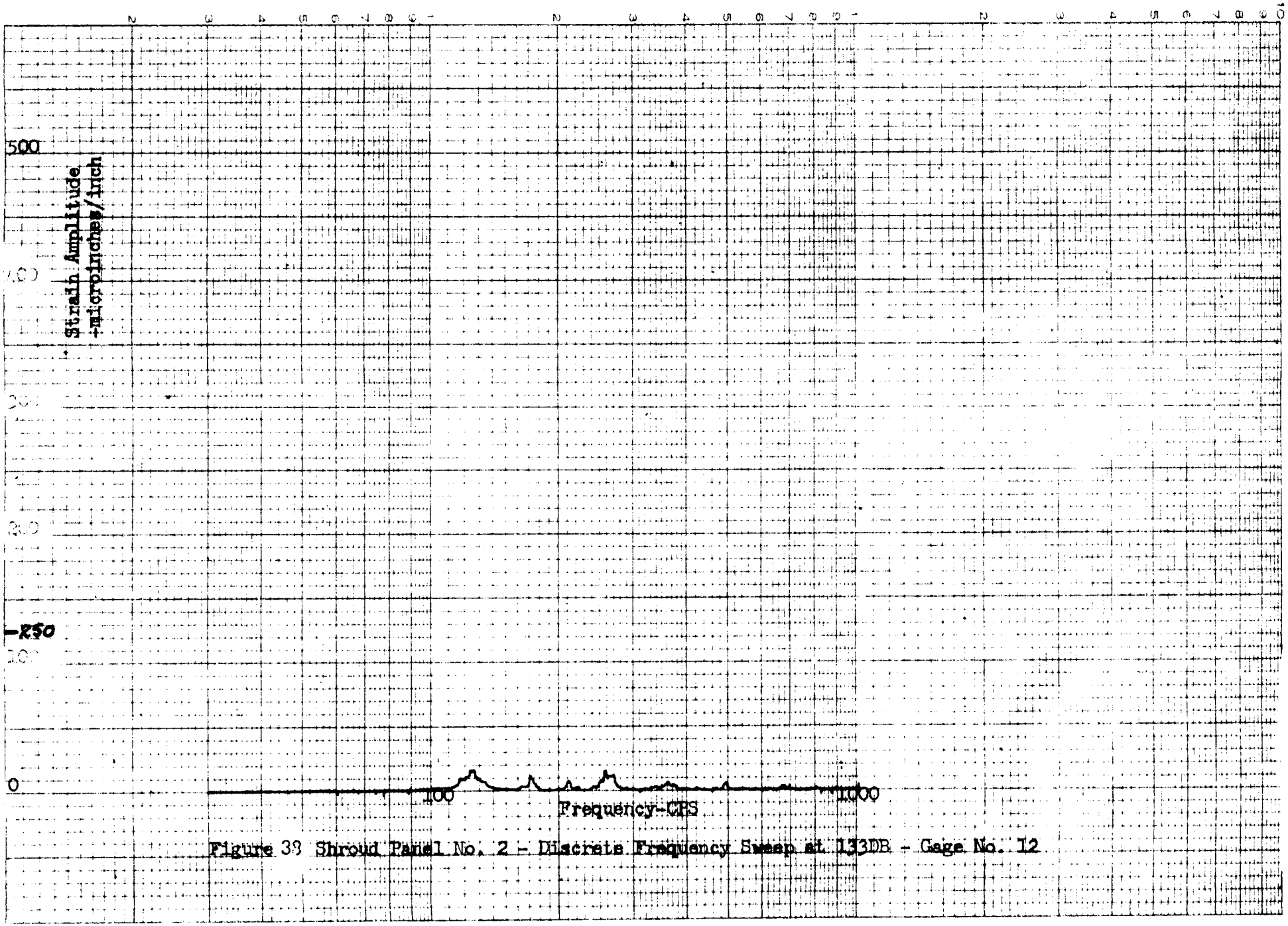


Figure 38 Shroud Panel No. 2 - Discrete Frequency Sweep at 133DB - Gage No. 12

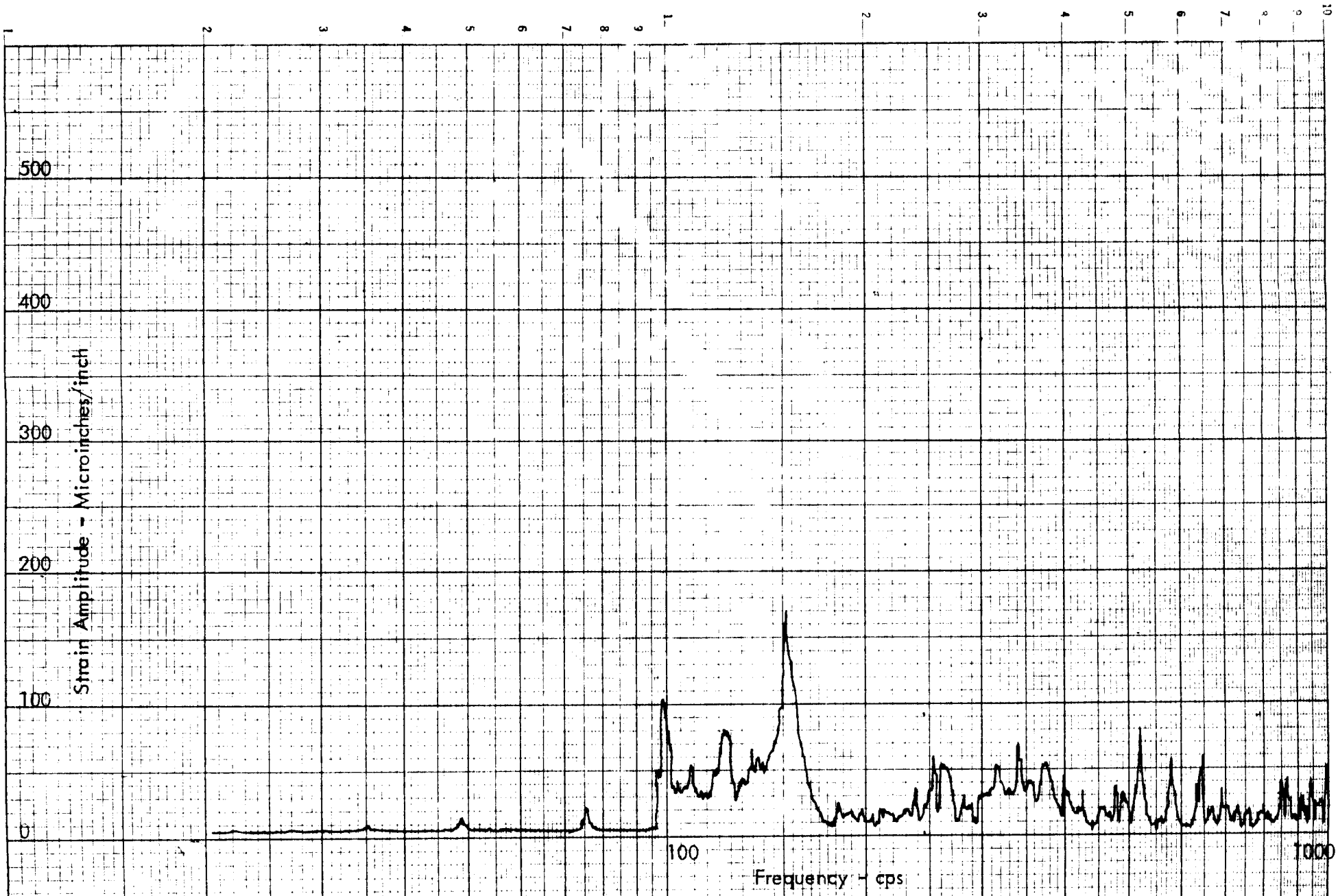


Figure 39 Shroud Panel No. 3 -Discrete Frequency Sweep at 136 db- Strain Gauge No. 2

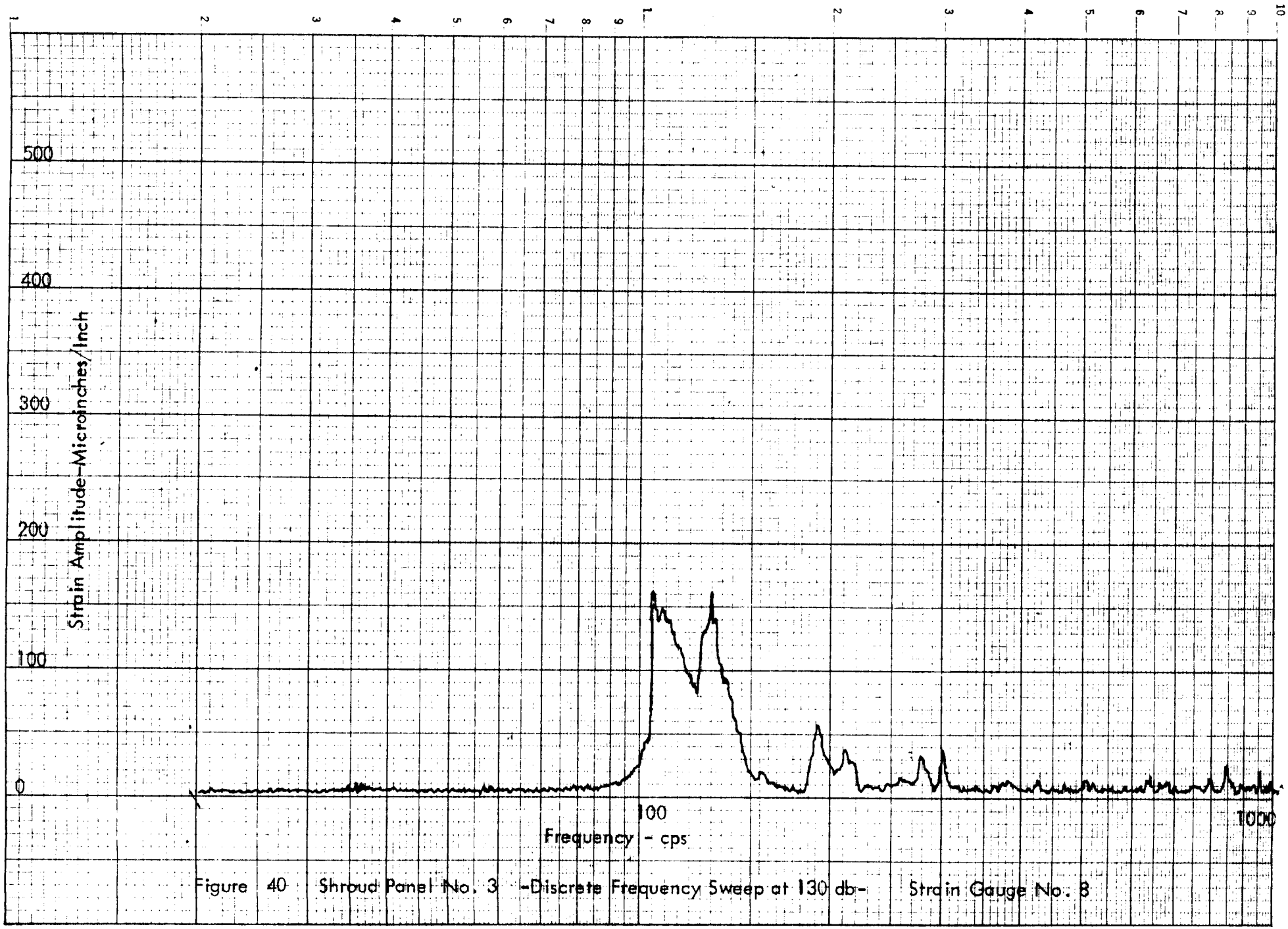


Figure 40 Shroud Panel No. 3 -Discrete Frequency Sweep at 130 db- Strain Gauge No. 8

KEUFFEL & ESSER CO.
2 CYCLE 3 X 70 DIVISIONS

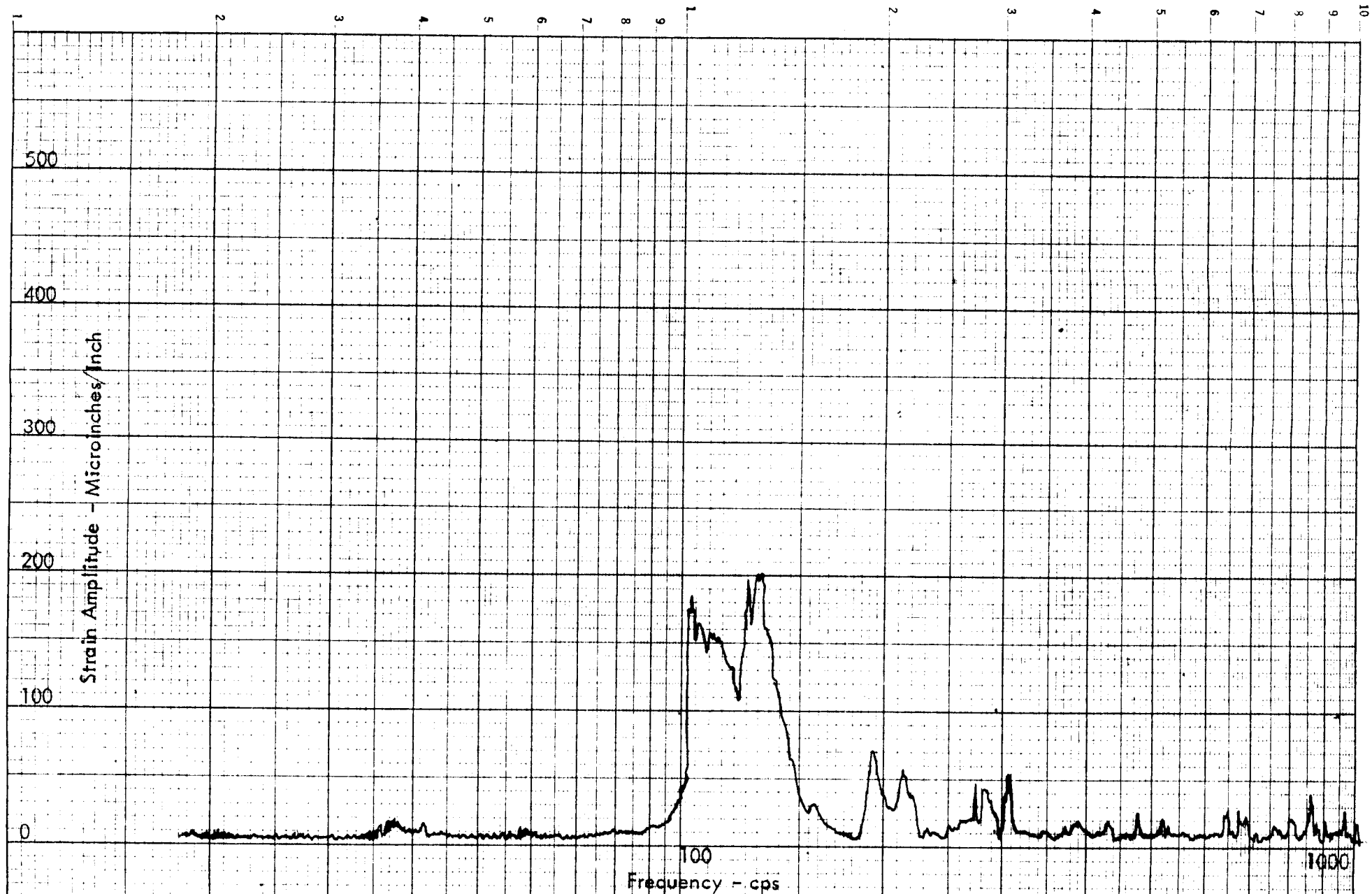


Figure 41 Shroud Panel No. 3 -Discrete Frequency Sweep at 133 db- Strain Gauge No. 8

KEUFFEL & ESSER CO.
2 CYCLES X 70 DIVISIONS

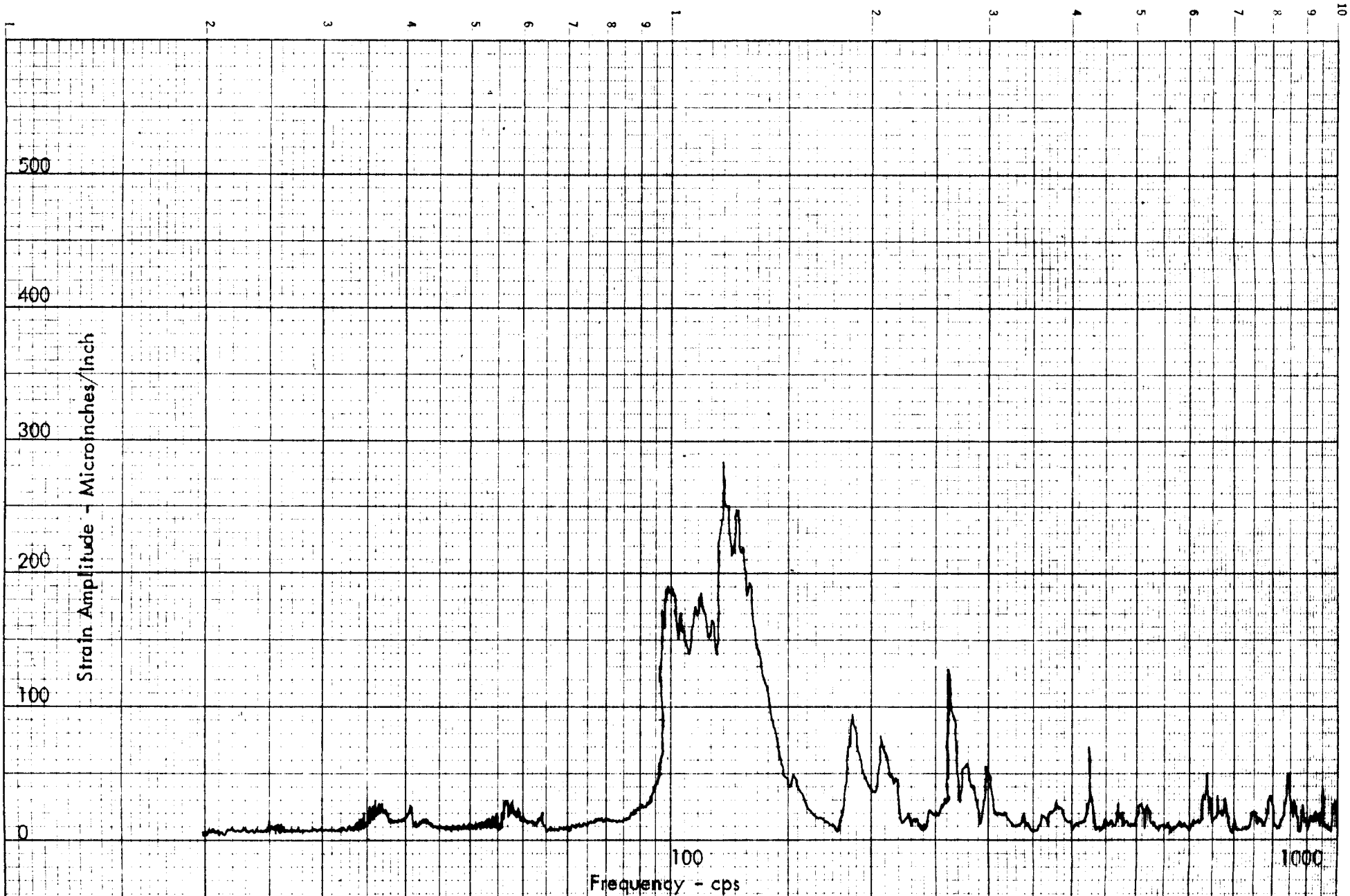


Figure 42 Shroud Panel No. 3 -Discrete Frequency Sweep at 136 db- Strain Gauge No. 8

KEUFFEL & ESSER CO.
2 CYCLES X 70 DIVISIONS

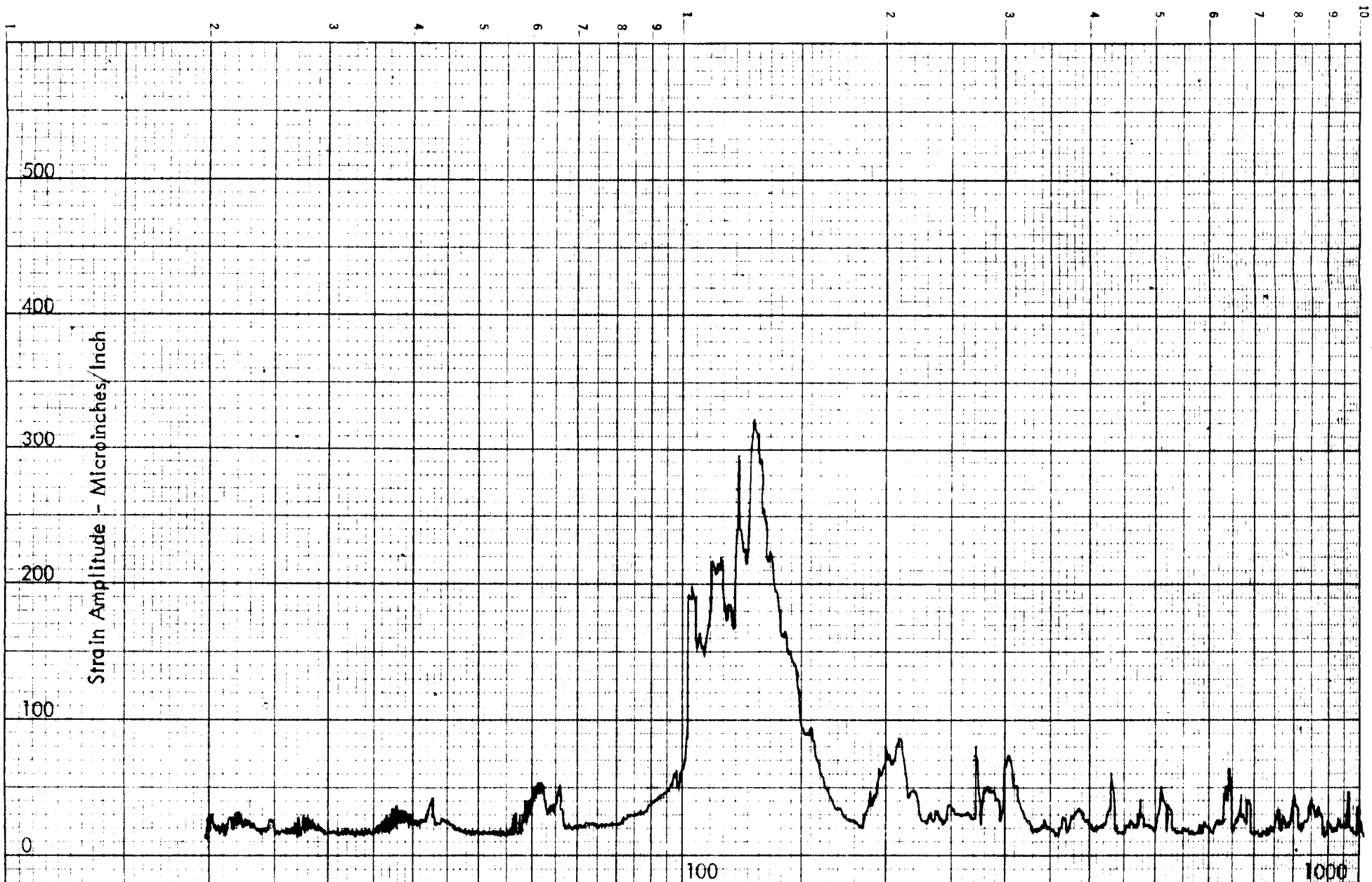


Figure 43 Shroud Panel No. 3 -Discrete Frequency Sweep at 136 db- Strain Gauge No. 8

SEMI-LOGARITHMIC 359-61C
EL & CO
2 CYCLES X 70 DIVISIONS

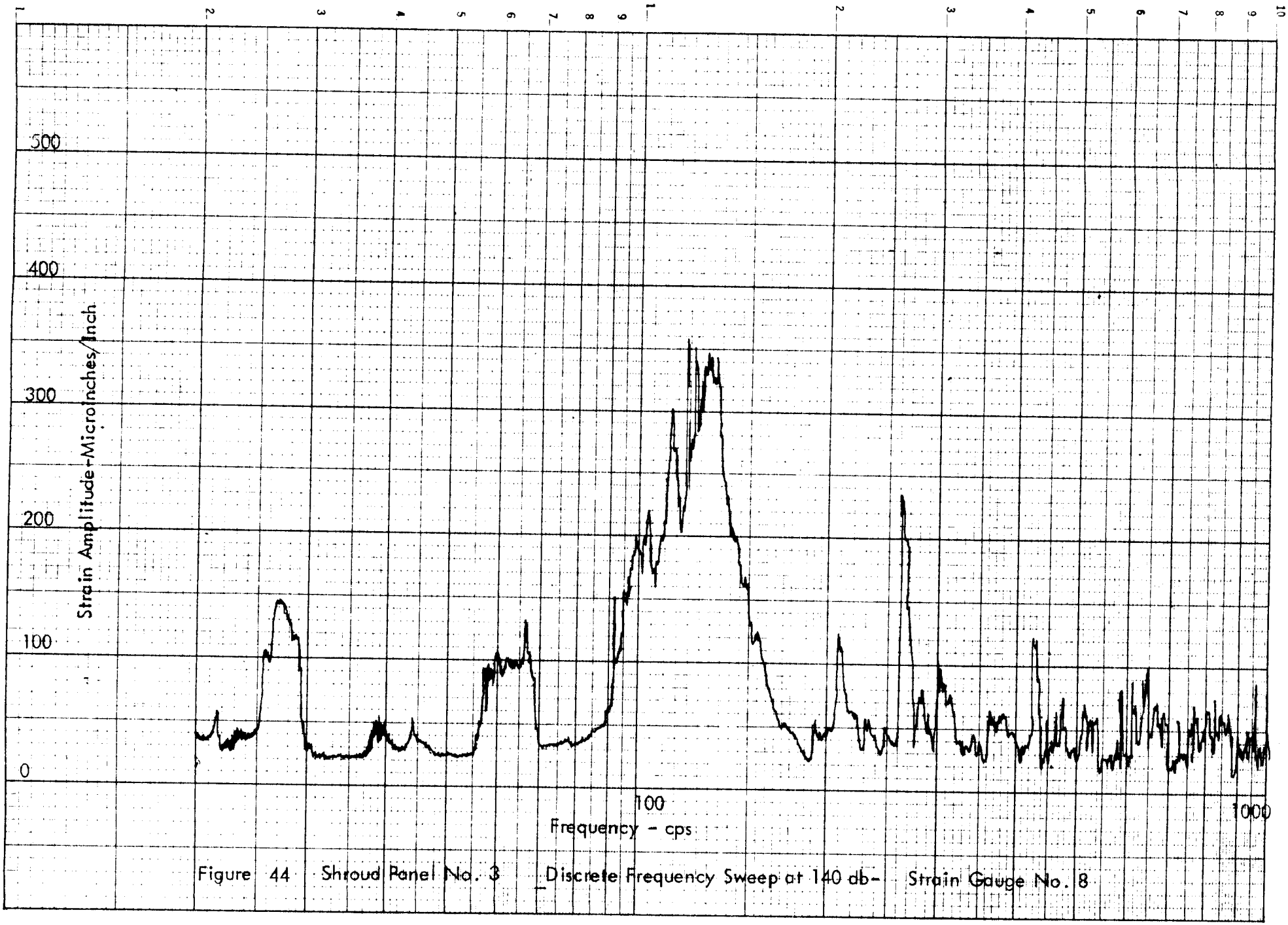


Figure 44 Shroud Panel No. 3 Discrete Frequency Sweep at 140 db- Strain Gauge No. 8

KEUFFEL & ESSER CO.
2 CYCLES X 70 DIVISIONS

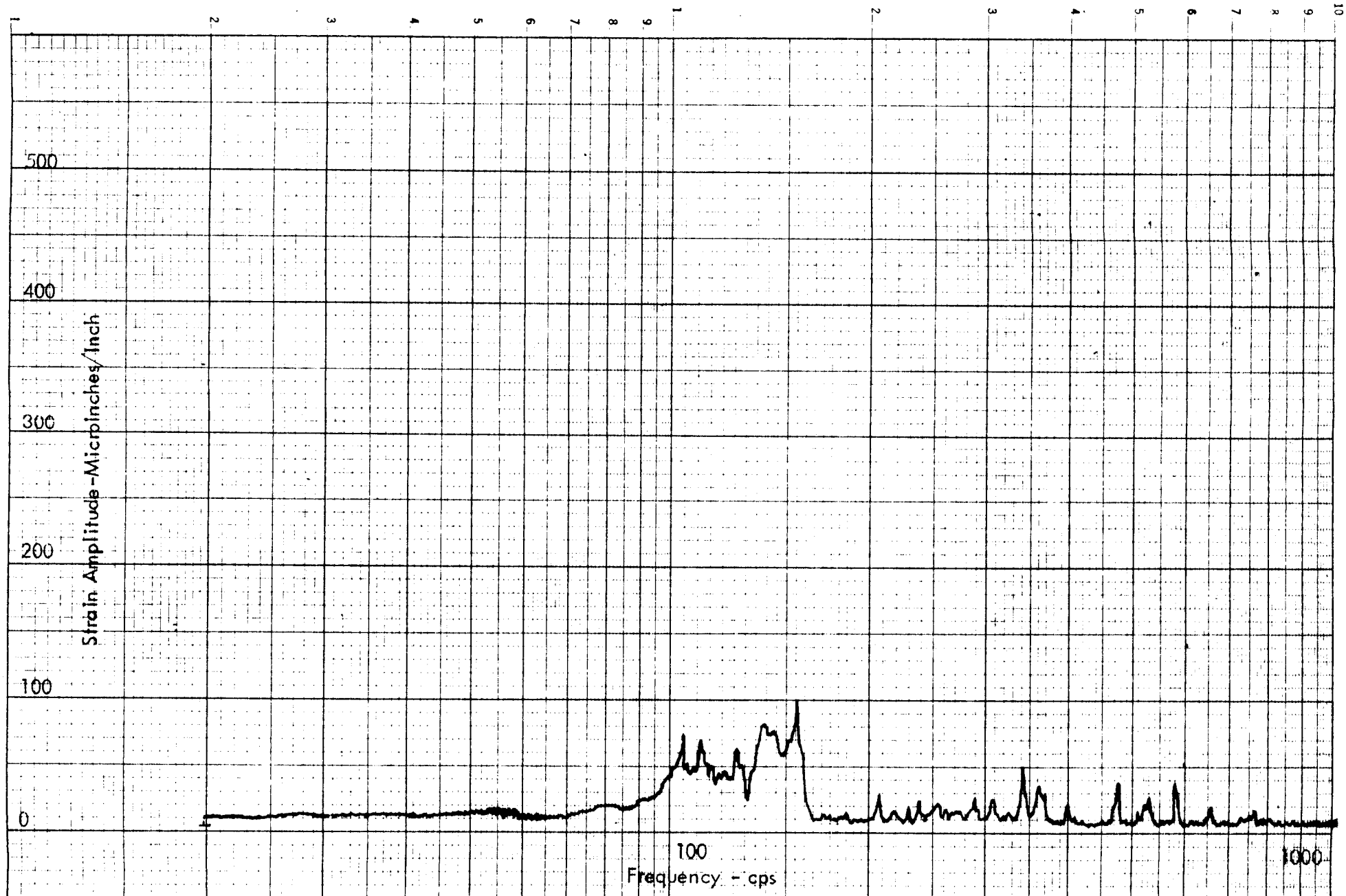


Figure 45 Shroud Panel No. 3 - Discrete Frequency Sweep at 130 db - Strain Gauge No. 11

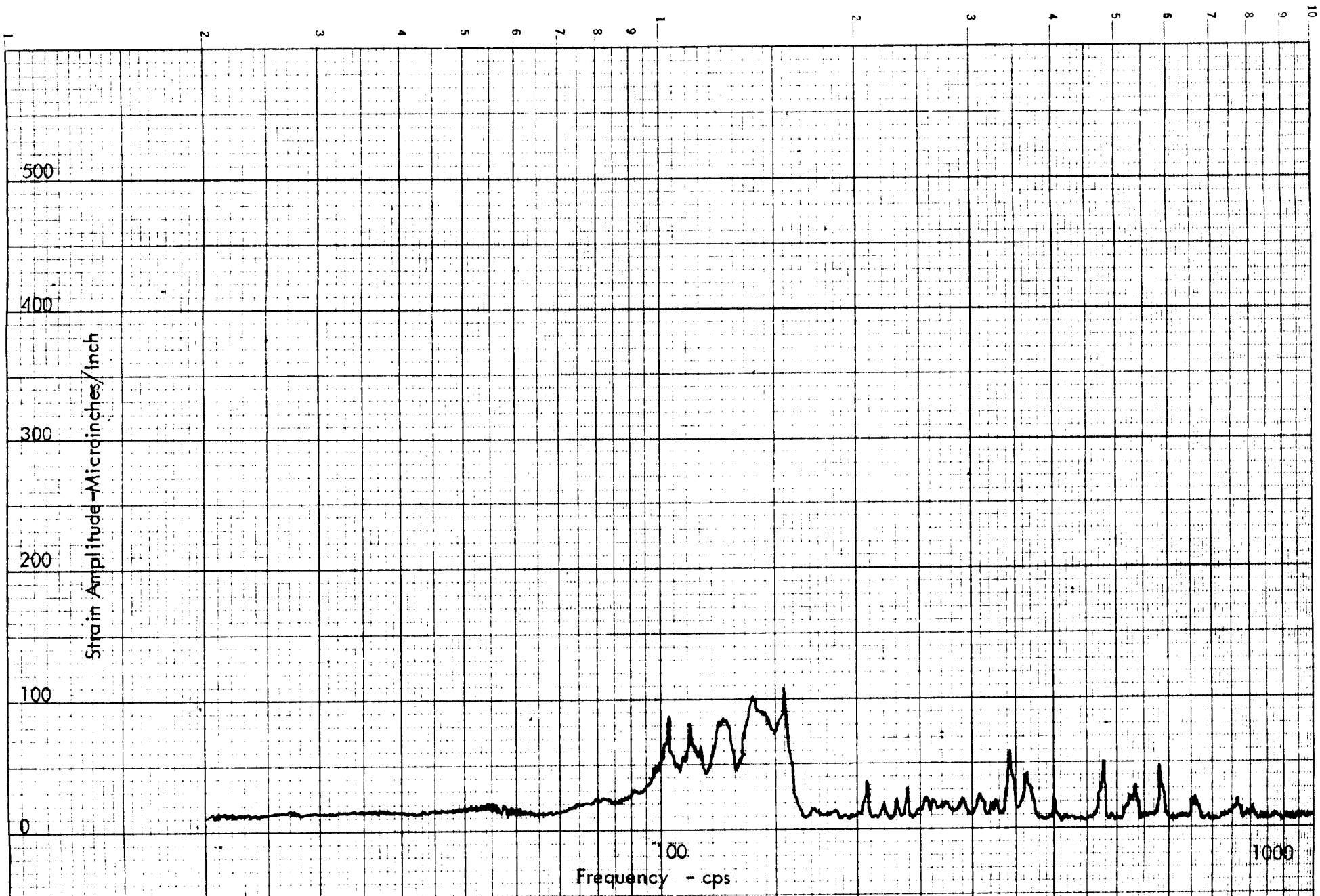


Figure 46 Shroud Panel No. 3 -Discrete Frequency Sweep at 133 db- Strain Gauge No. 11

K+E SEMI-LOGARITHMIC 359-61G
KEUFFEL & ESSER CO.
2 CYCLES X 70 DIVISIONS

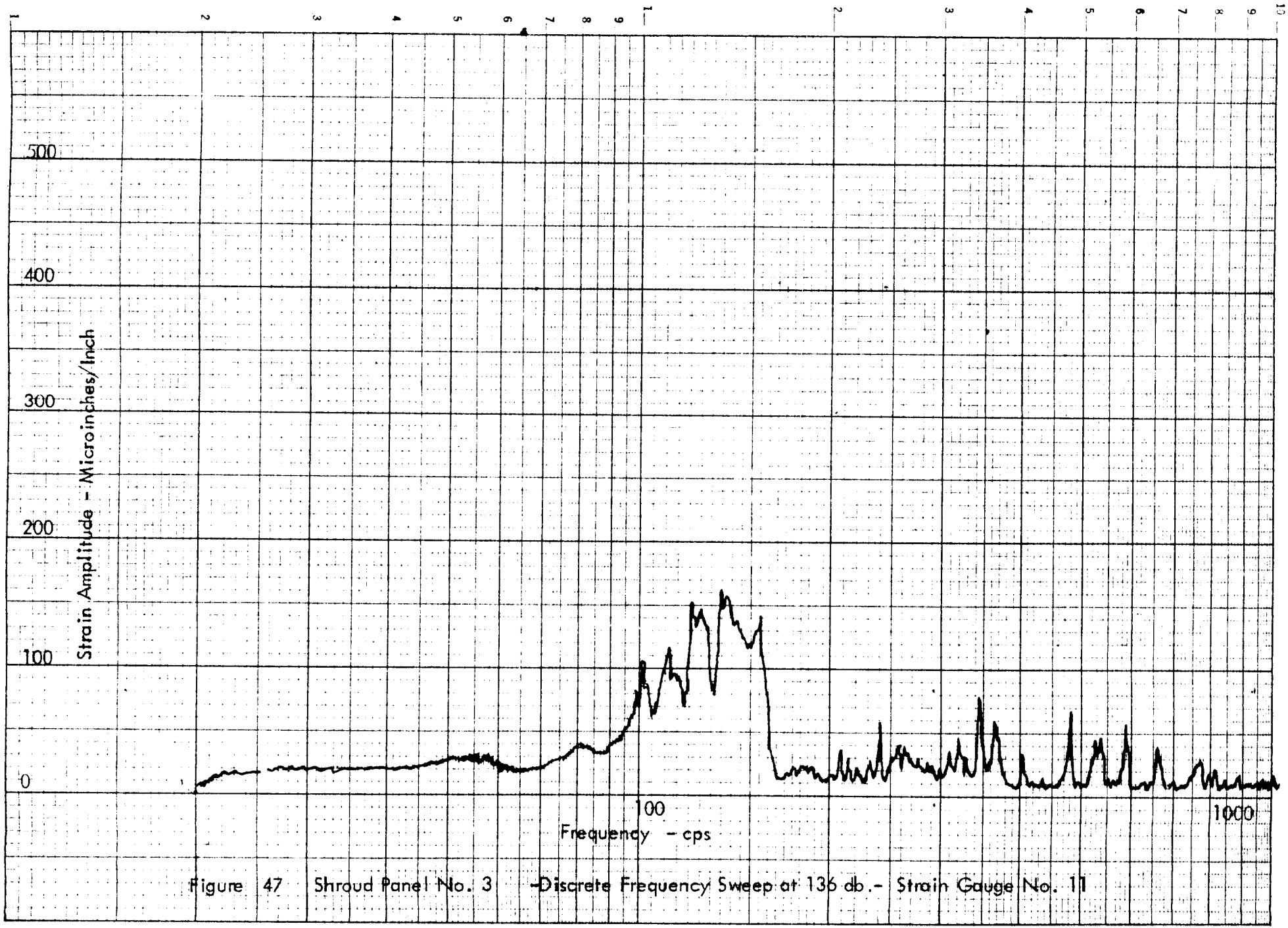


Figure 47 Shroud Panel No. 3 -Discrete Frequency Sweep at 136 db.- Strain Gauge No. 11

LOGARITHMIC 61C
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 CYCLES X 70 DIVISIONS

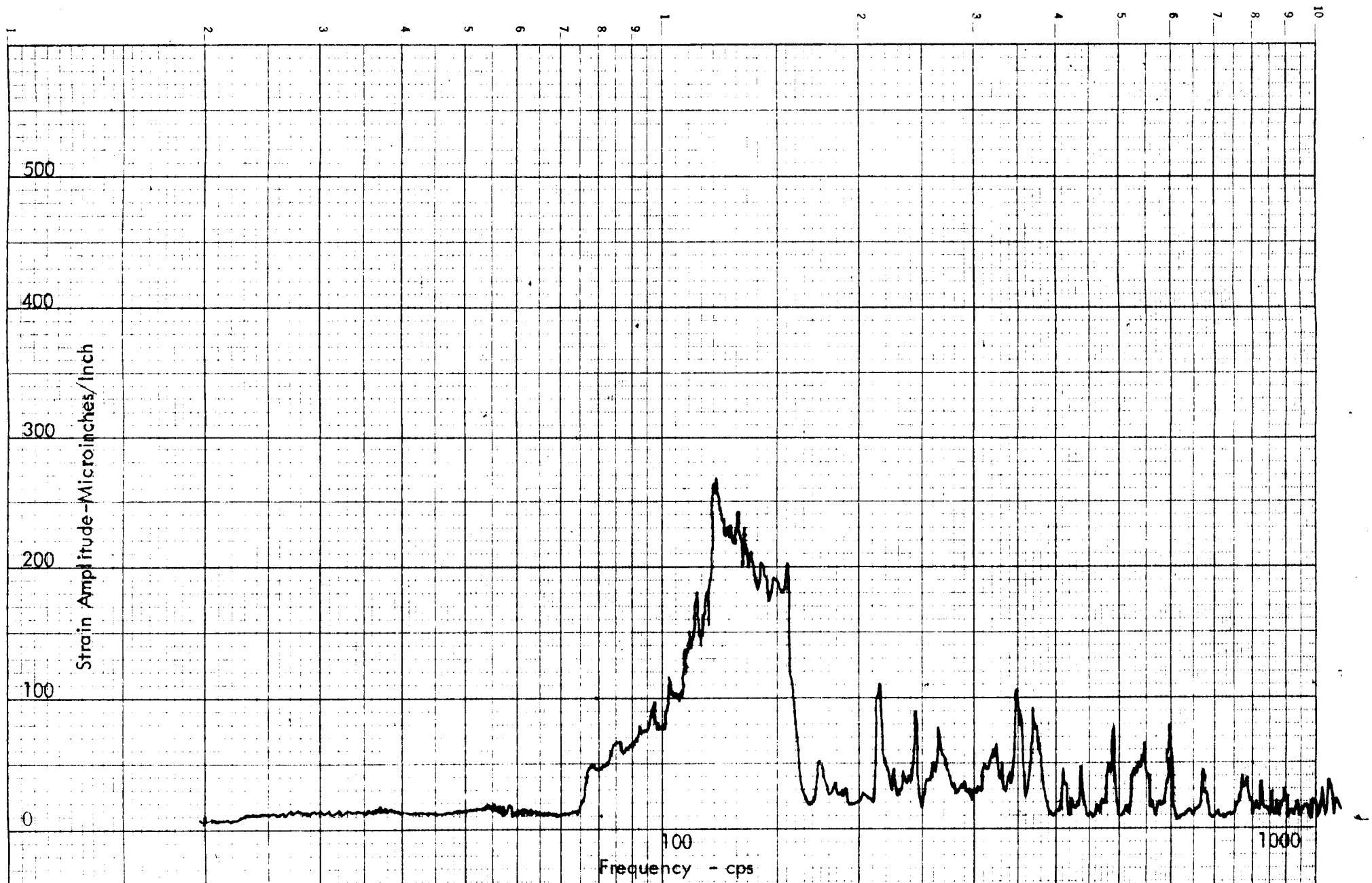


Figure 48 Shroud Panel No. 3 -Discrete Frequency Sweep at 140 db- Strain Gauge No. 11

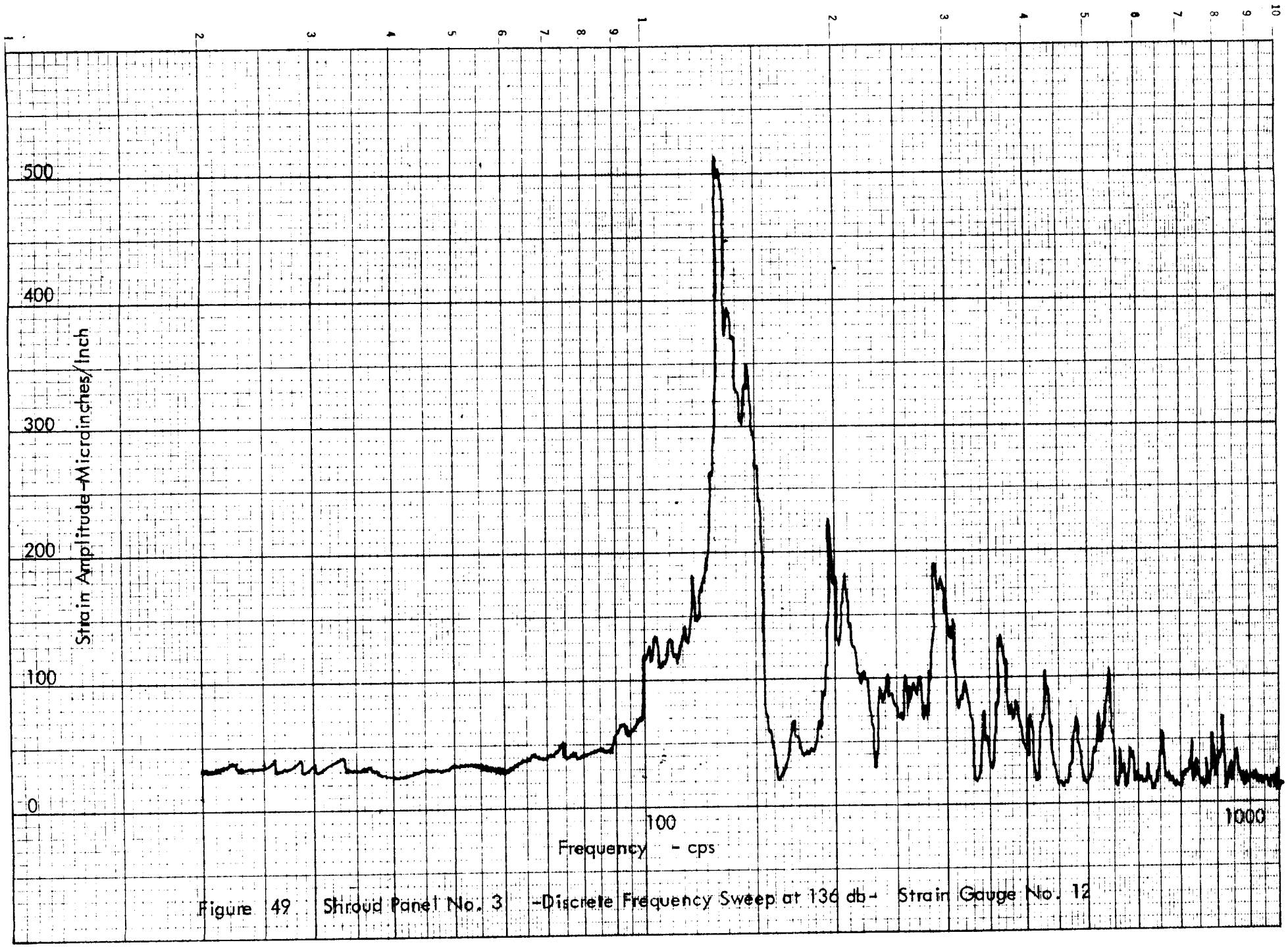


Figure 49 Shroud Panel No. 3 -Discrete Frequency Sweep at 136 db- Strain Gauge No. 12

KEUFFEL & ESSER CO.
2 CYCLES X 70 DIVISIONS

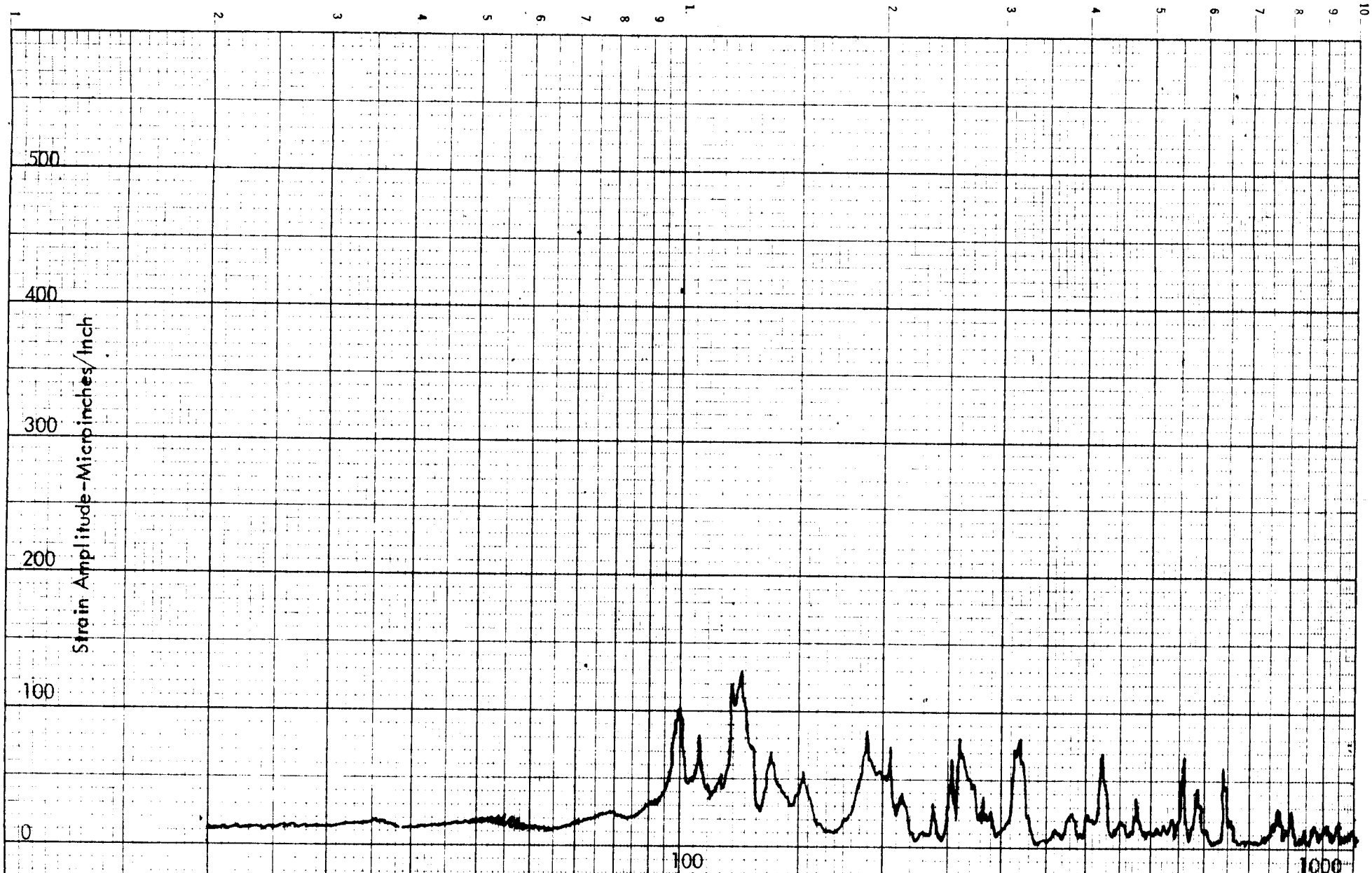


Figure 50 Shroud Panel No. 3 -Discrete Frequency Sweep at 136 db- Strain Gauge No. 13

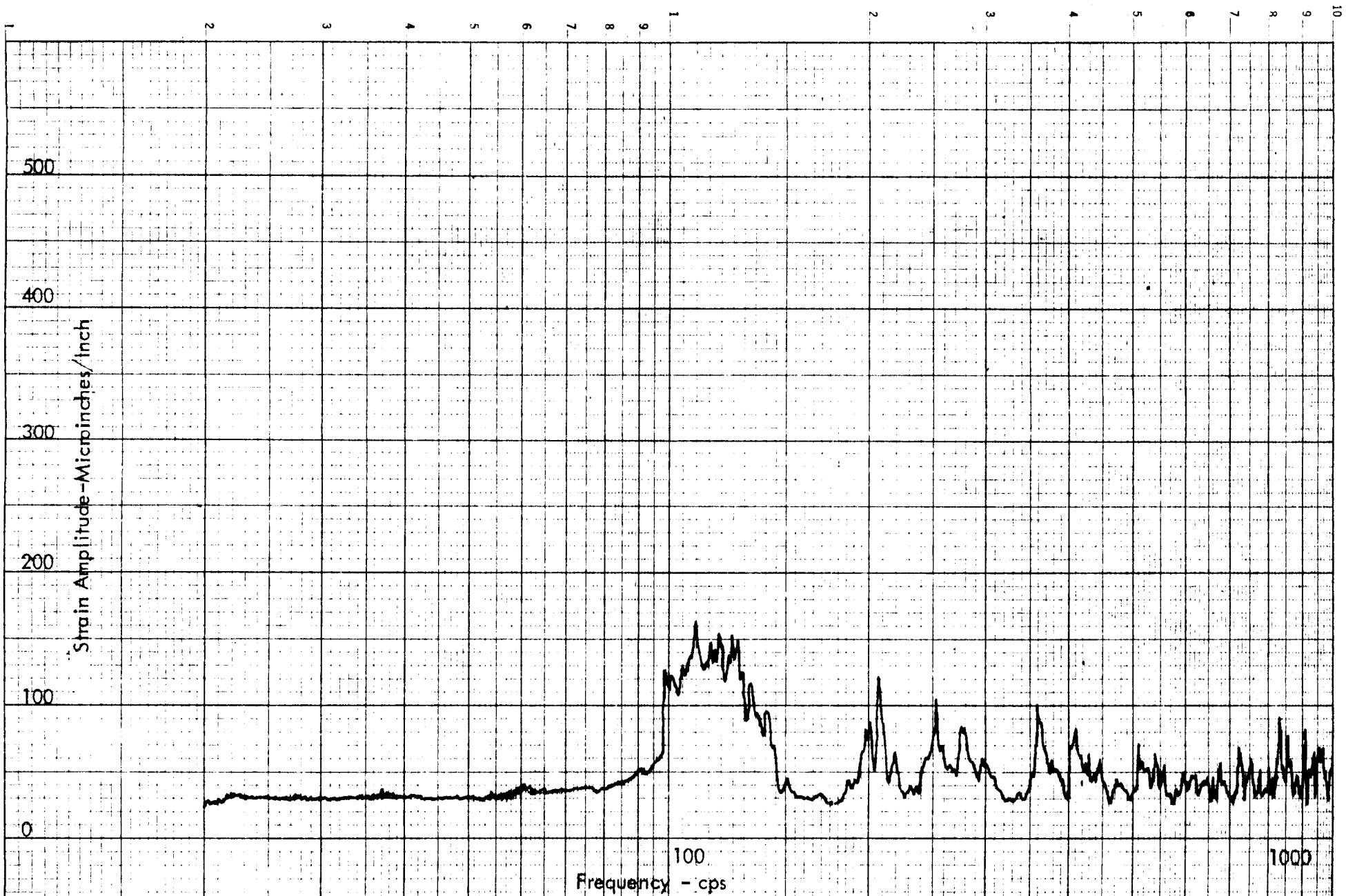
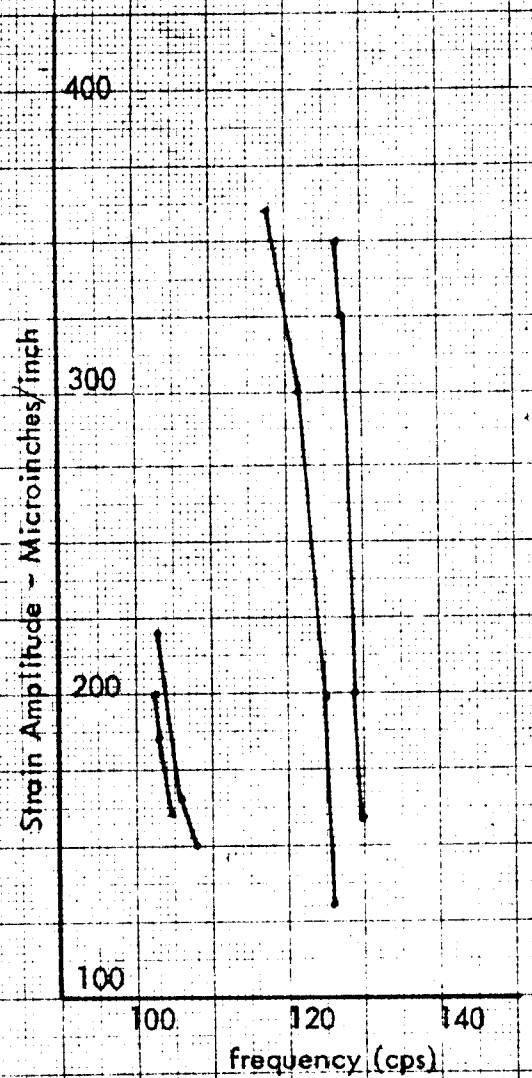
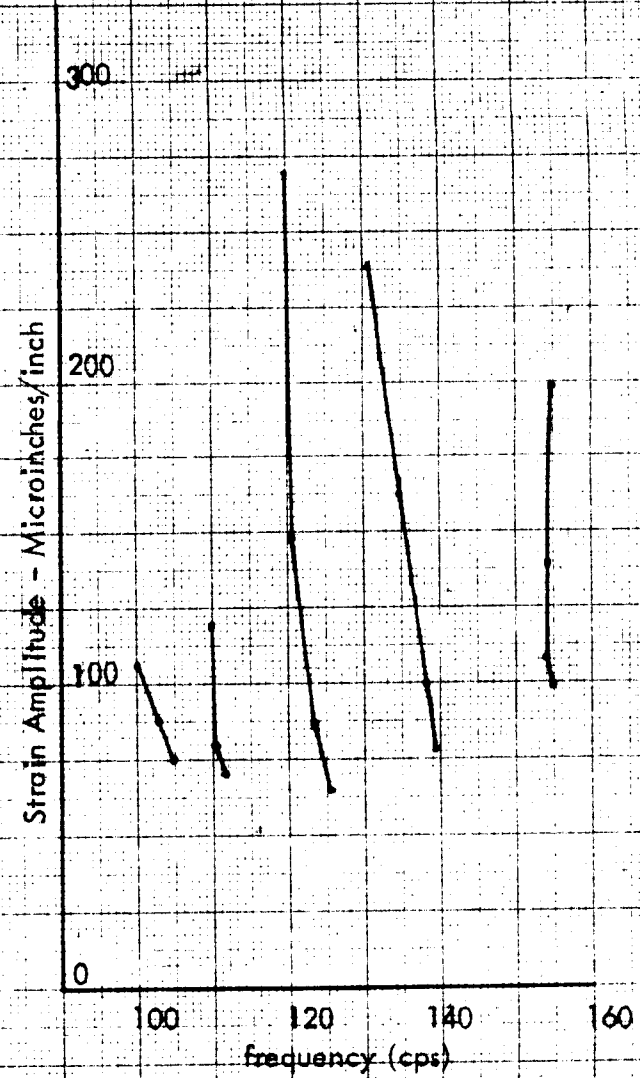


Figure 51 Shroud Panel No. 3 -Discrete Frequency Sweep at 136 db- Strain Gauge No. 14

K+E 10 X 10 TO THE CM 359-14
KEUFFEL & ESSER CO.



Strain Gauge No. 8



Strain Gauge No. 11

Figure 52: Strain Amplitude versus Frequency

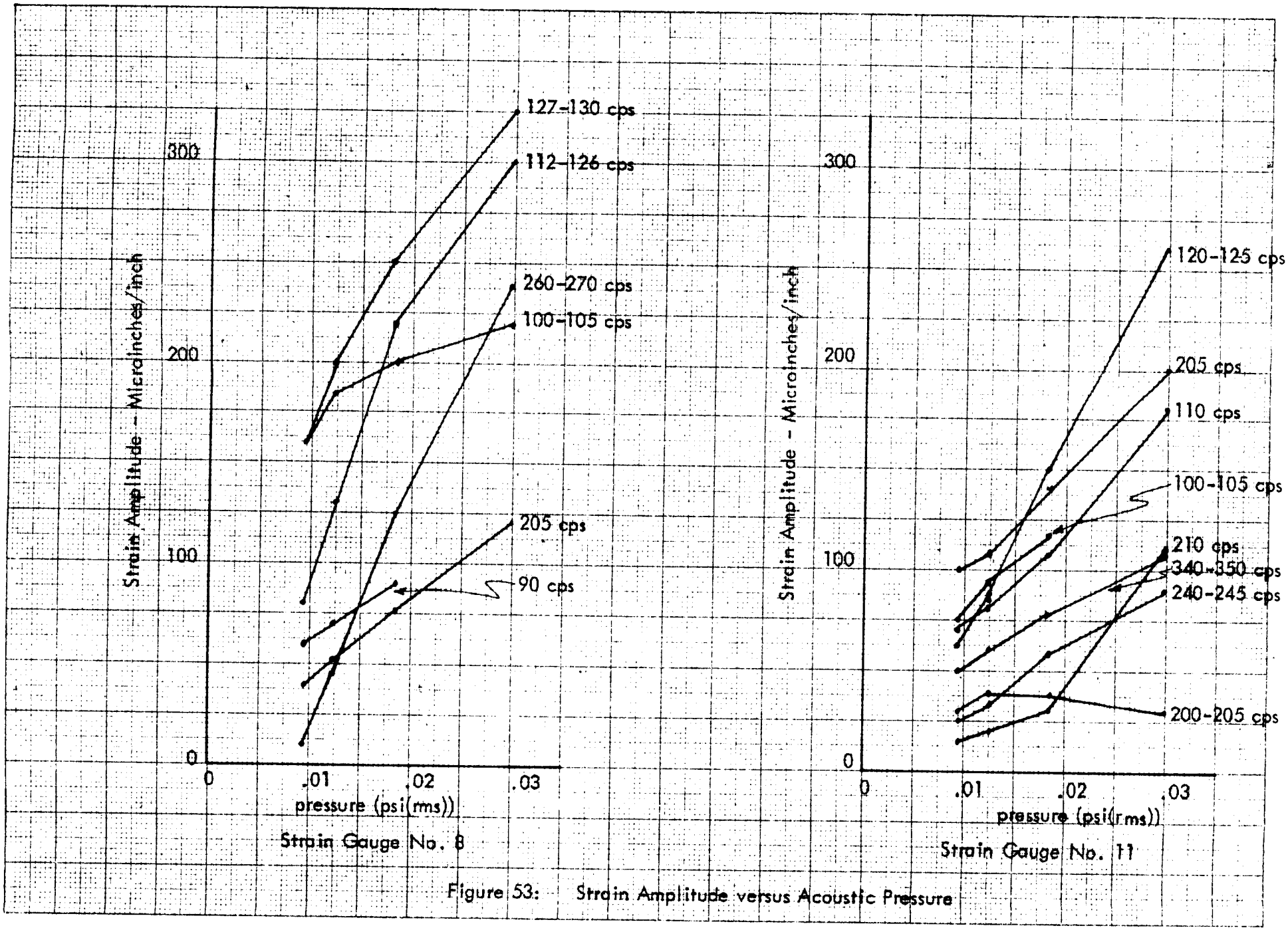


Figure 53: Strain Amplitude versus Acoustic Pressure

Run No. : 1
Track No. : 7
Filter Bandwidth : 10 cps

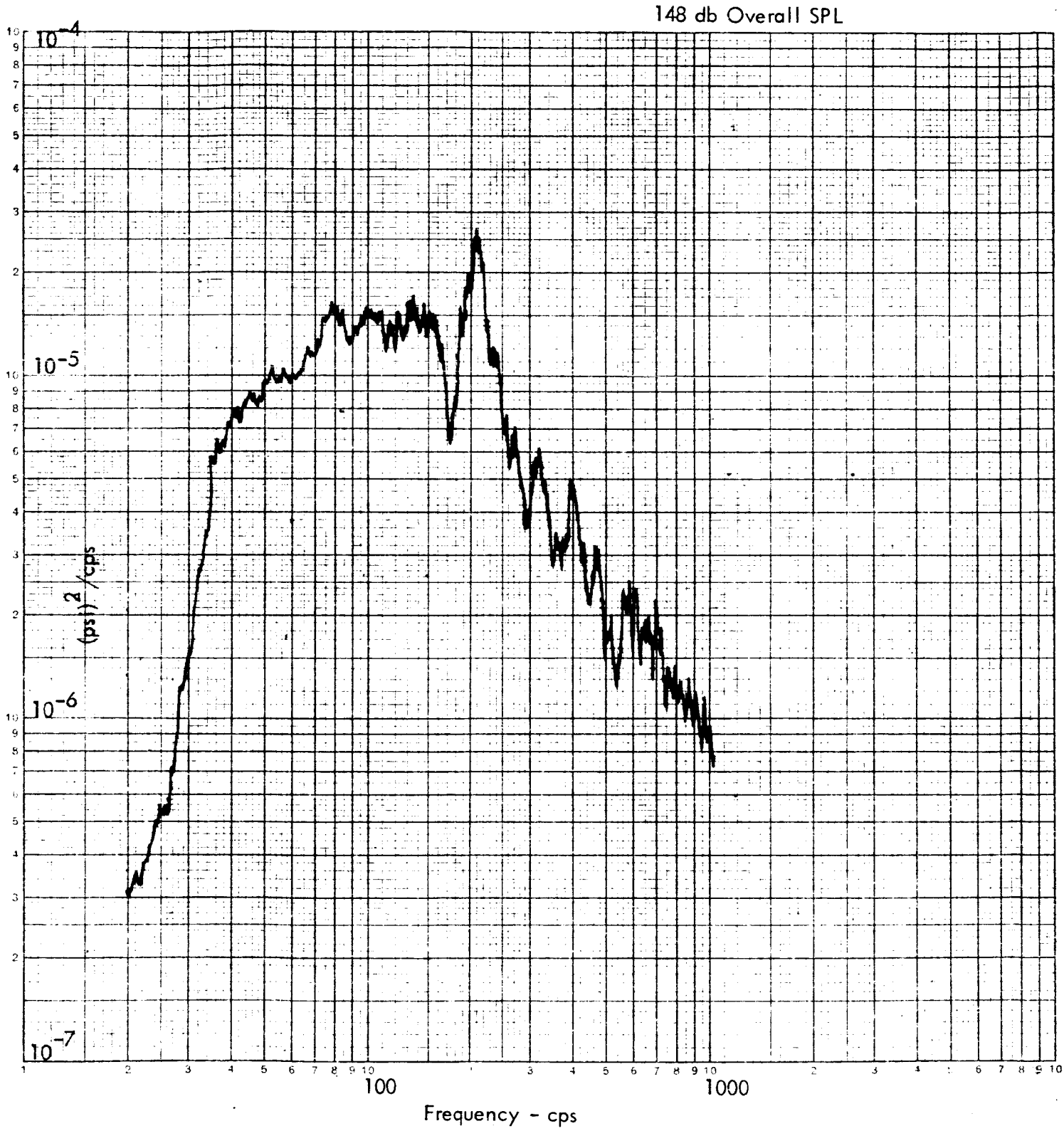


Figure 54 Shroud Panel No. 2 -Power Spectral Density - Microphone No. 2

Run No. : 1
Track No. : 8
Filter Bandwidth : 10 cps

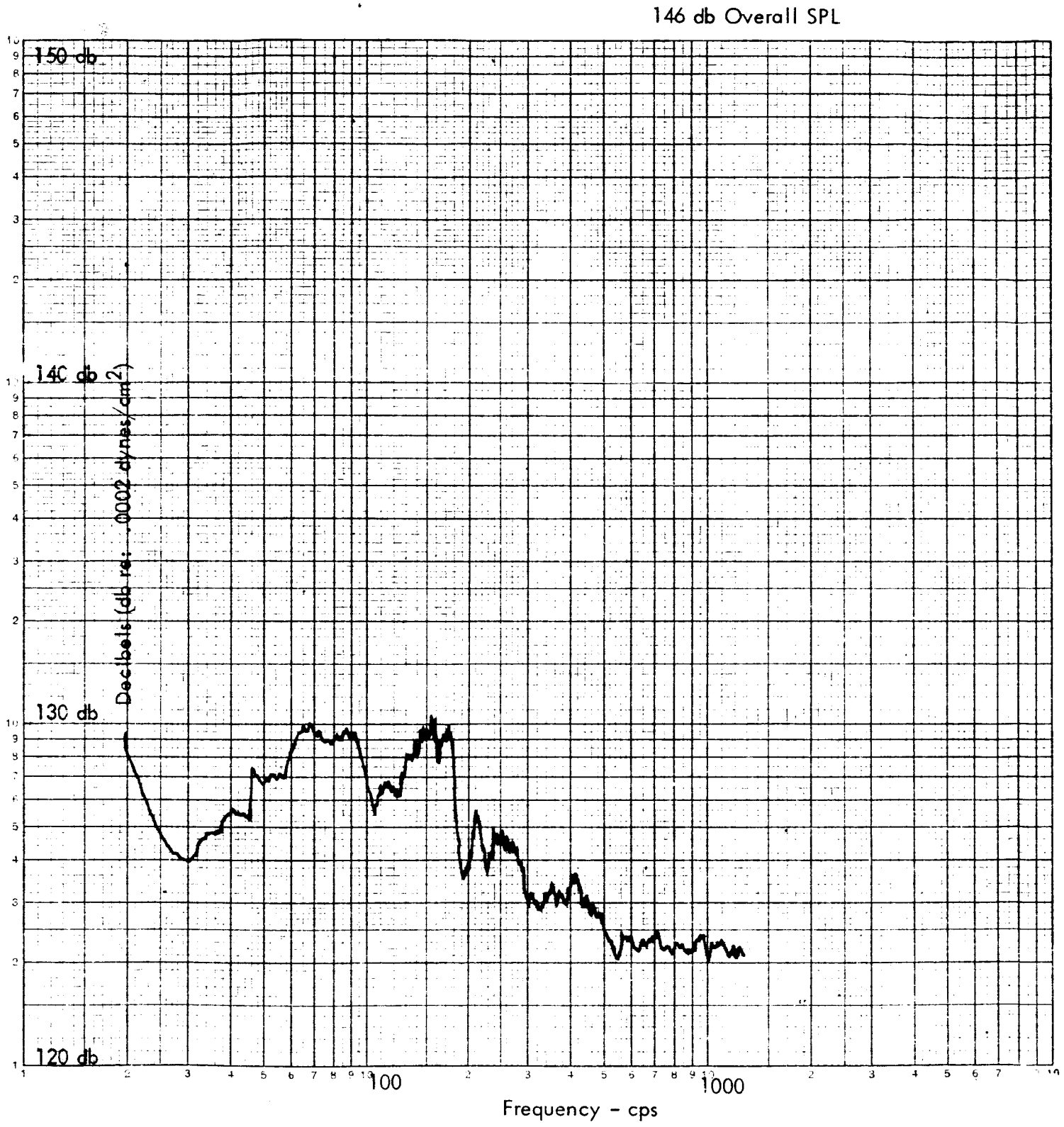


Figure 55 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 3

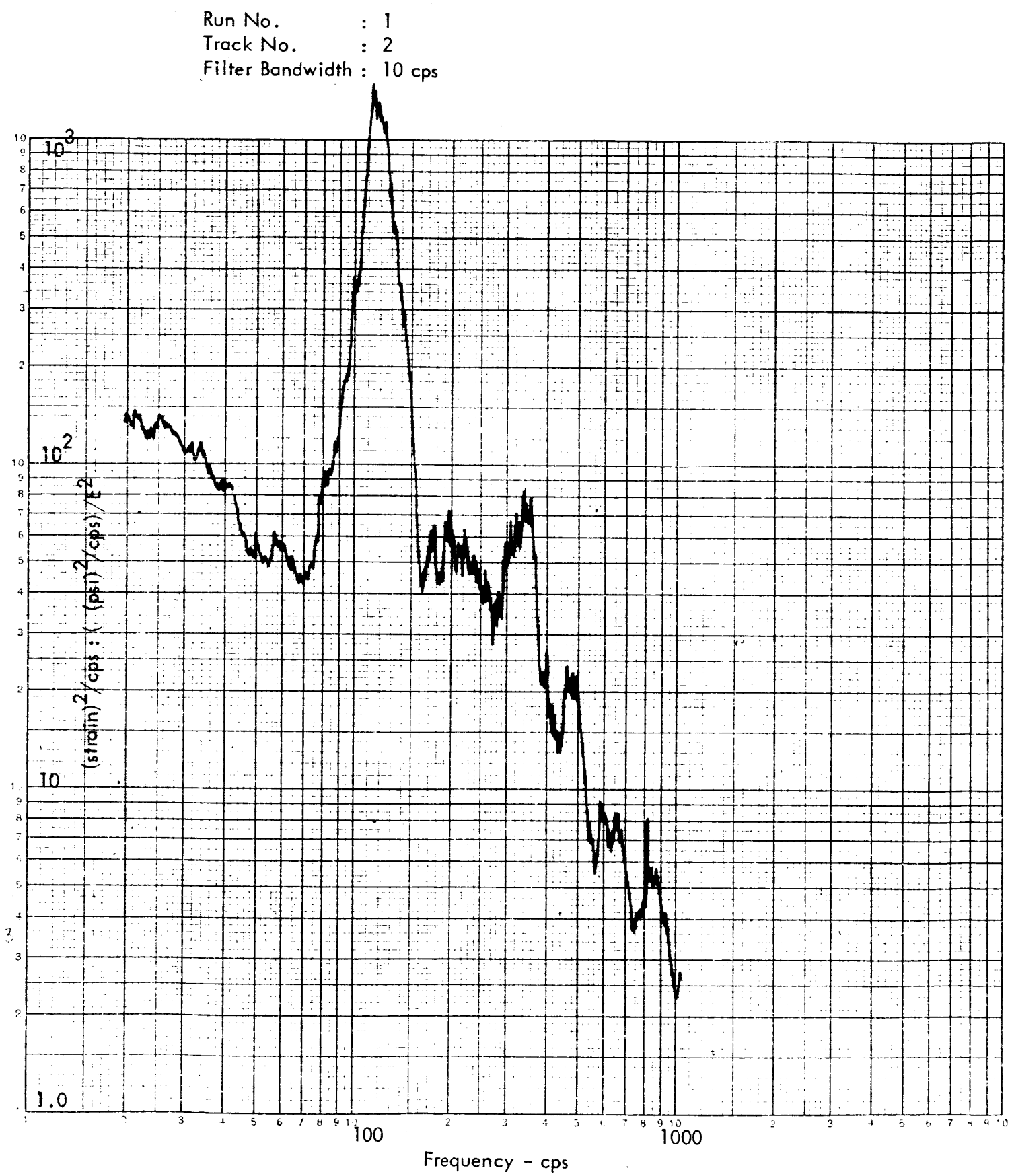


Figure 56 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 2

Run No. : 1
Track No. : 3
Filter Bandwidth : 10 cps

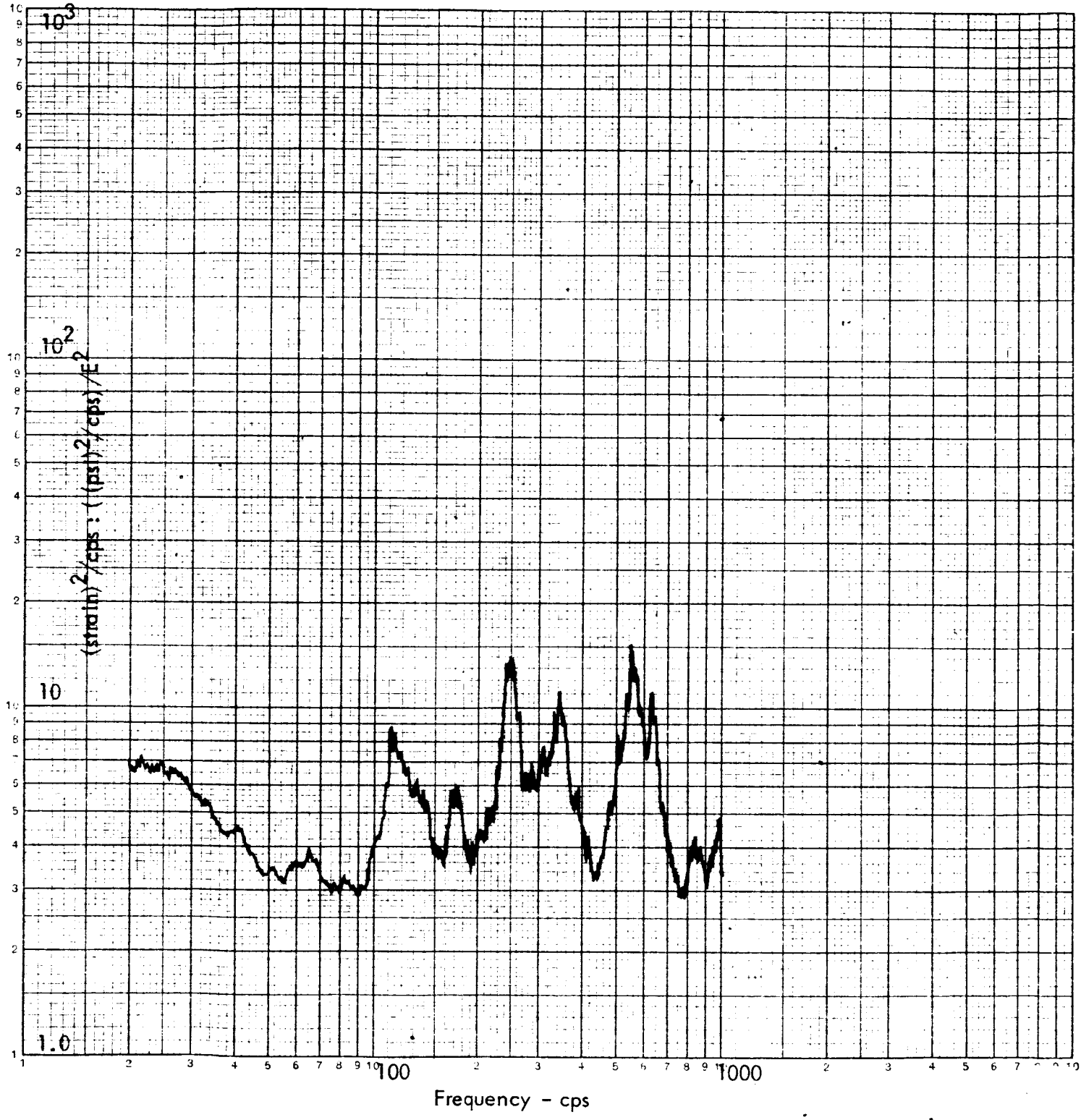


Figure 57 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 3

Run No. : 1
Track No. : 4
Filter Bandwidth : 10 cps

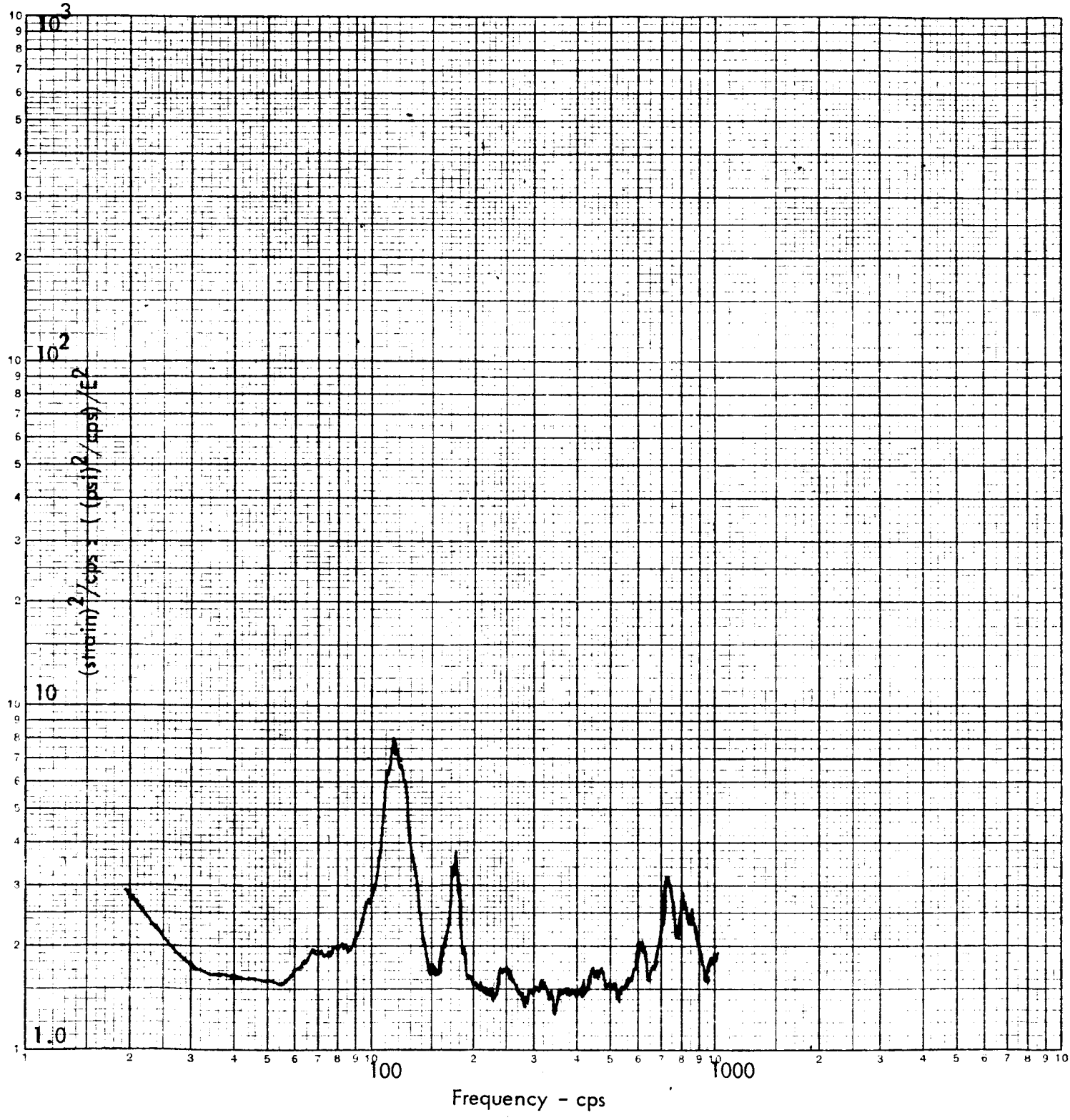


Figure 58 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 6

Run No. : 1
Track No. : 5
Filter Bandwidth : 10 cps

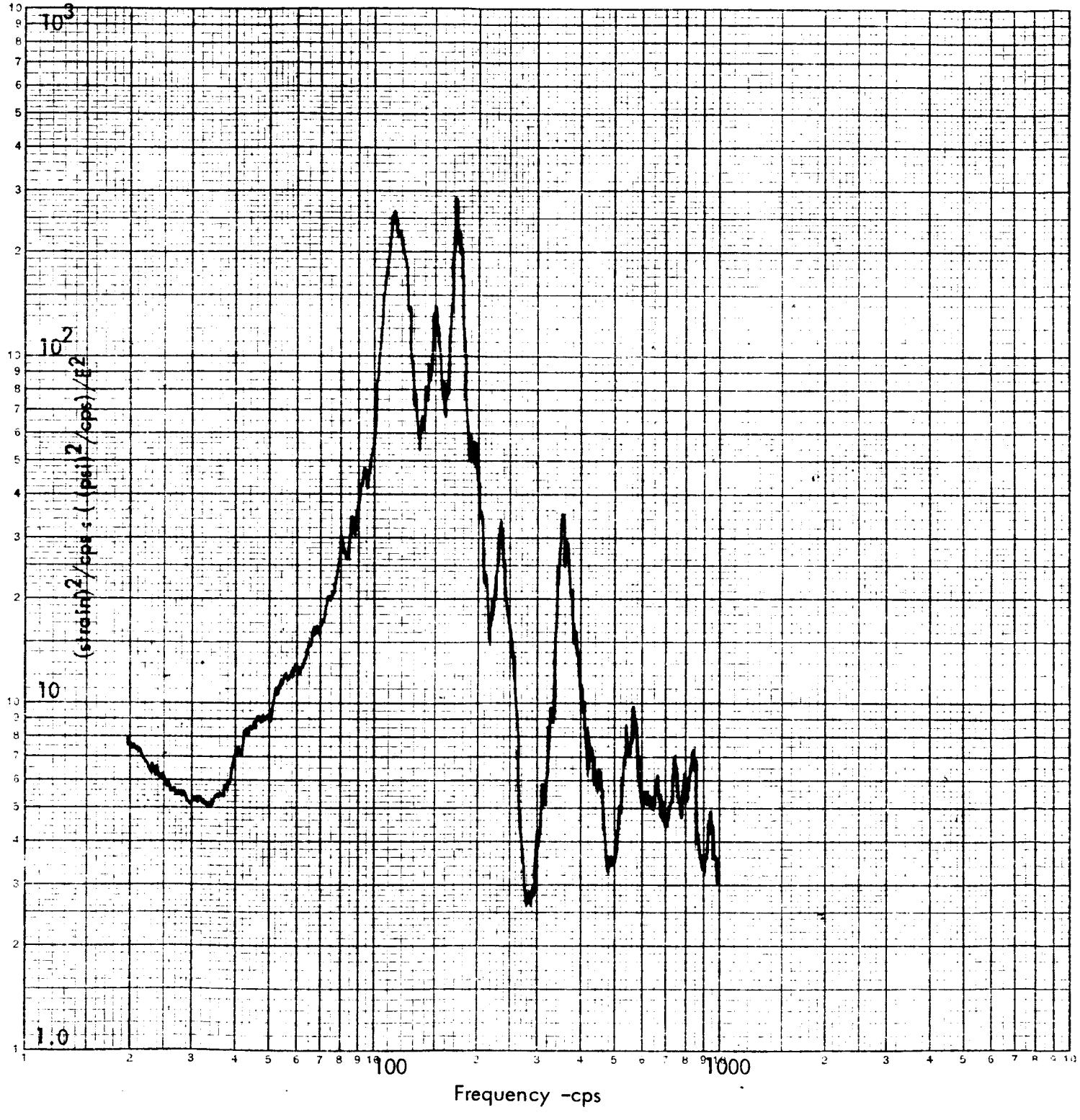


Figure 59 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 11

Run No. : 2
Track No. : 7
Filter Bandwidth : 10 cps

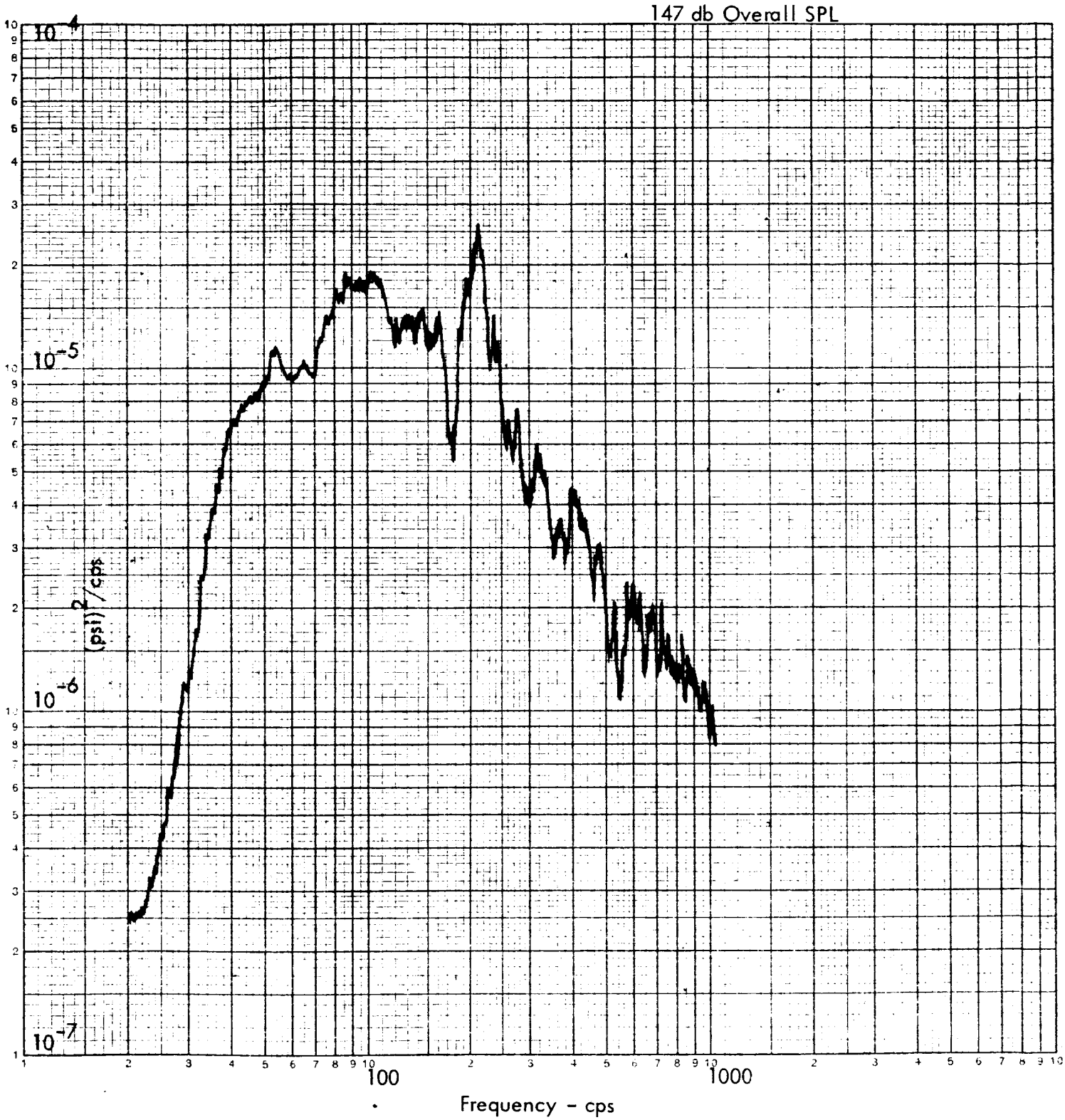


Figure 60 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 2

Run No. : 2
Track No. : 8
Filter Bandwidth : 10 cps

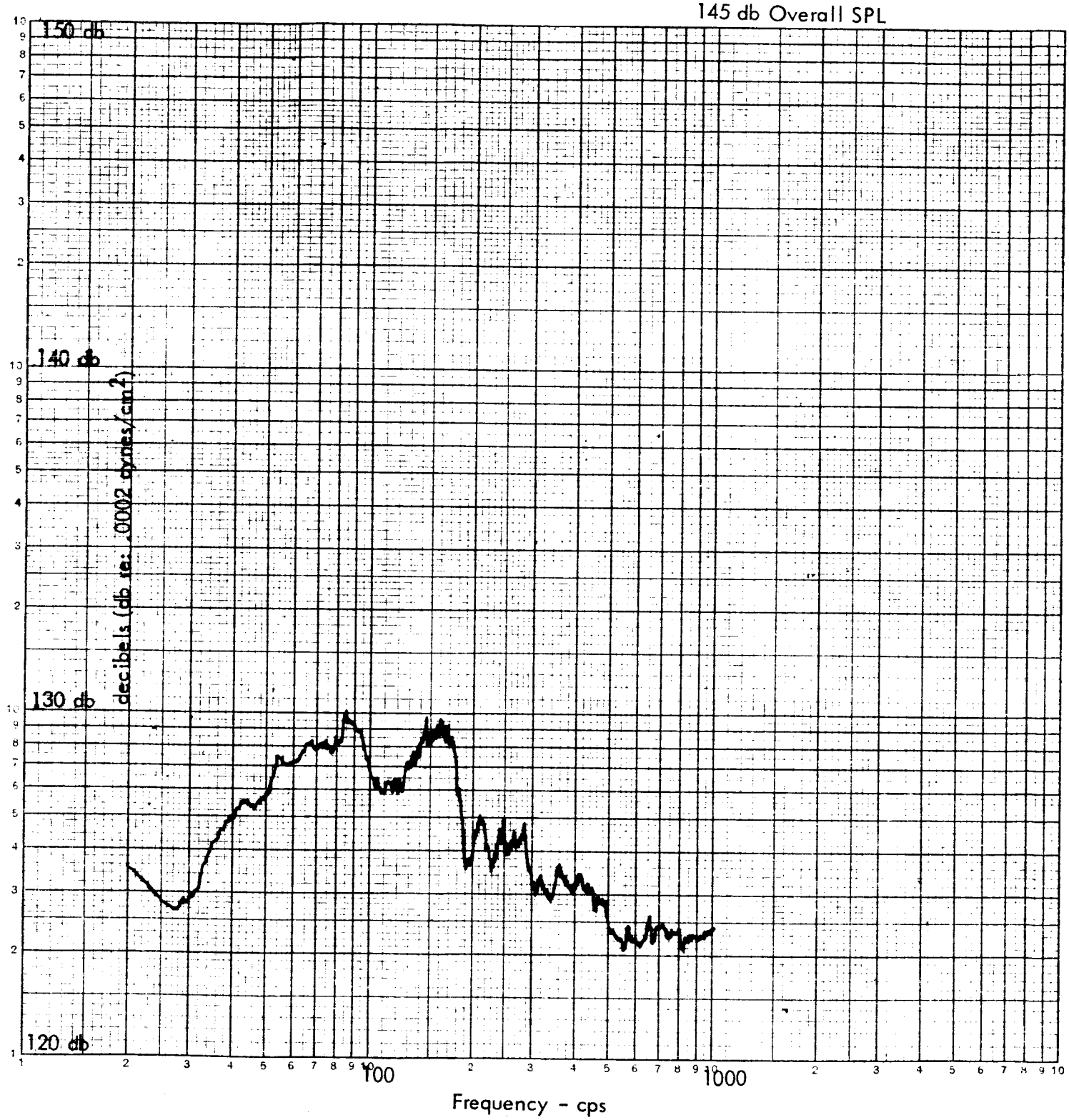


Figure 61 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 3

Run No. : 2
Track No. : 3
Filter Bandwidth : 10 cps

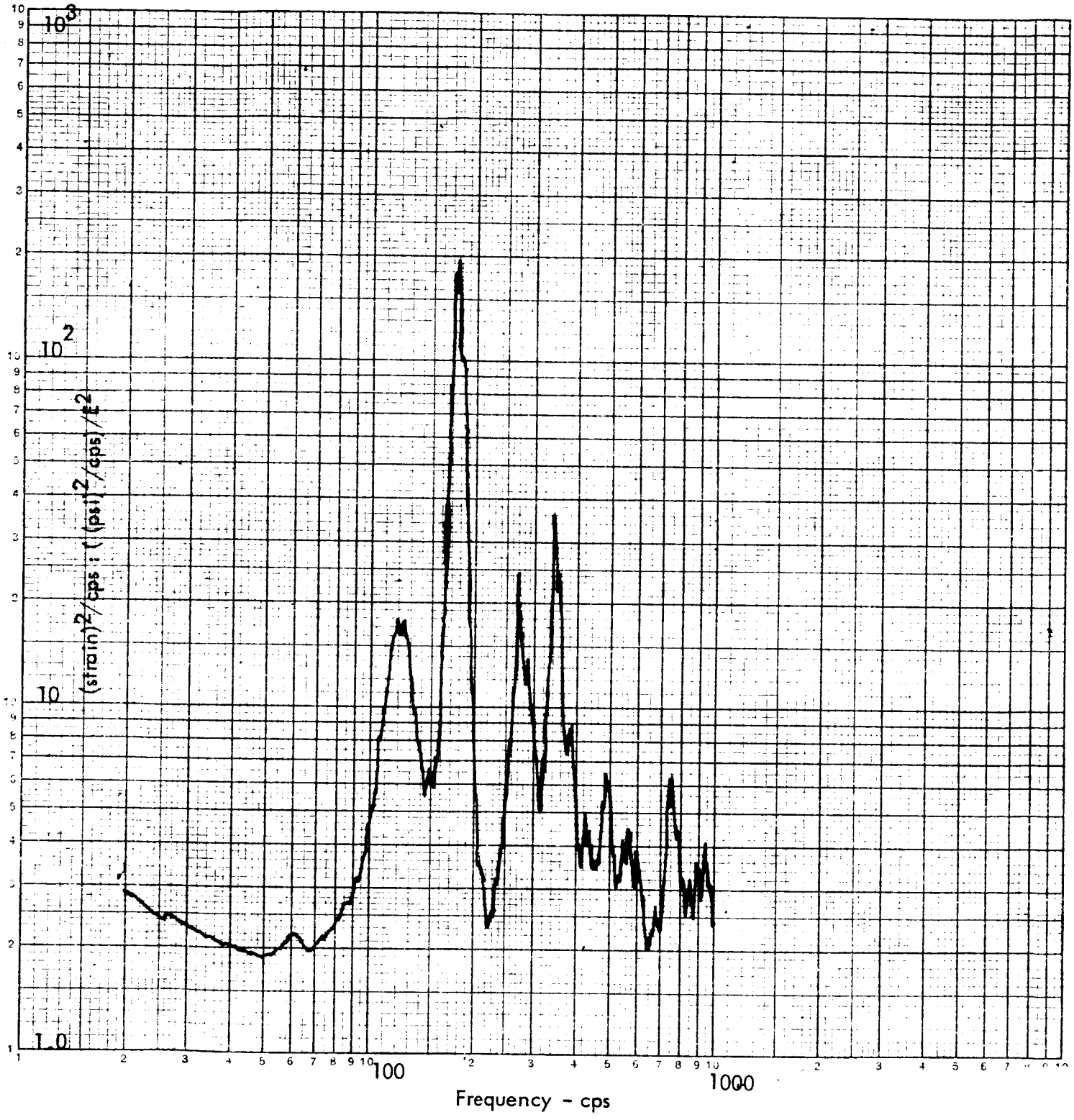


Figure 62 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 7

Run No. : 2
Track No. : 4
Filter Bandwidth : 10 cps

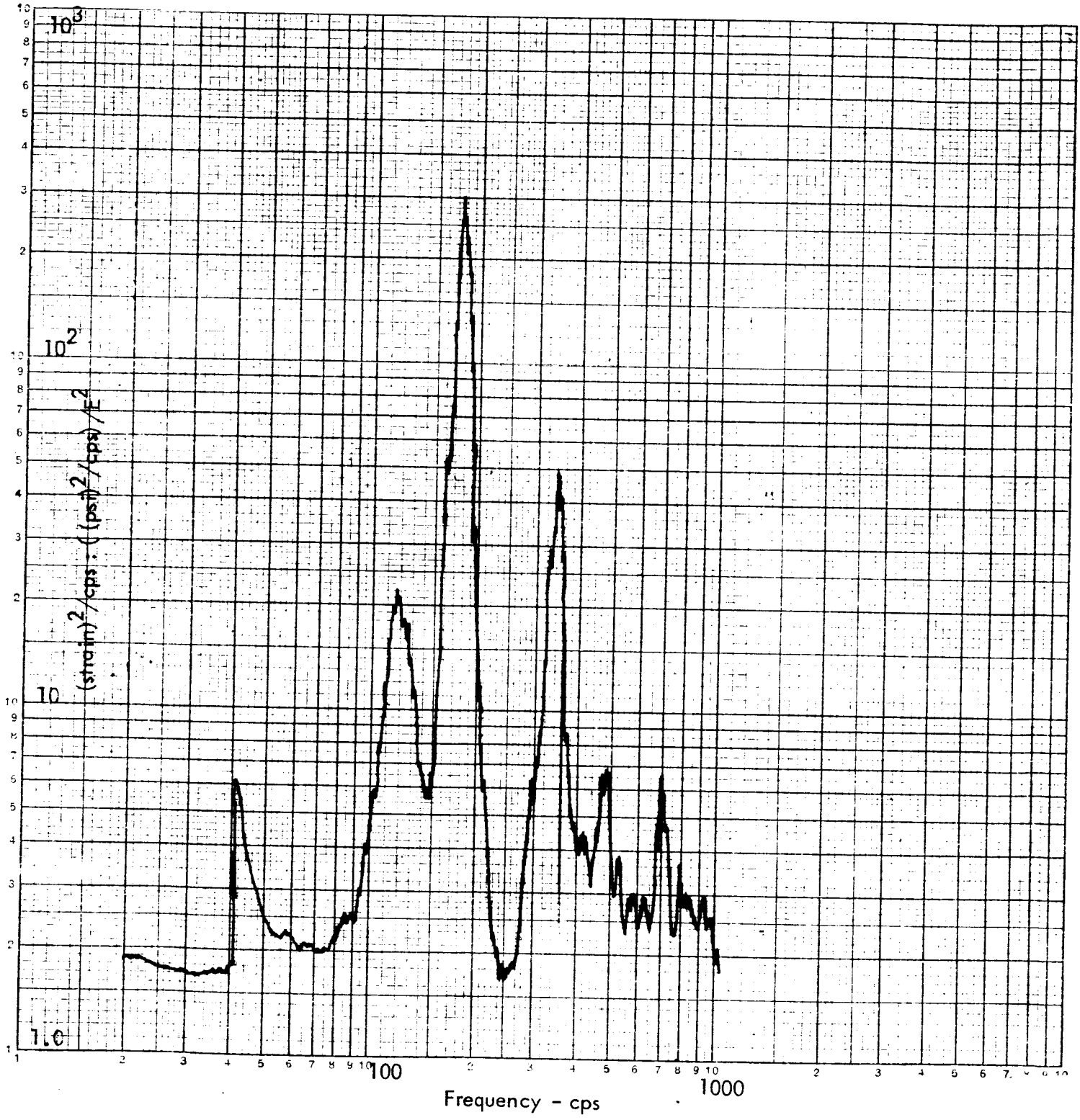


Figure 63 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 8

Date : 5 April 1963
Run No. : 2
Track No. : 1
Filter Bandwidth : 10 cps

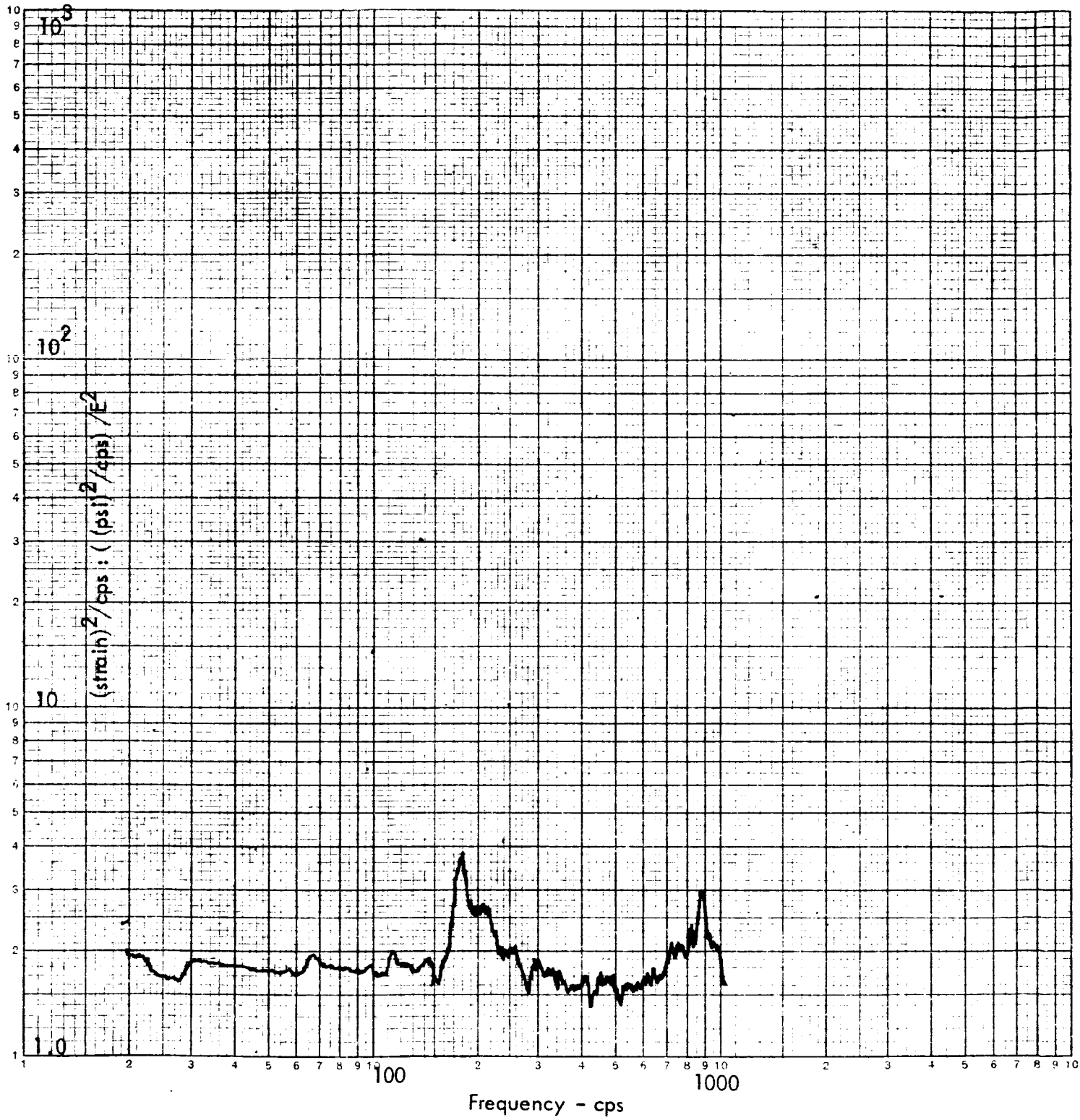


Figure 64 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 9

Run No. : 2
Track No. : 2
Filter Bandwidth : 10 cps

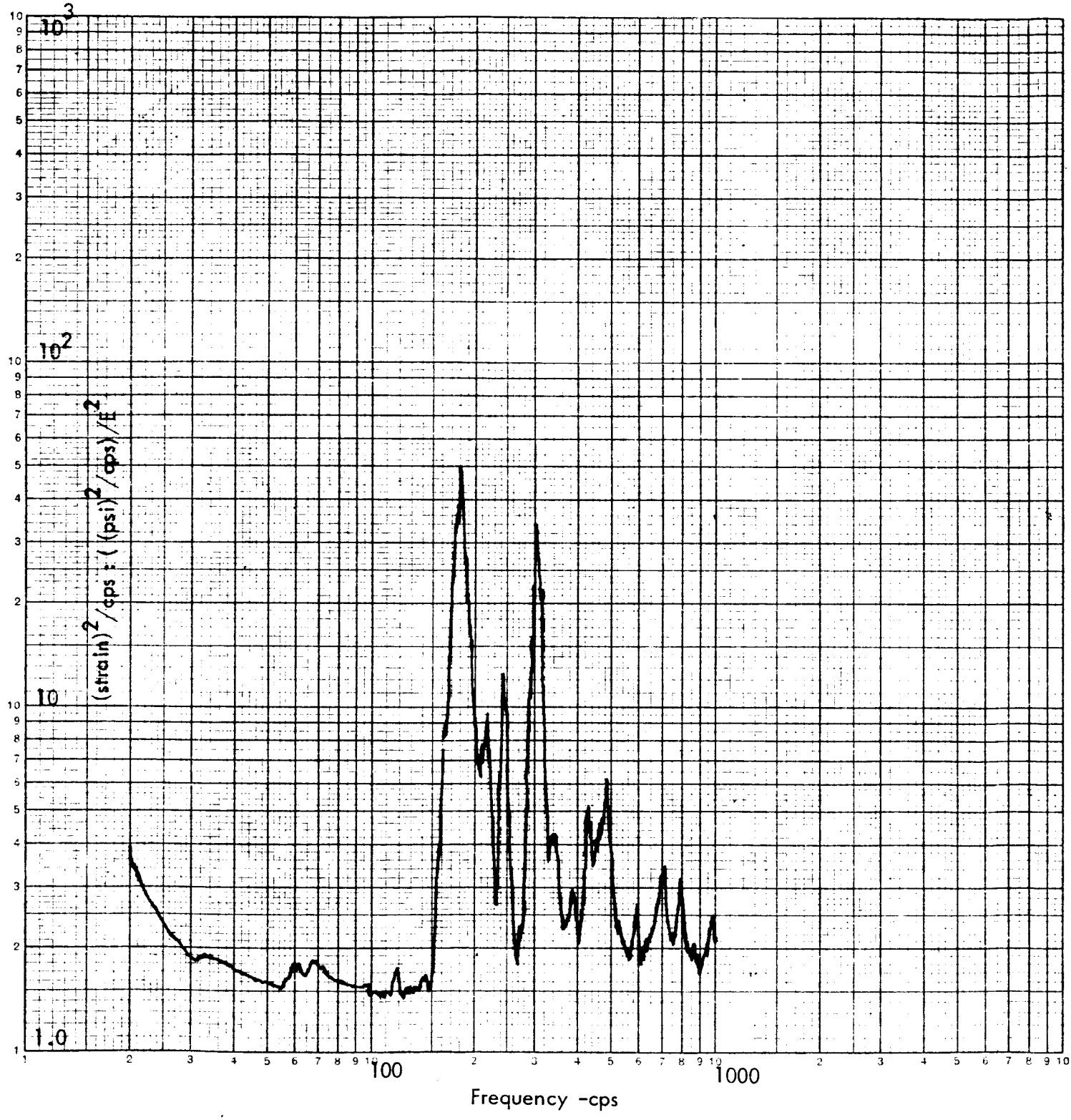


Figure 65 · Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 10

Run No. : 2
Track No. : 5
Filter Bandwidth : 10 cps

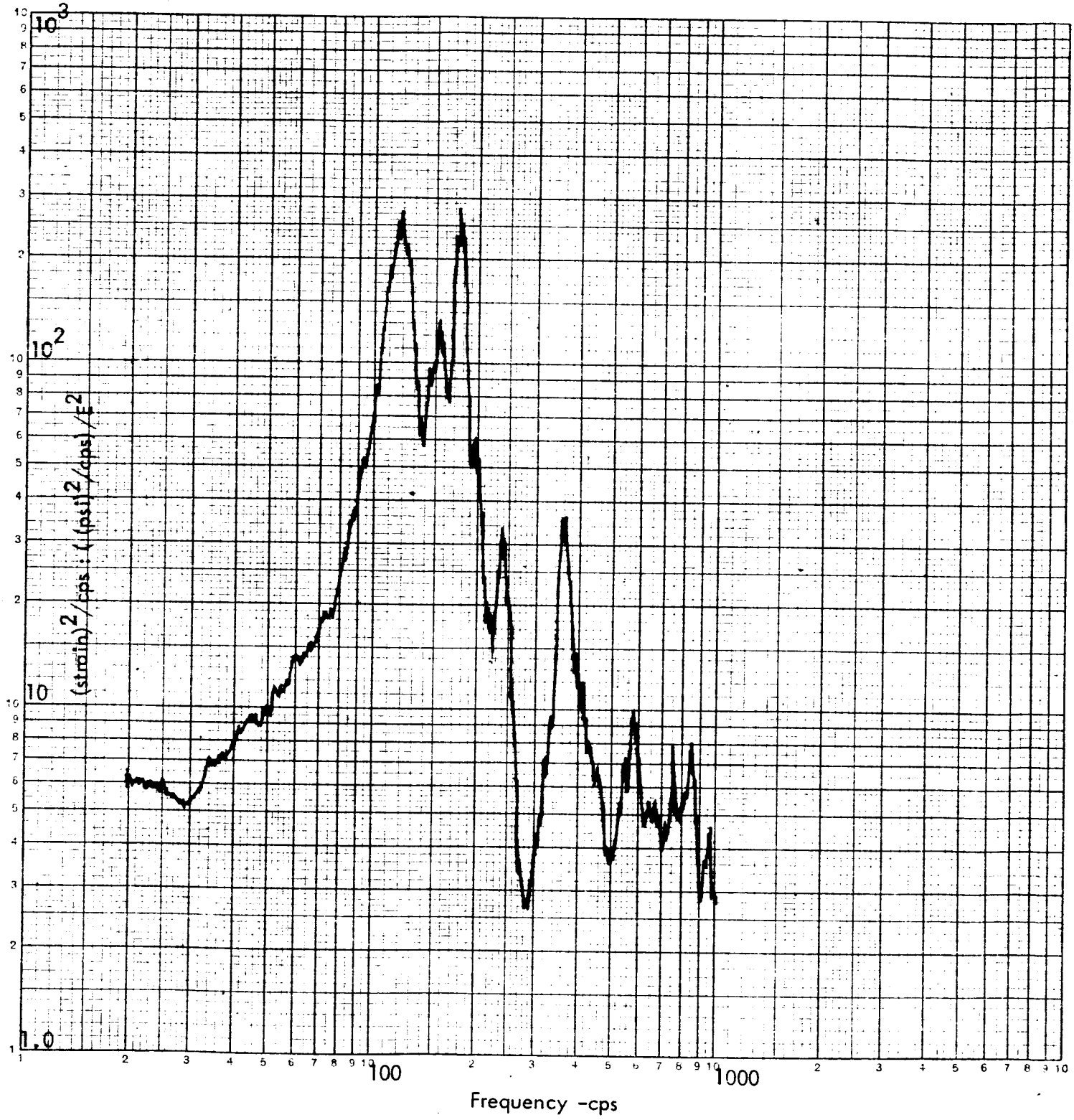


Figure 66 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 11

Run No. : 3
Track No. : 7
Filter Bandwidth : 10 cps

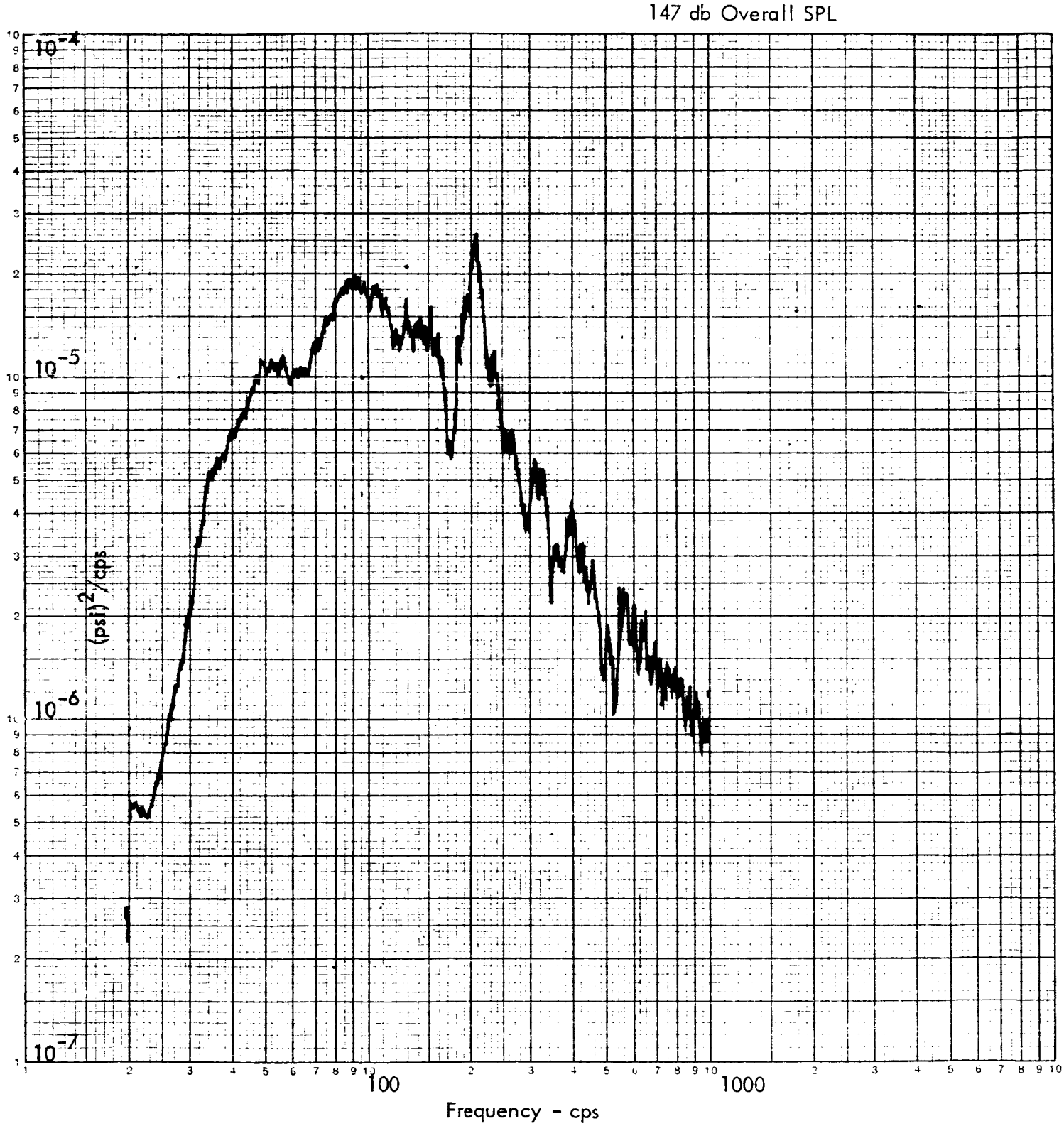


Figure 67 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 2

Date : 4 April 1963
Run No. : 3
Track No. : 7
Filter Bandwidth : 2 cps and 10 cps

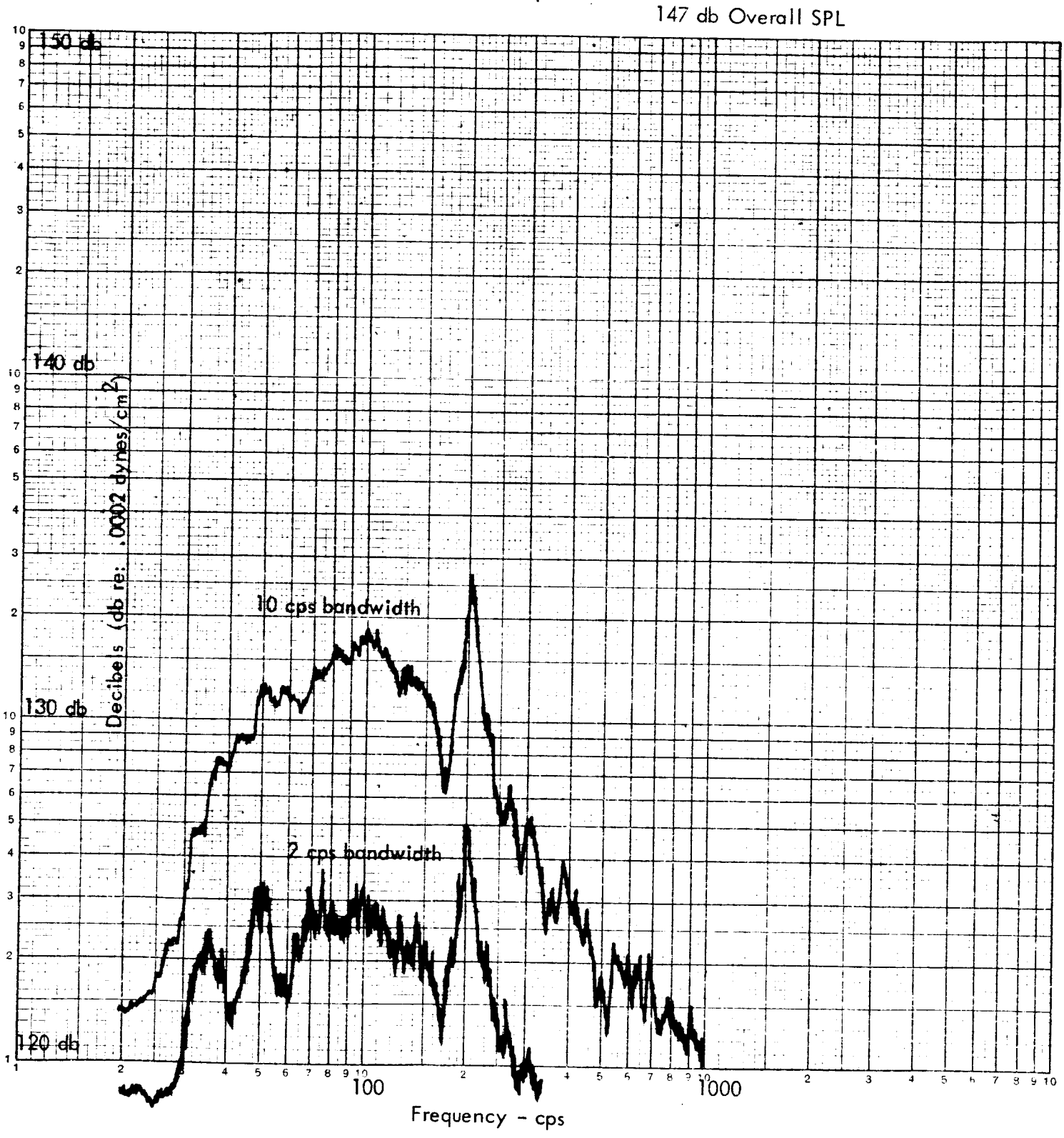


Figure 68 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 2

Run No. : 3
Track No. : 8
Filter Bandwidth : 10 cps

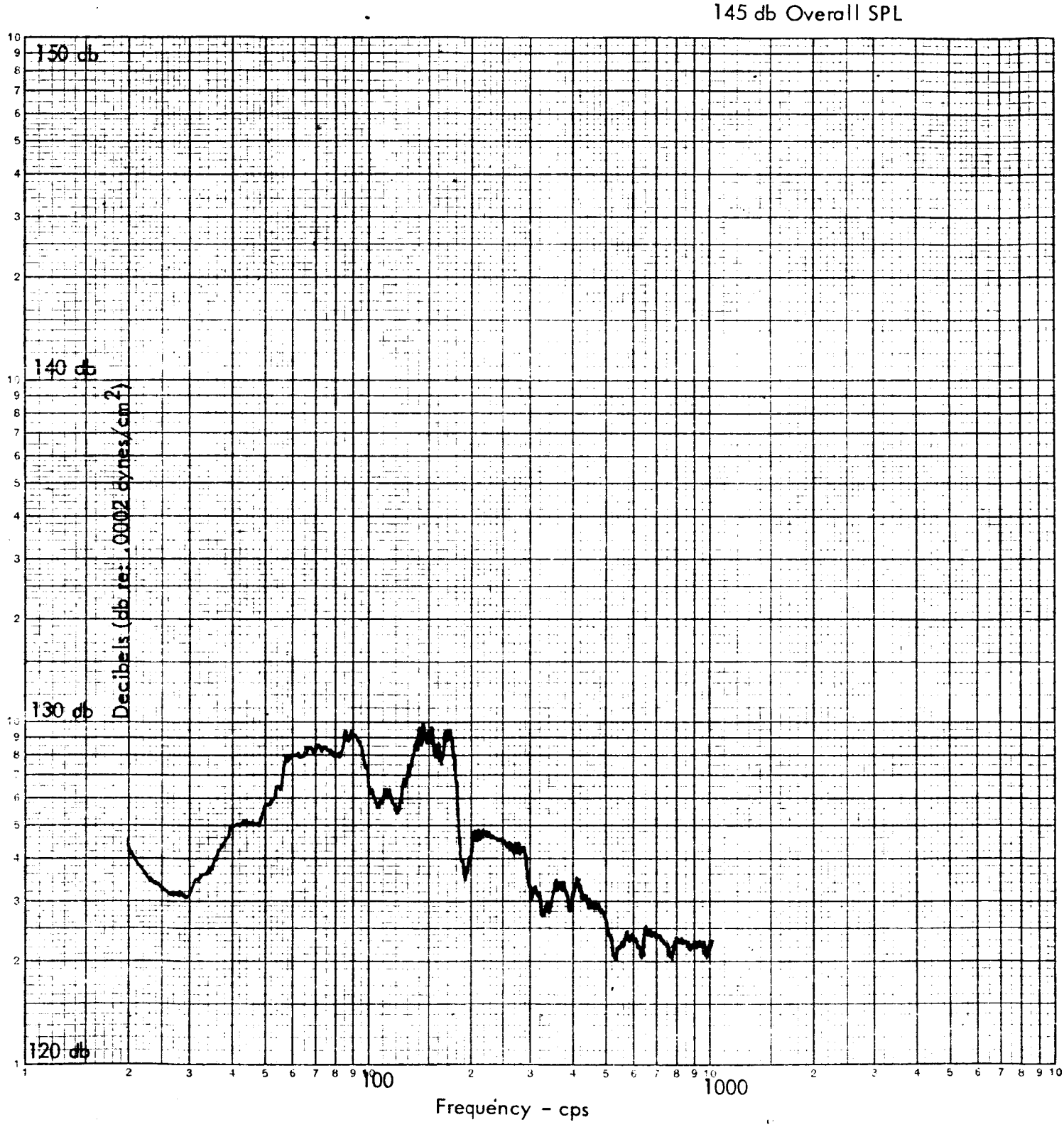


Figure 69 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 3

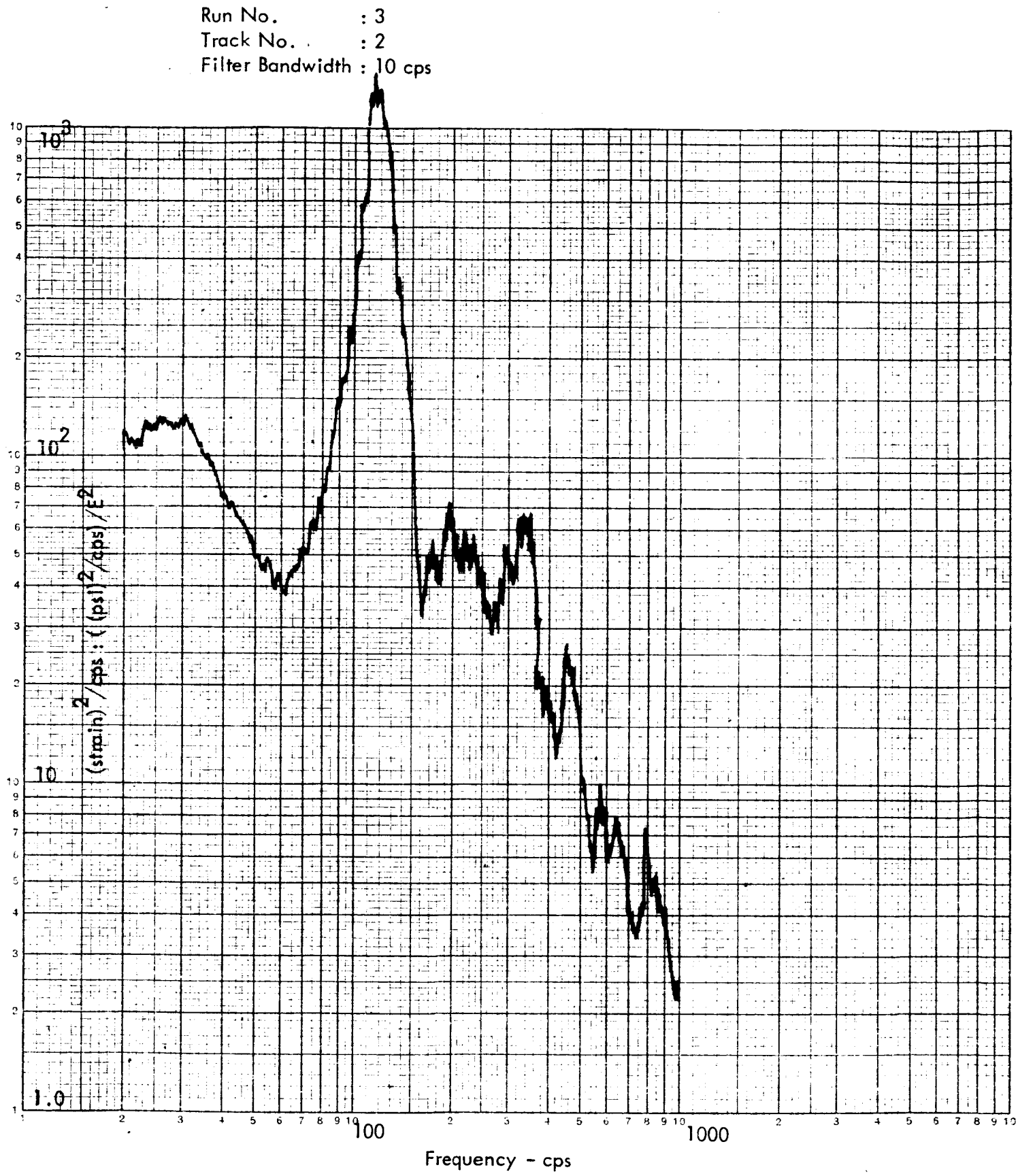


Figure 70 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 2

Date : 5 April 1963
Run No. : 1
Track No. : 1
Filter Bandwidth : 10 cps

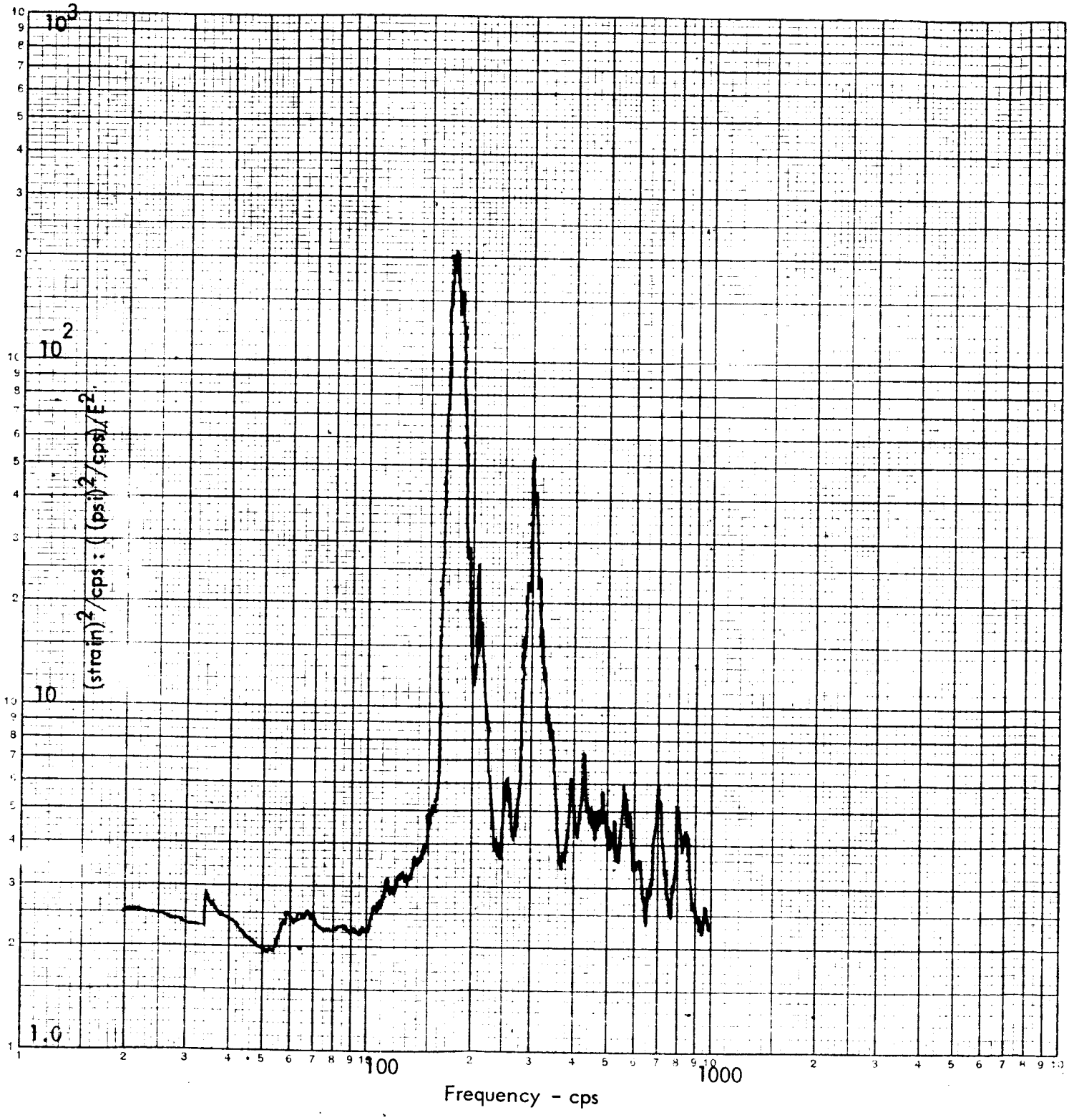


Figure 71 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 5

Run No. : 3
Track No. : 3
Filter Bandwidth : 10 cps

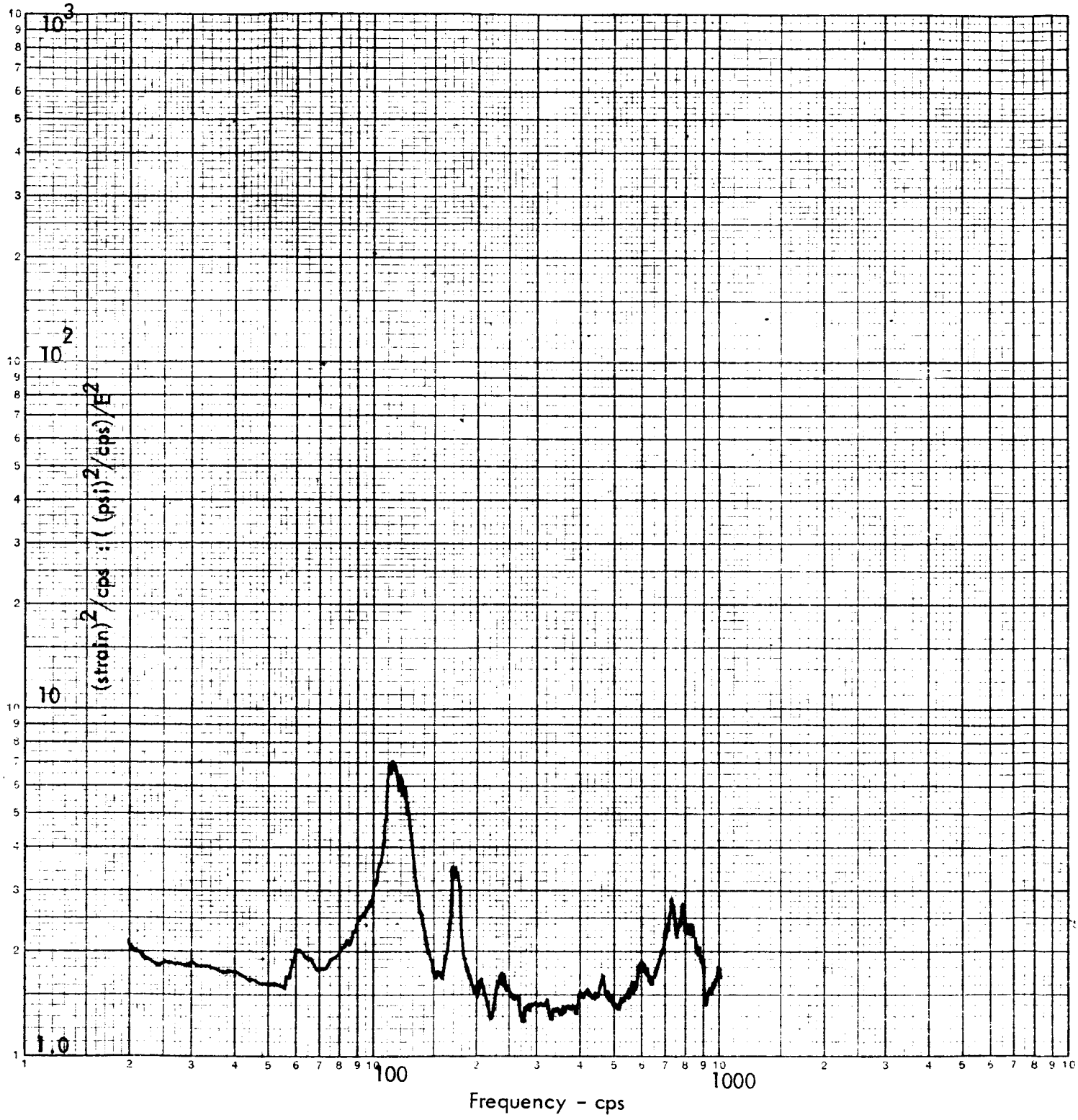


Figure 72 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 6

Run No. : 3
Track No. : 4
Filter Bandwidth : 10 cps

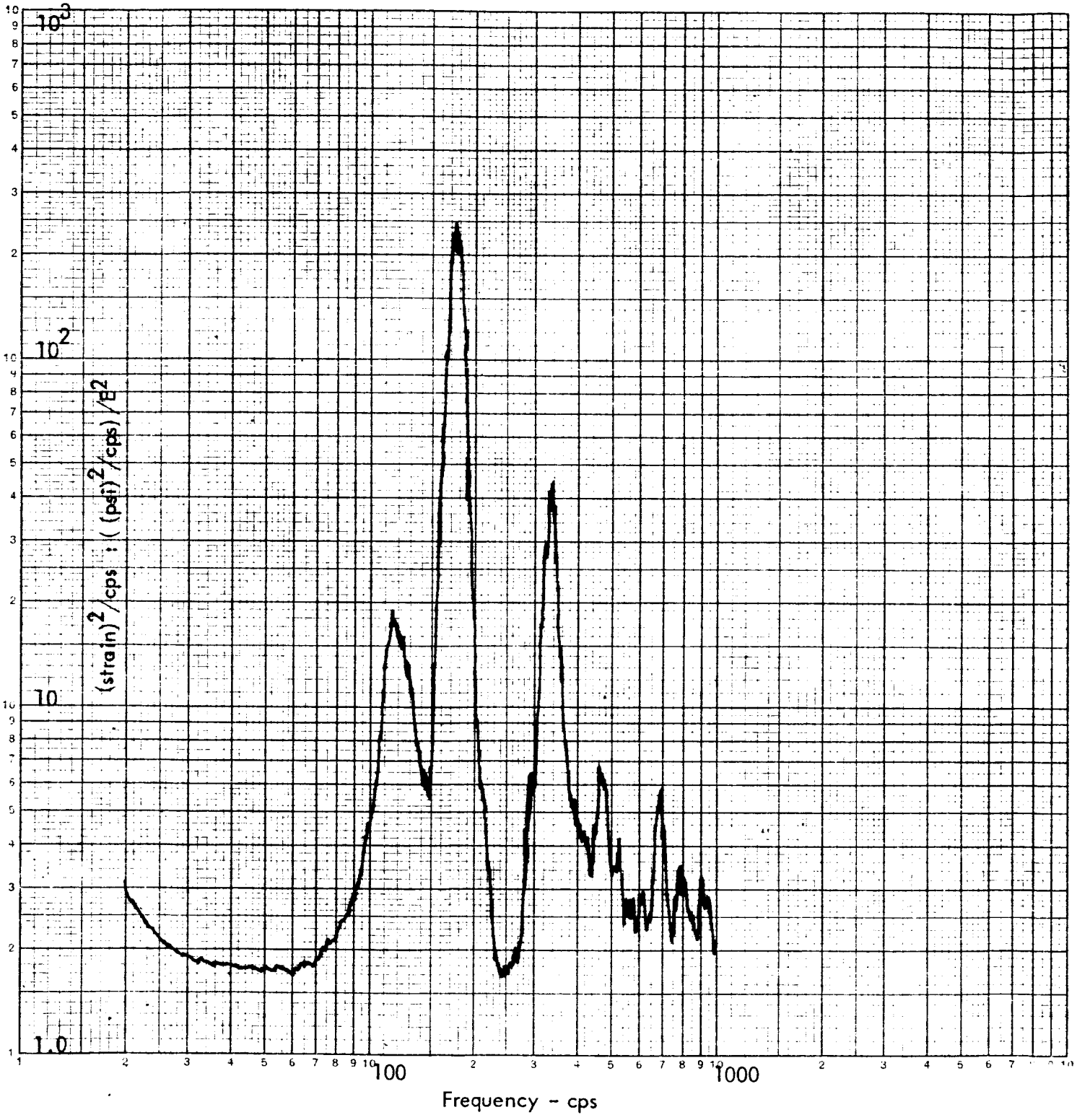


Figure 73 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 3

Run No. : 3
Track : 5
Filter Bandwidth : 10 cps

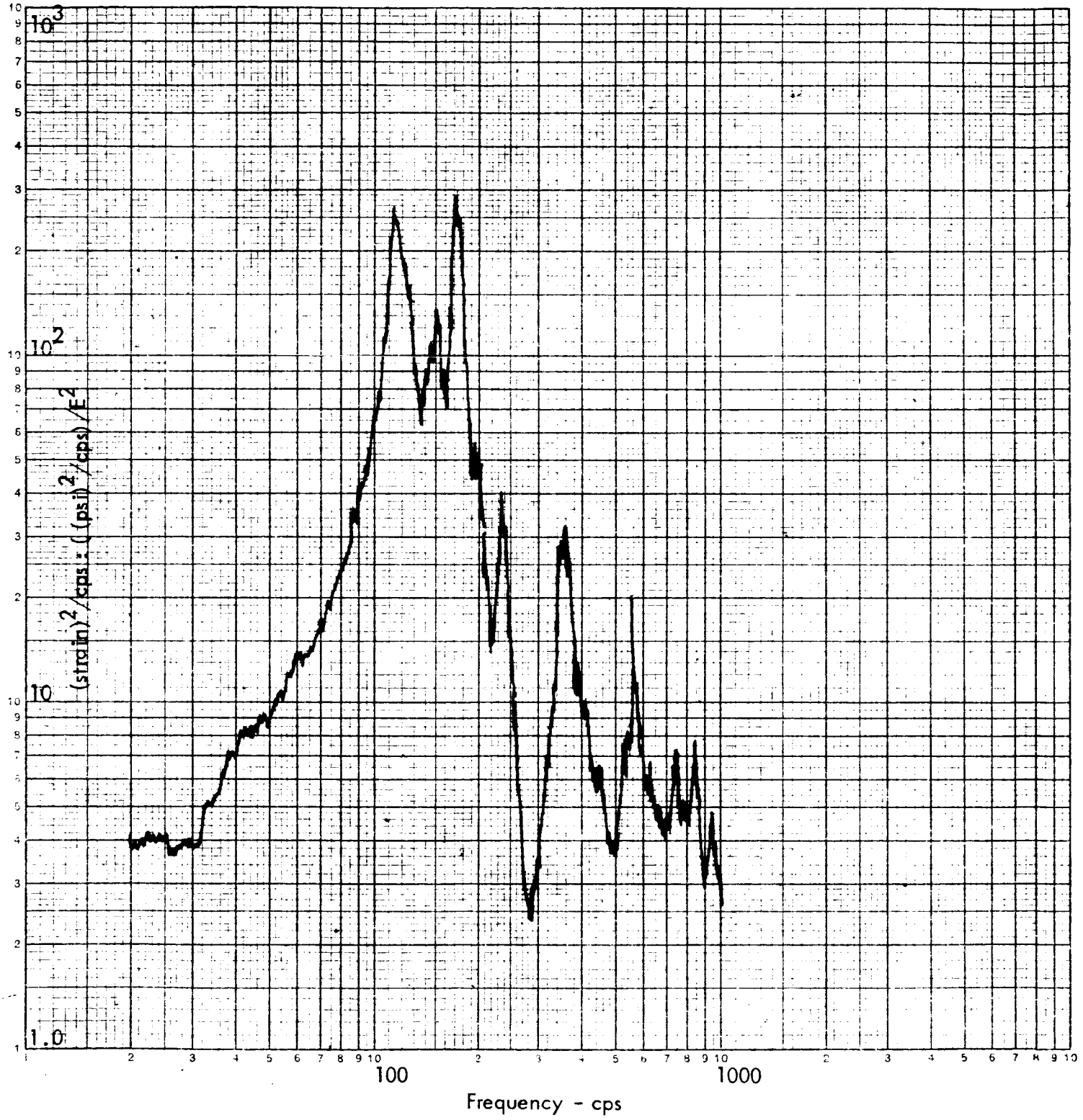


Figure 74 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 11

Run No. : 3
Track No. : 4
Filter Bandwidth : 10 cps

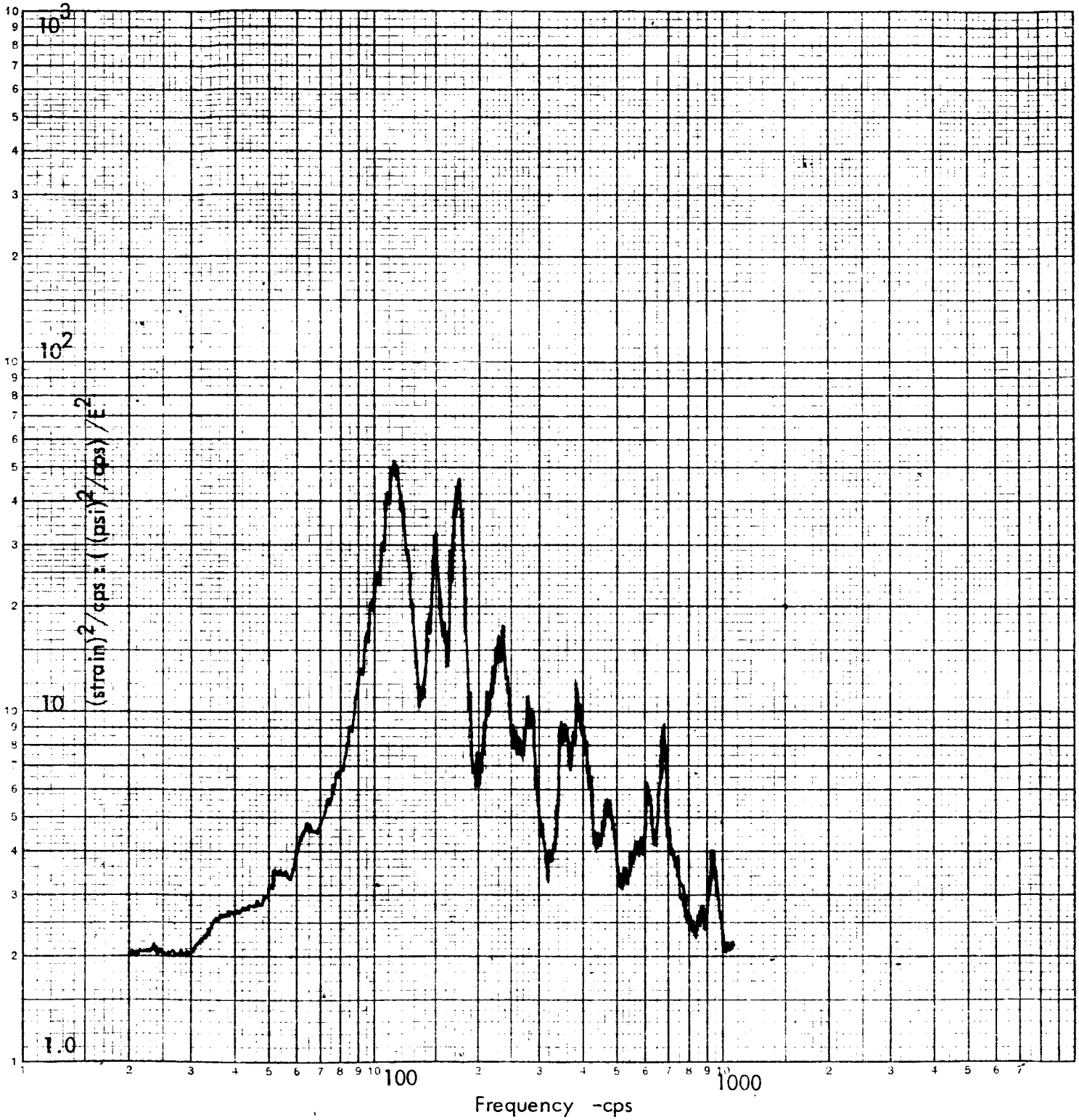


Figure 75 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 12

Run No. : 3
Track No. : 1
Filter Bandwidth : 2 cps

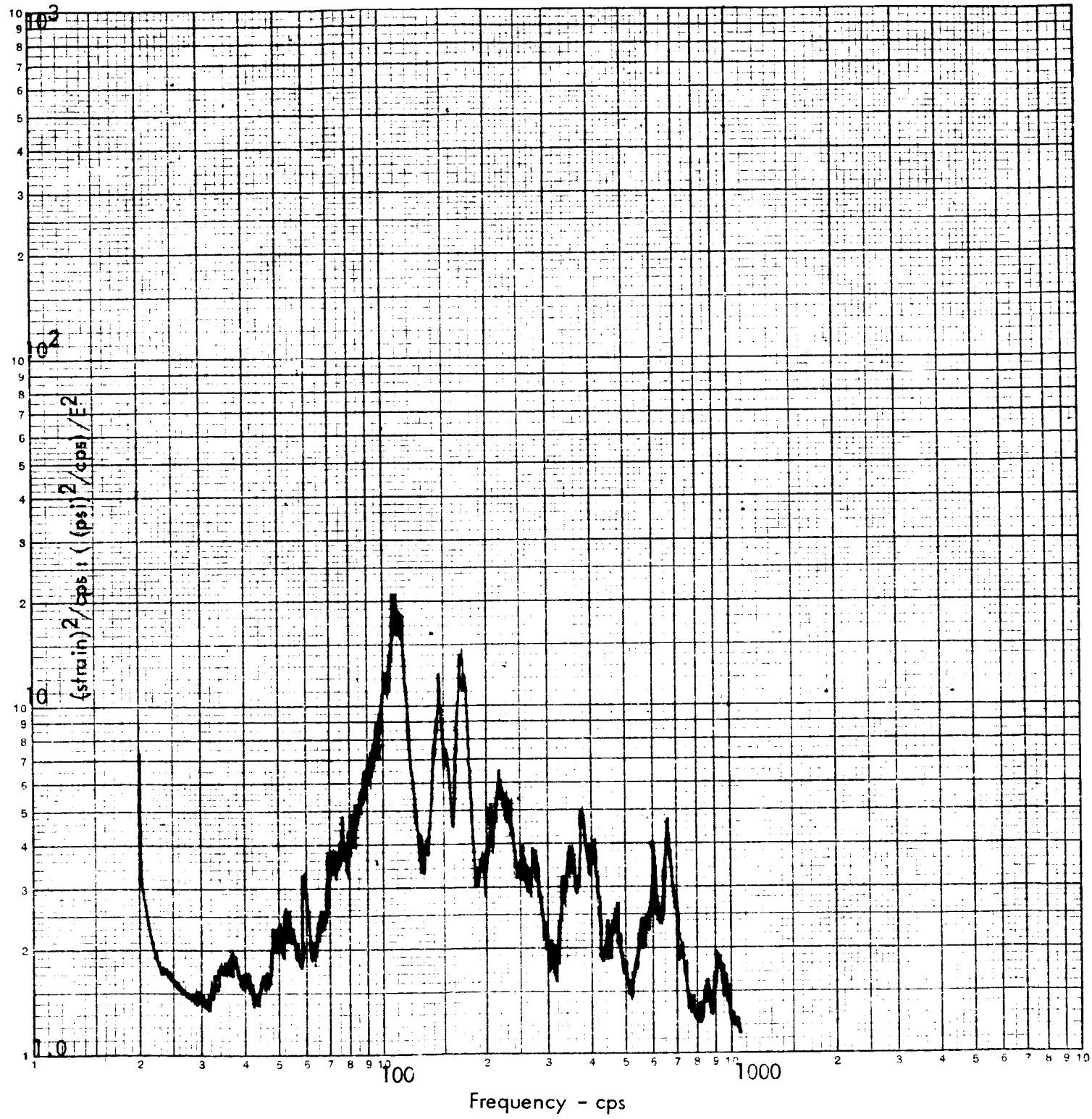


Figure No. 76 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 12

Run No. : 4
Track No. : 1
Filter Bandwidth : 10 cps

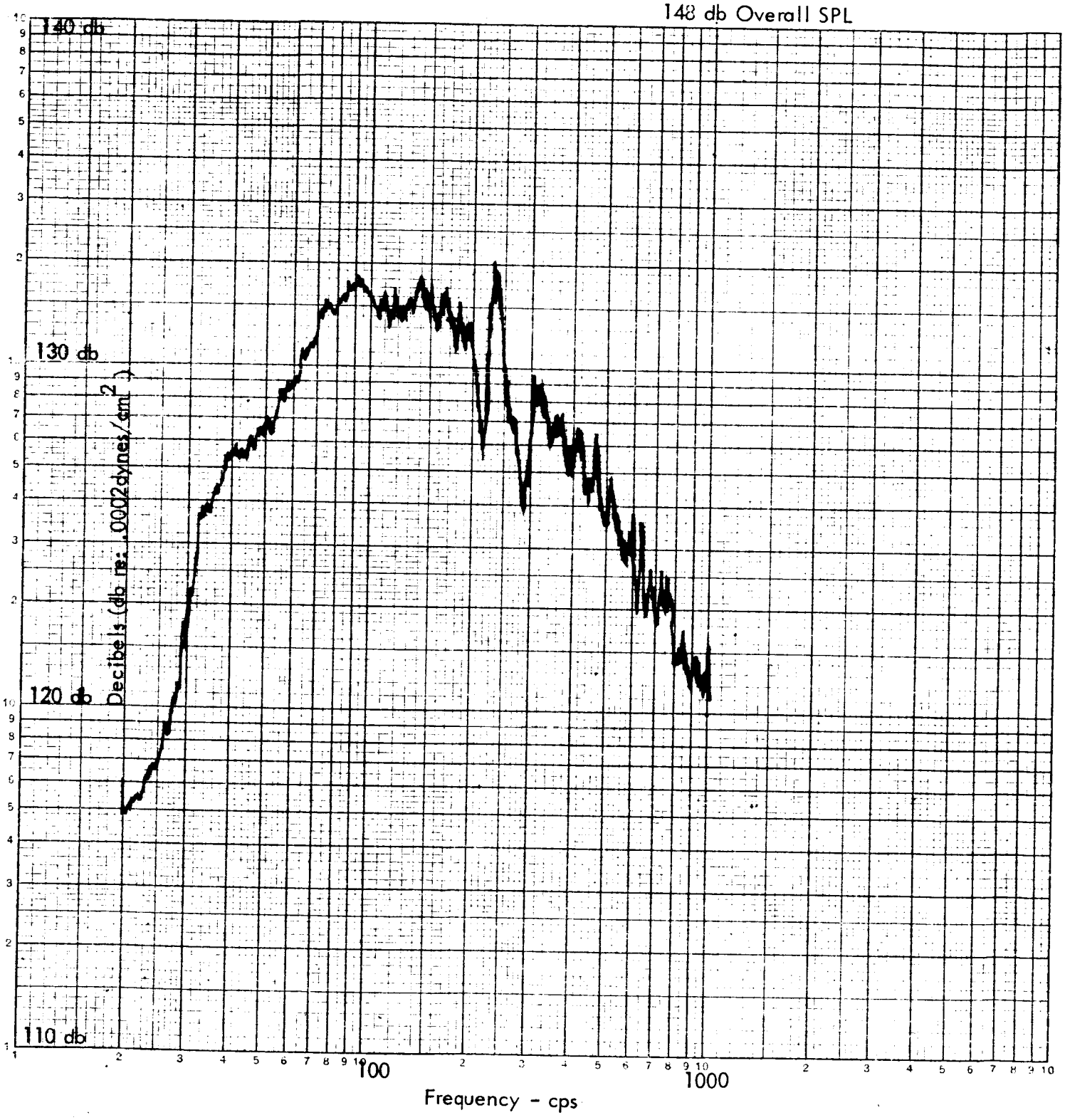


Figure 77 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 1

Run No. : 4
Track No. : 2
Filter Bandwidth : 10 cps

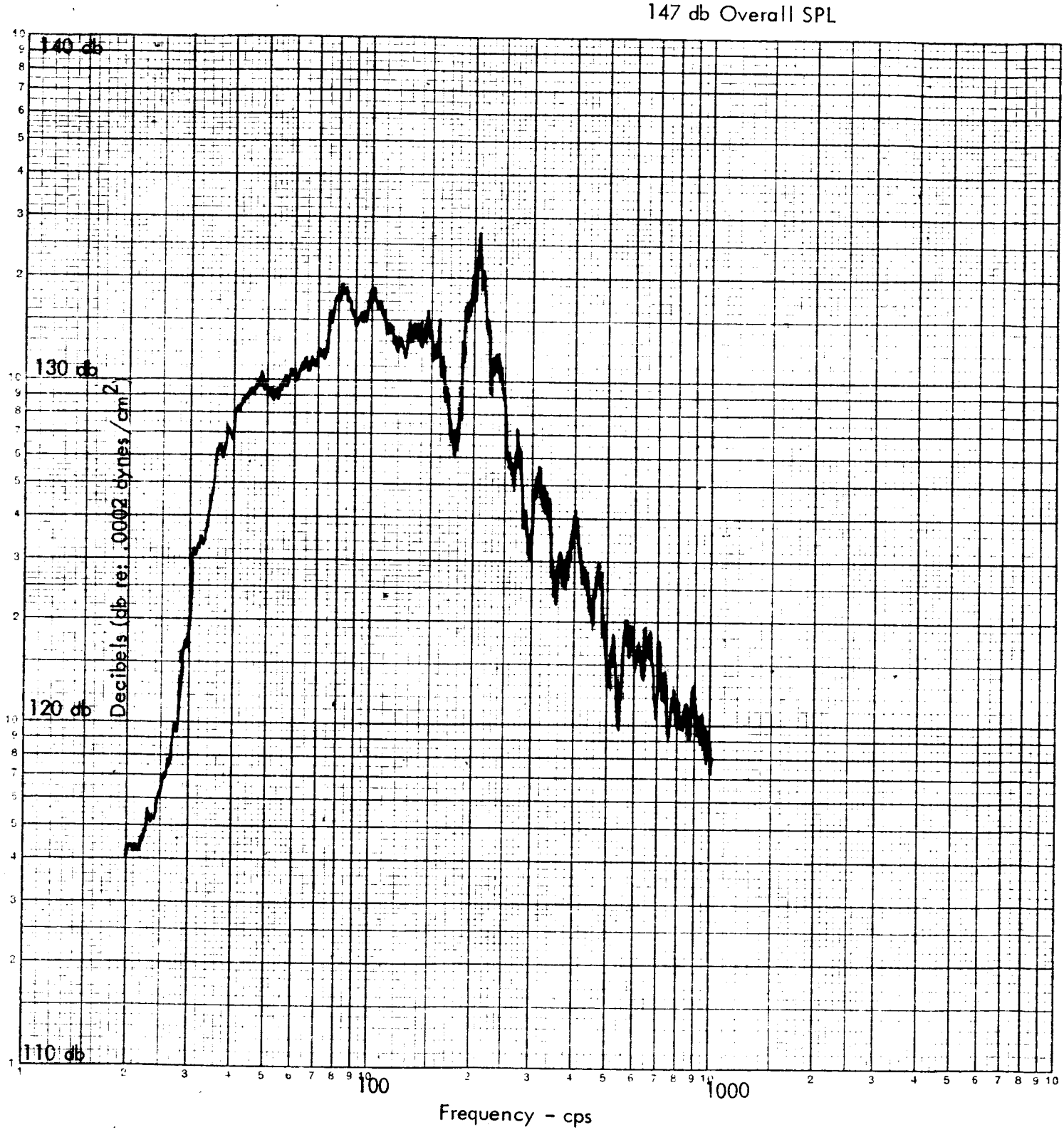


Figure 78 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 2

Run No. : 4
Track No. : 3
Filter Bandwidth : 10 cps

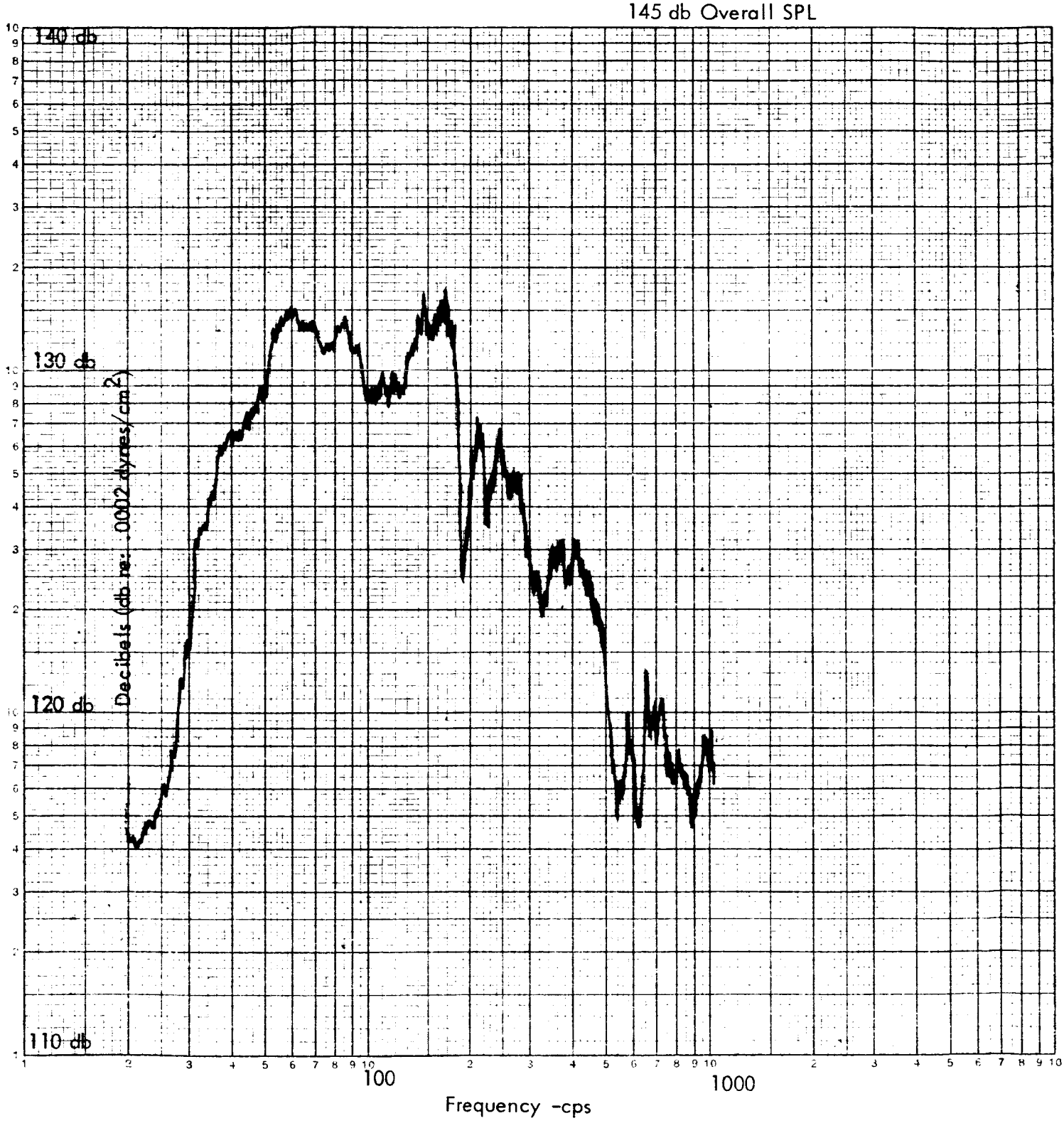


Figure 79 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 3

Run No. : 4
Track No. : 4
Filter Bandwidth : 10 cps

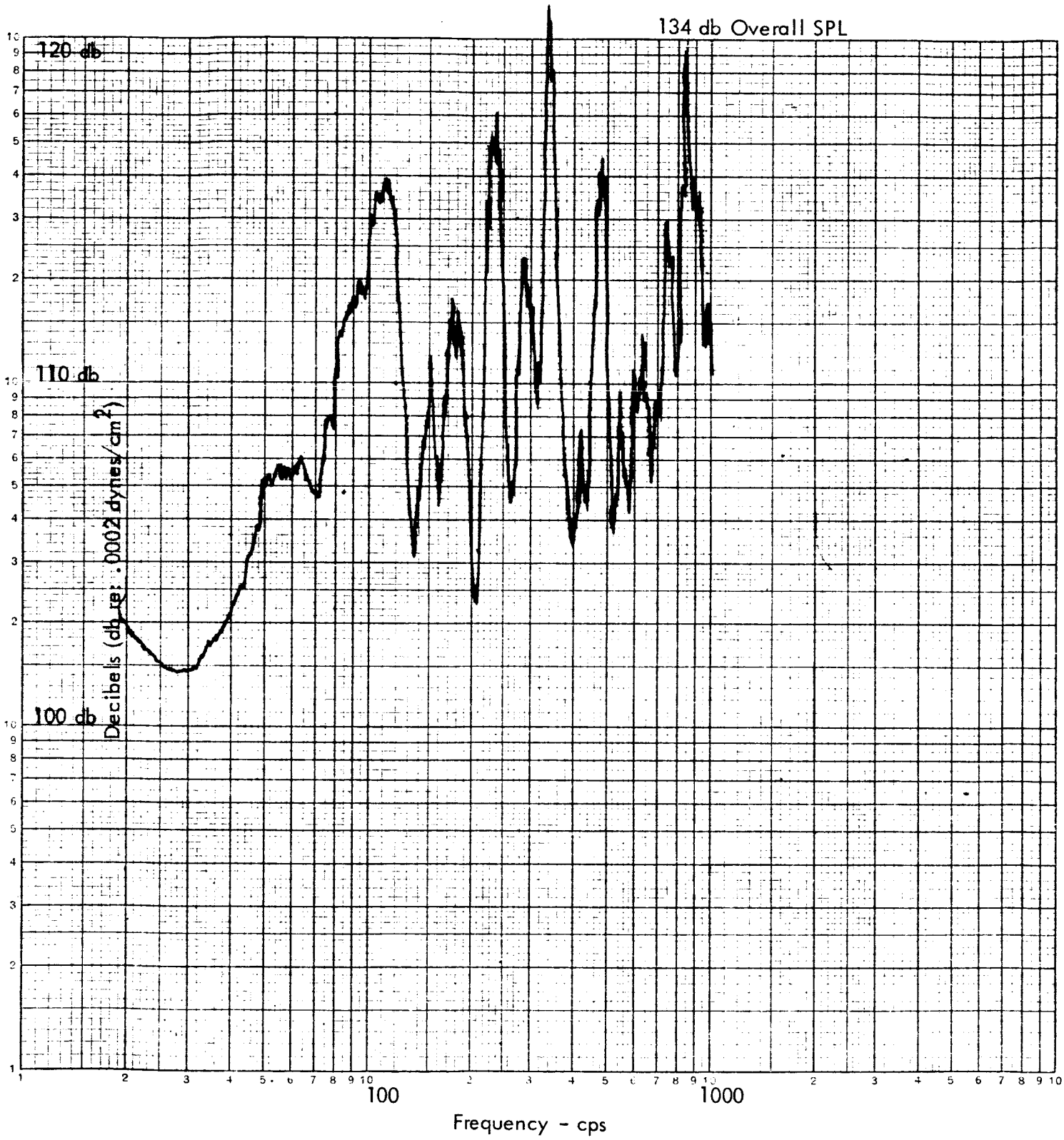


Figure 80 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 4

Date : 15 April 1963
Run No. : 1
Track No. : 1
Filter Bandwidth : 10 cps

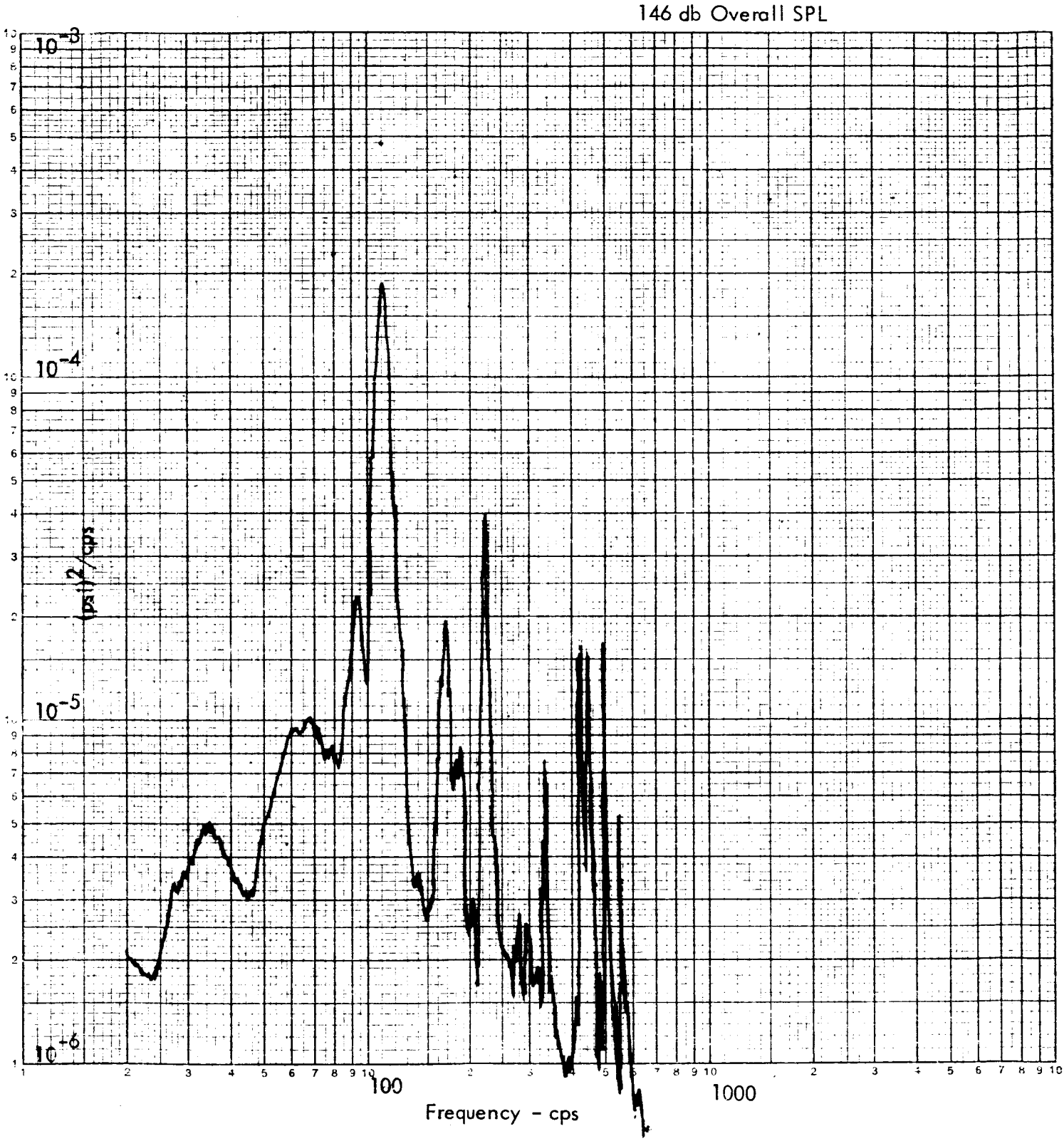


Figure No. 81 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 1

Date : 15 April 1963
Run No. : 1
Track No. : 2
Filter Bandwidth : 10 cps

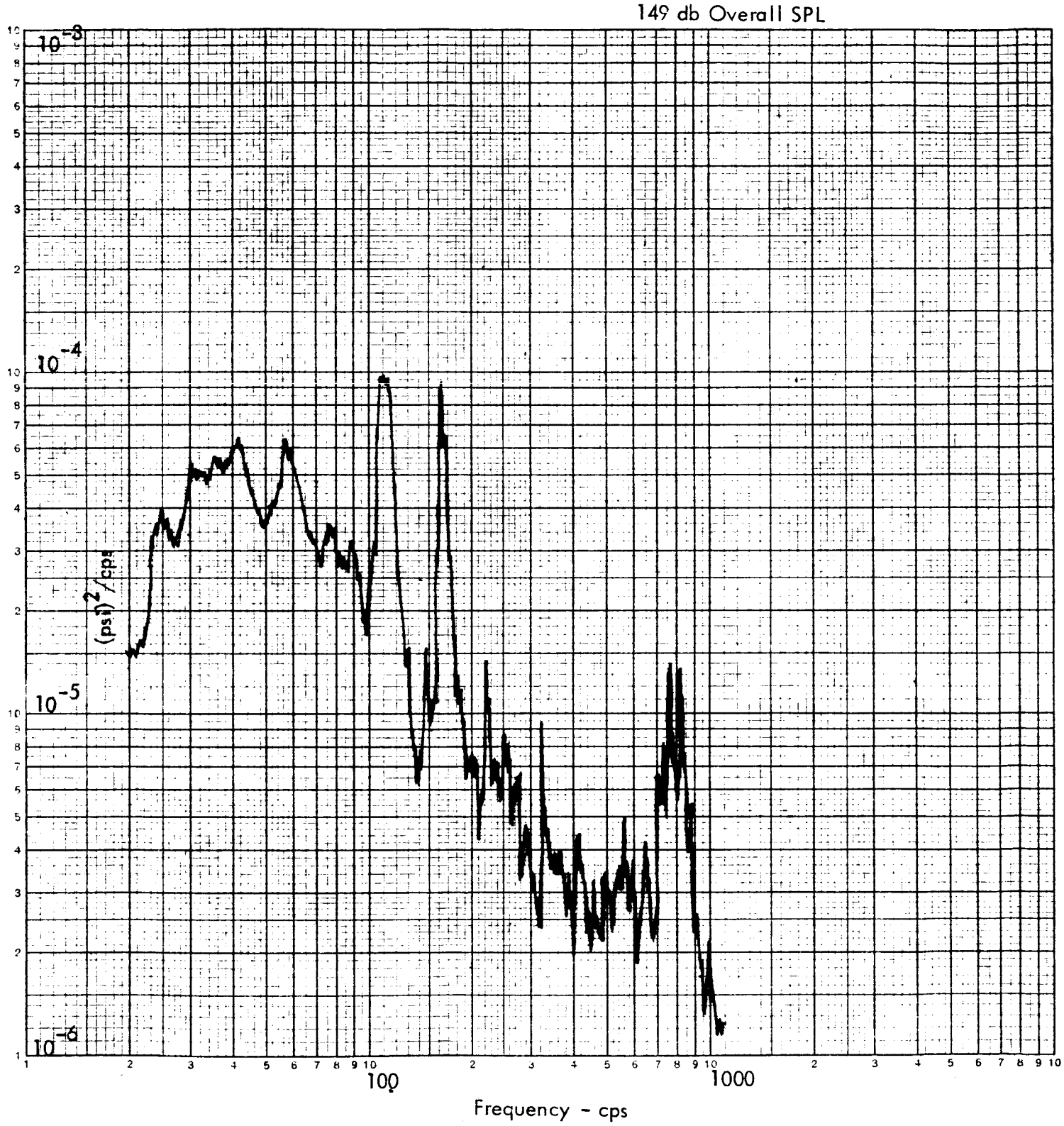


Figure 82 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 2

Date : 15 April 1963
Run No. : 1
Track No. : 3
Filter Bandwidth : 10 cps

145 db Overall SPL

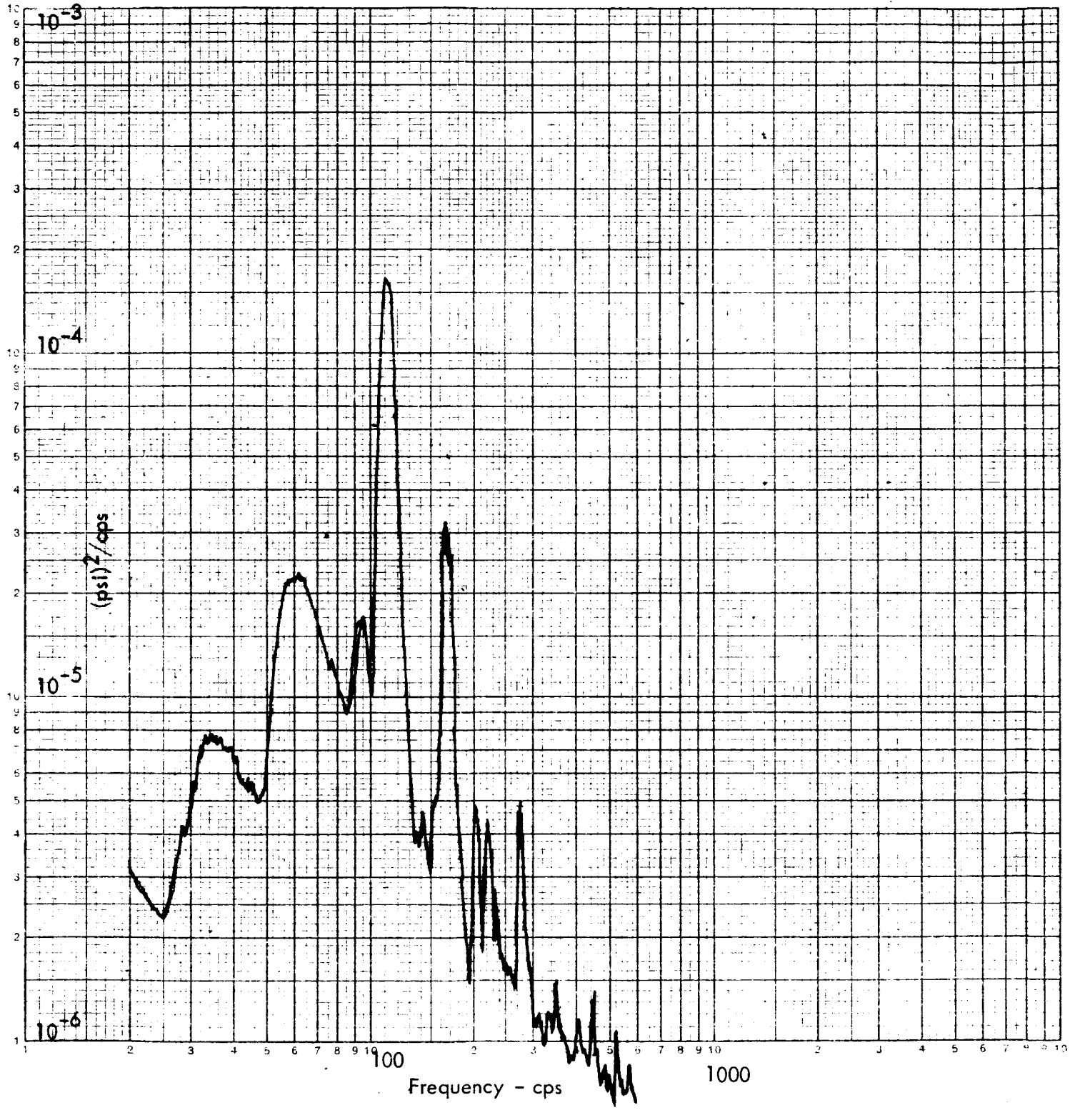


Figure No. 83 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 3

Date : 15 April 1963
Run No. : 1
Track No. : 6
Filter Bandwidth : 10 cps

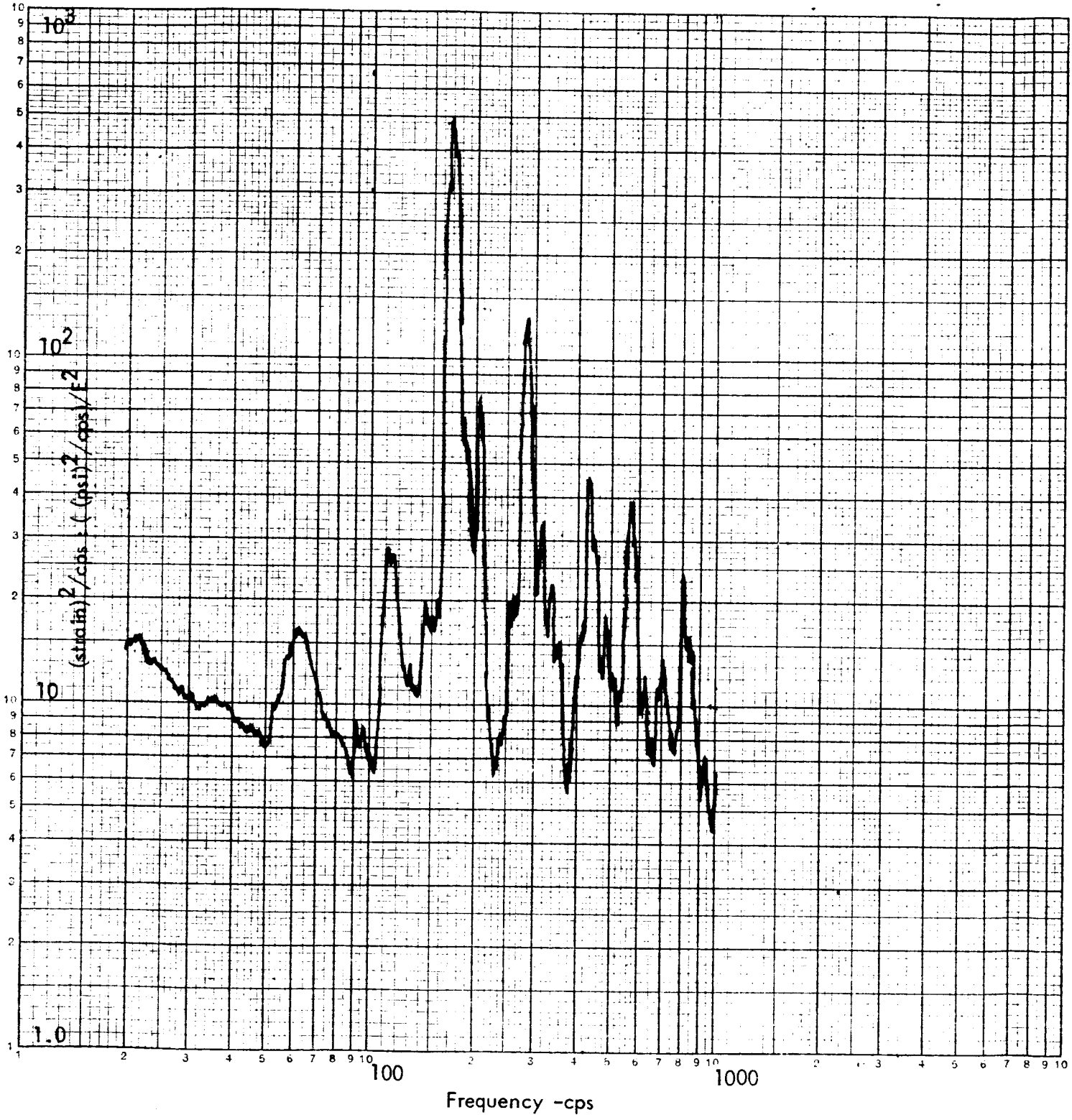


Figure 84 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 5

Date : 15 April 1963
Run No. : 1
Track No. : 7
Filter Bandwidth : 10 cps

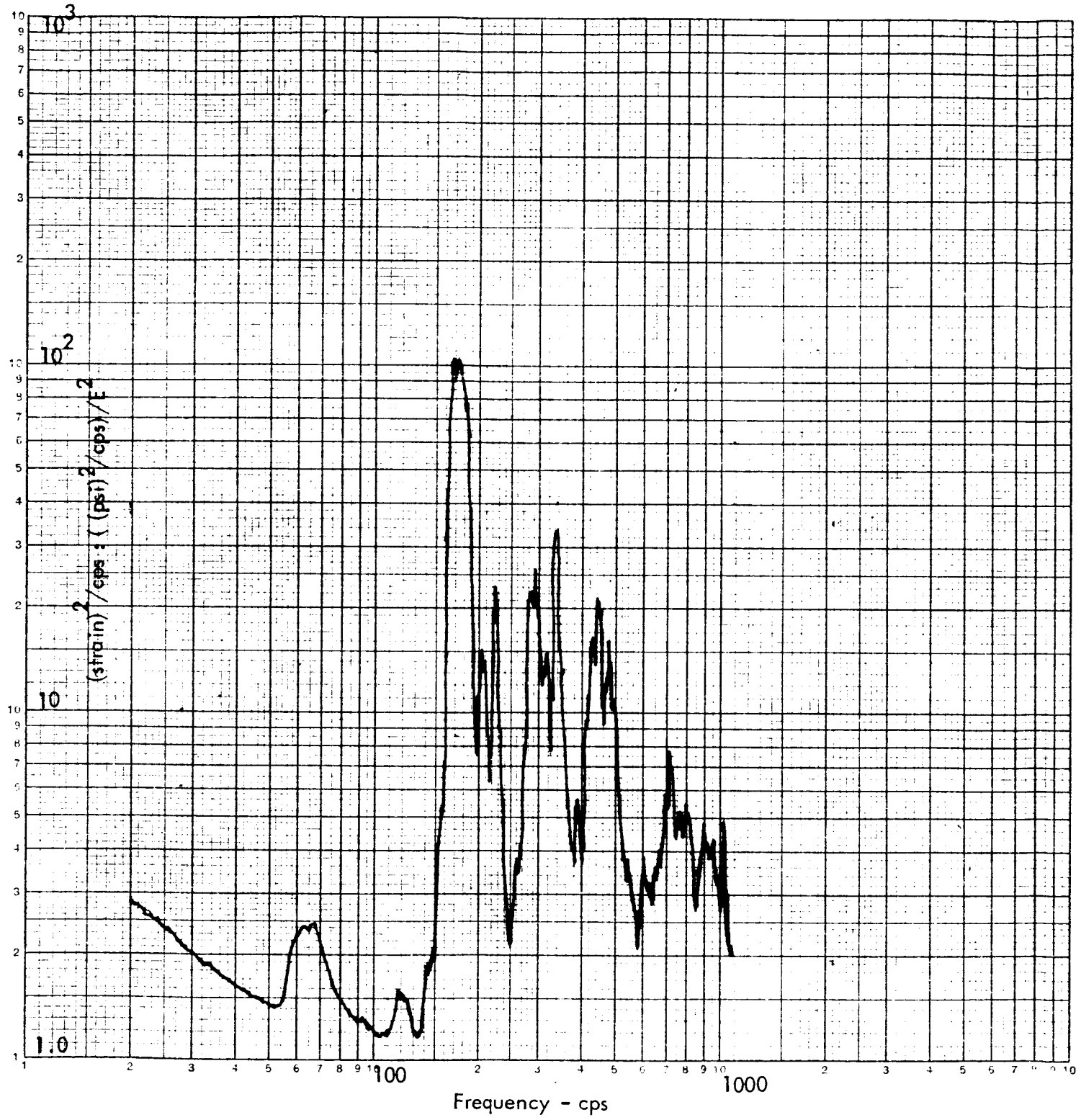


Figure 85 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 10

Date : 15 April 1963
Run No. : 1
Track No. : 8
Filter Bandwidth : 10 cps

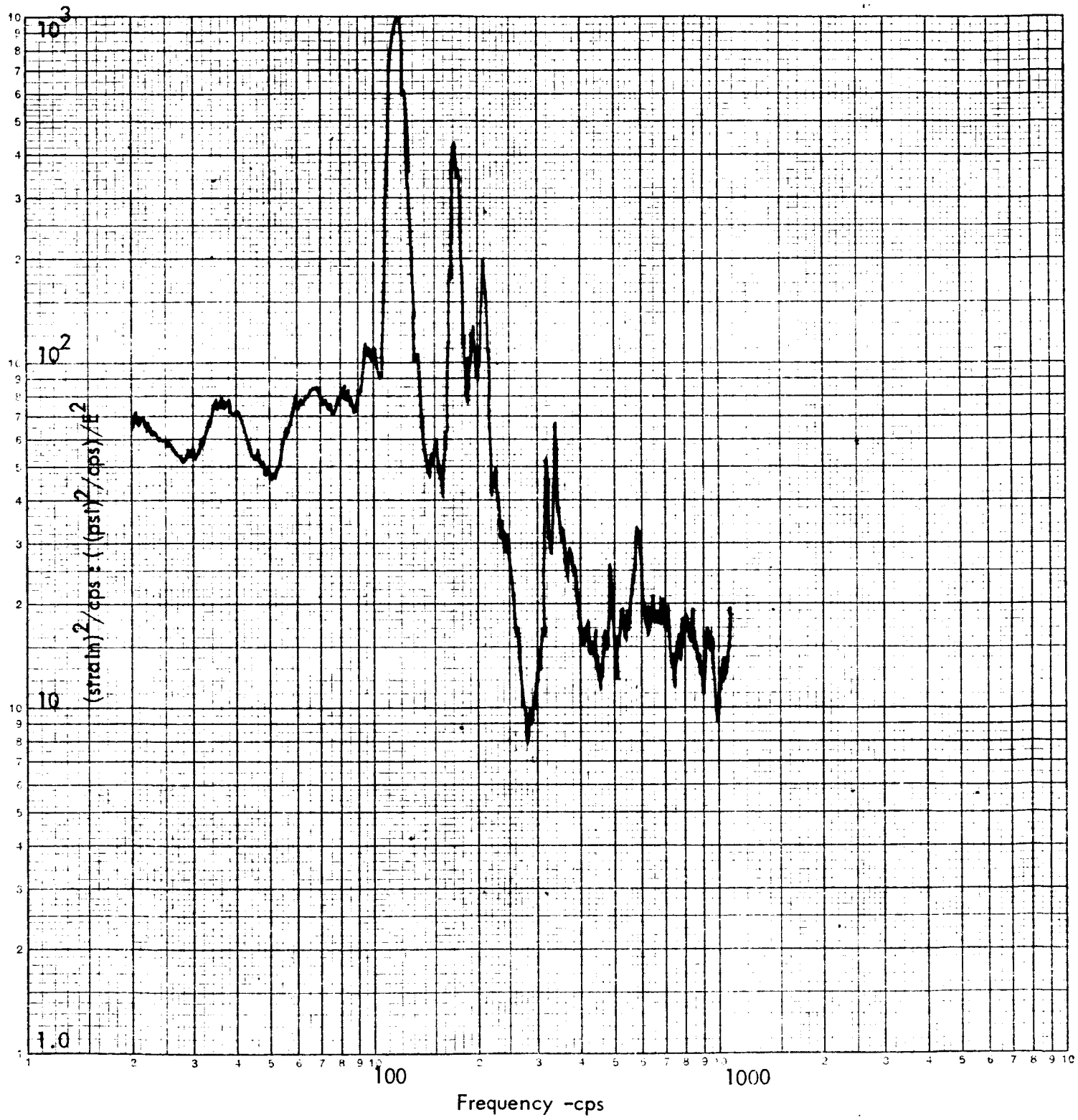


Figure 86 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 11

Date : 15 April 1963
Run No. : 1
Track No. : 9
Filter Bandwidth 10 cps

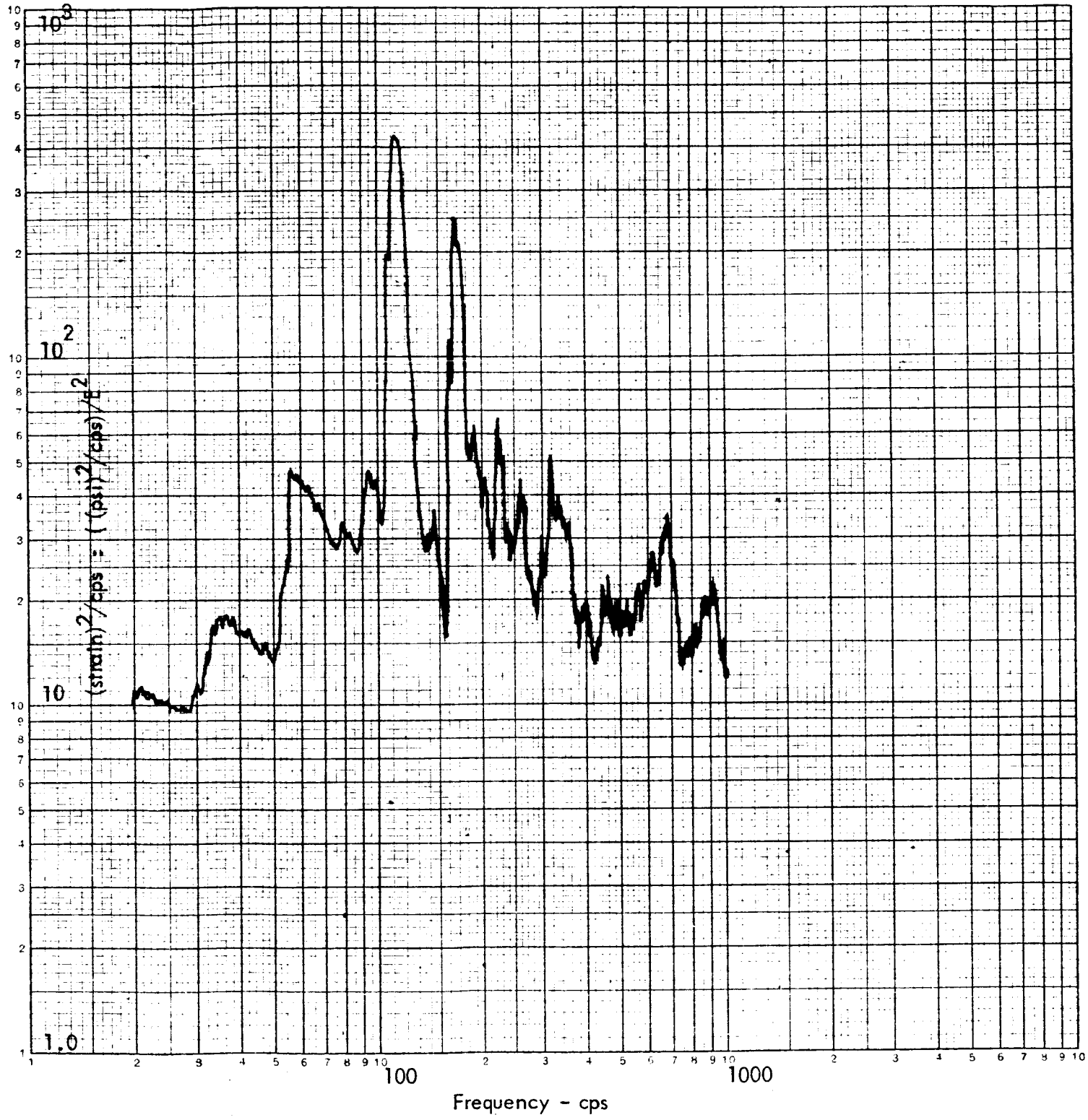


Figure 87 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 12

Date : 15 April 1963
Run No. : 2
Track No. : 1
Filter Bandwidth : 10 cps Average time 12 seconds

155 db Overall SPL

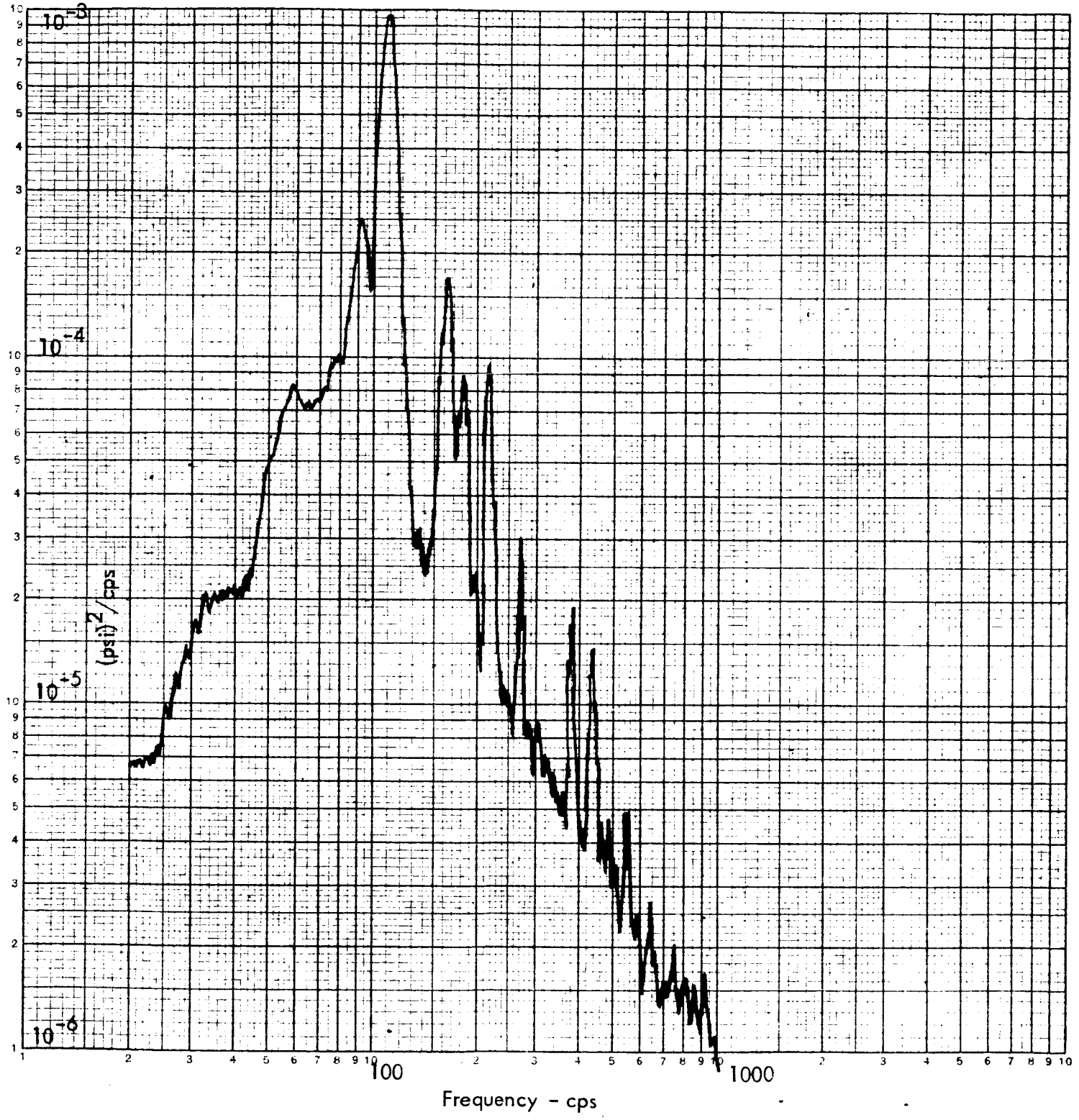


Figure 88 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 1

Date : 15 April 1963
Run No. : 2
Track No. : 2
Filter Bandwidth : 10 cps Average time 12 seconds

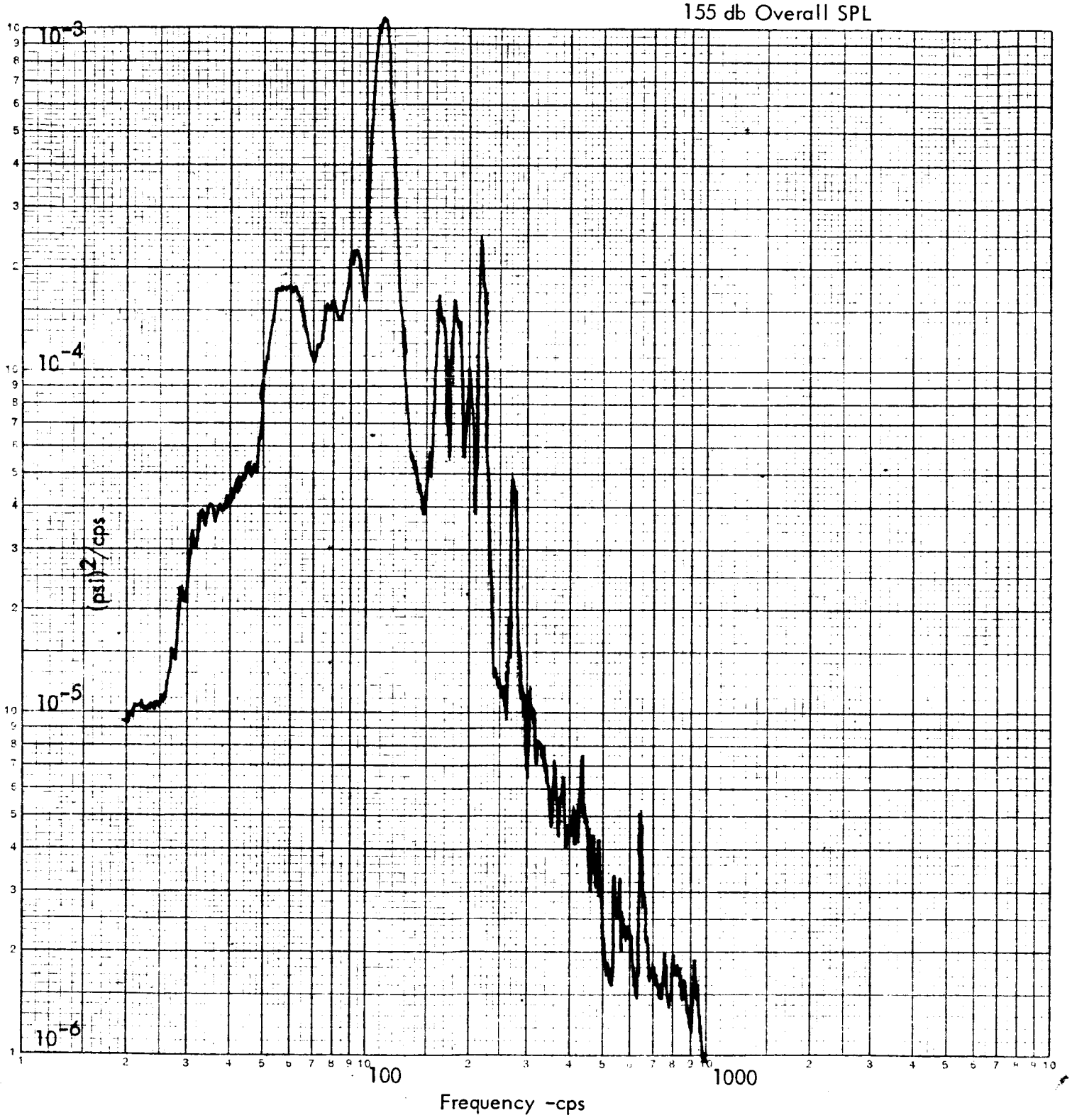


Figure 89 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 2

Date : 15 April 1963
Run No. : 2
Track No. : 2
Filter Bandwidth : 10 cps Average time 12 seconds

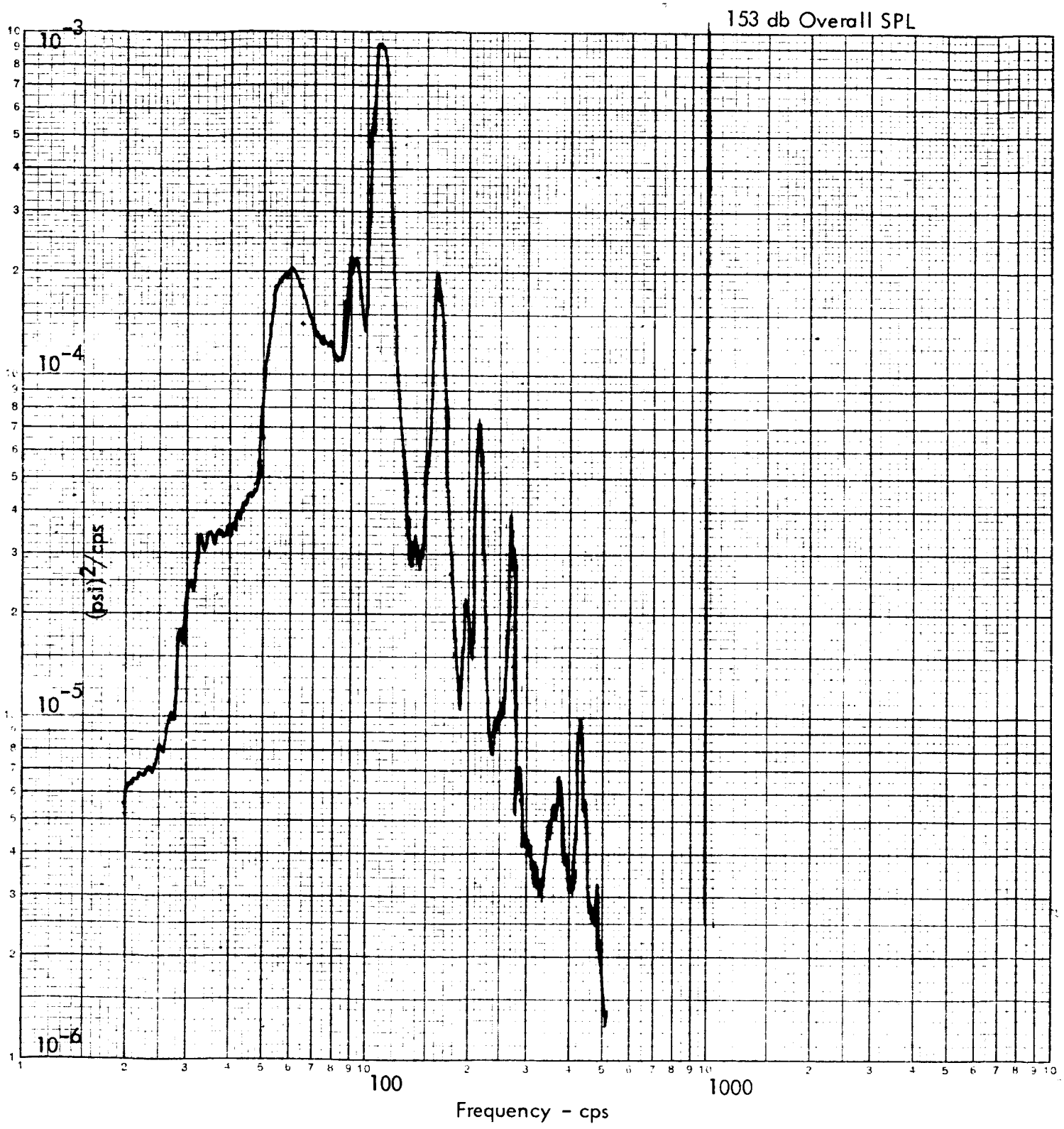


Figure 90 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 3

Date : 15 April 1963
Run No. : 2
Track No. : 7
Filter Bandwidth :

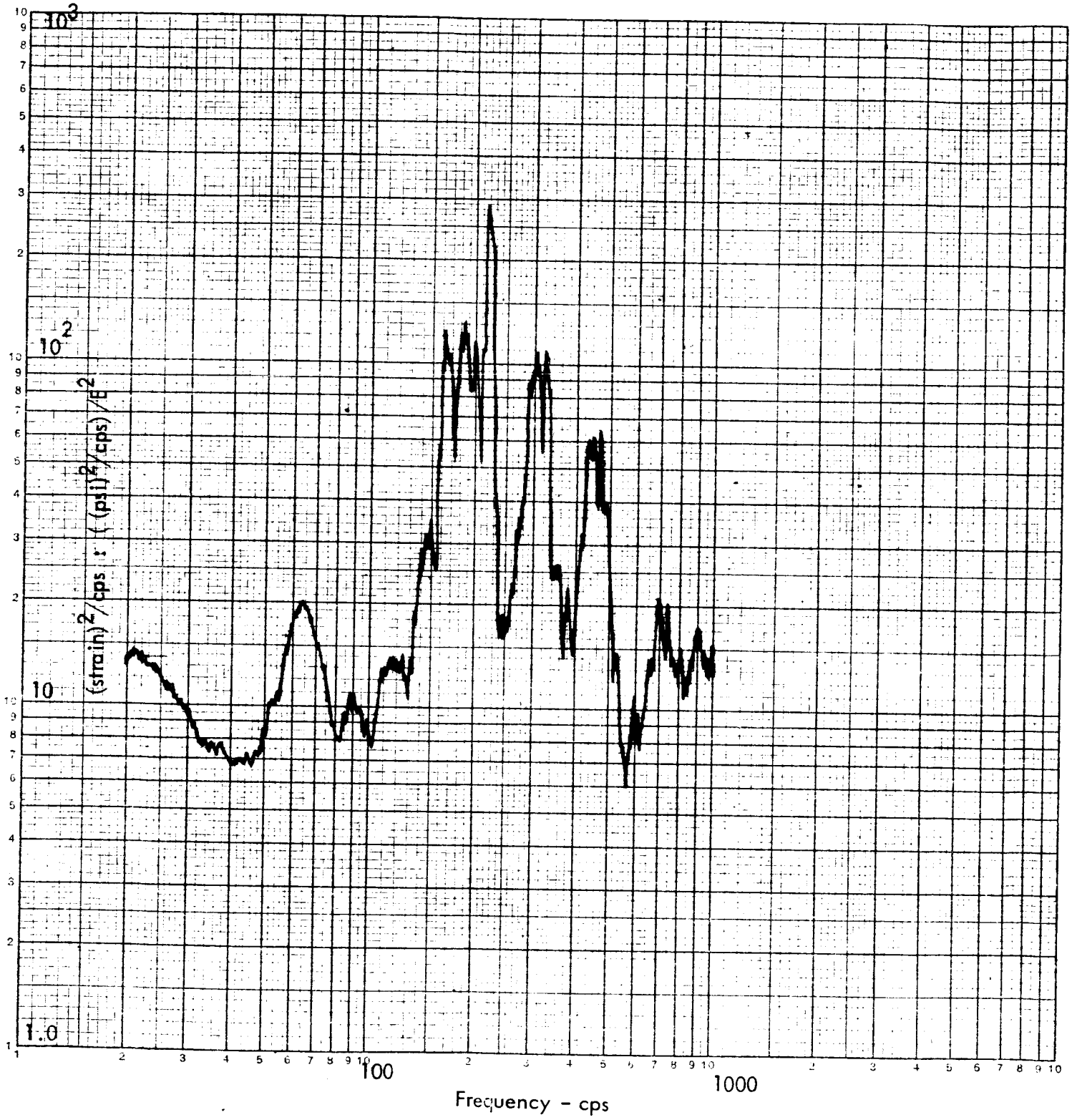


Figure 91 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 10

Date : 19 April 1963
Run No. : 1
Track No. : 1
Filter Bandwidth : 10 cps Average time 12 seconds

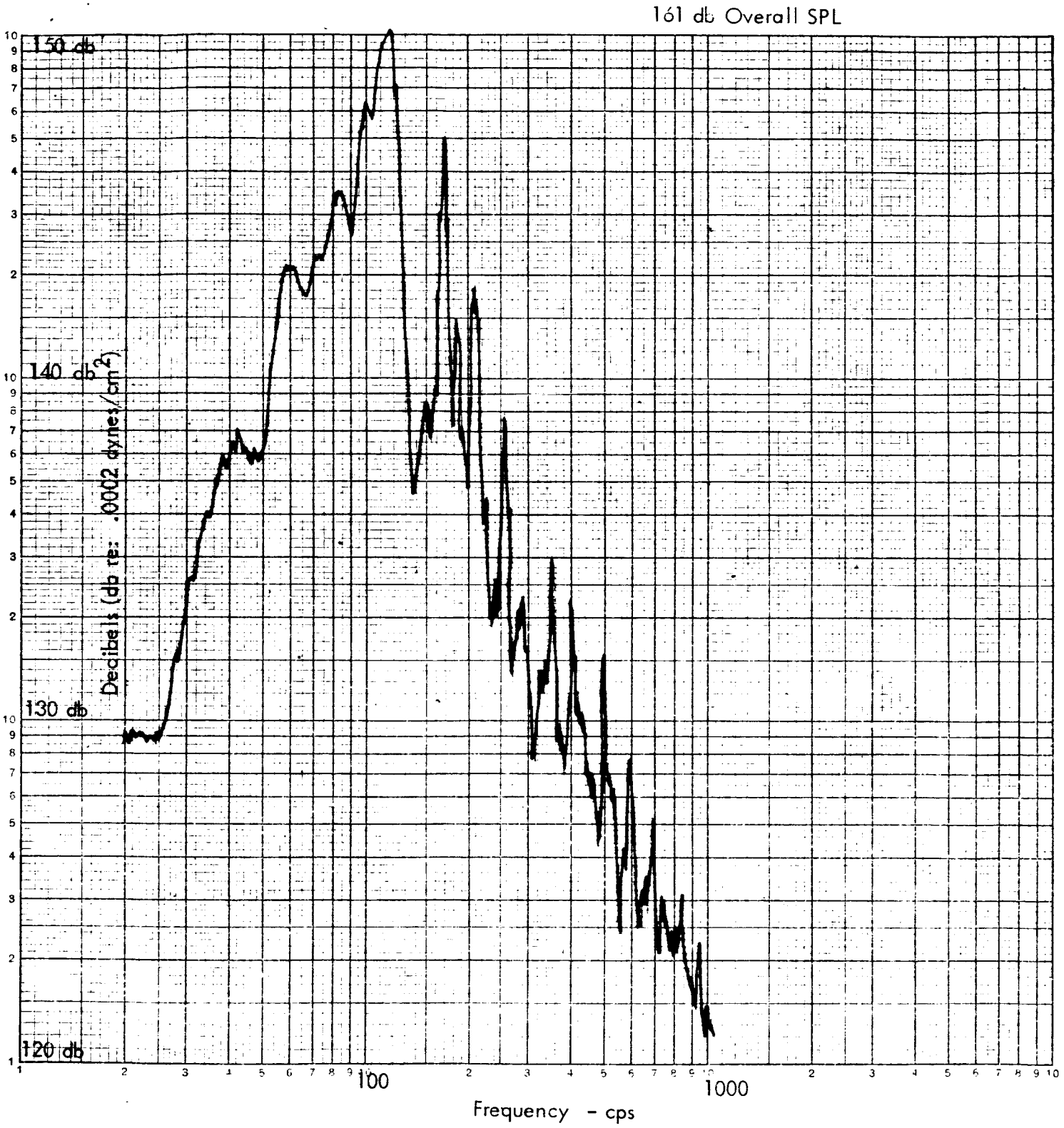


Figure 92 Shroud Panel No. 2 - Power Spectral Density - Microphone No. 1

Date : 19 April 1963
Run No. : 1
Track No. : 1
Filter Bandwidth : 2 cps Average time 20 seconds

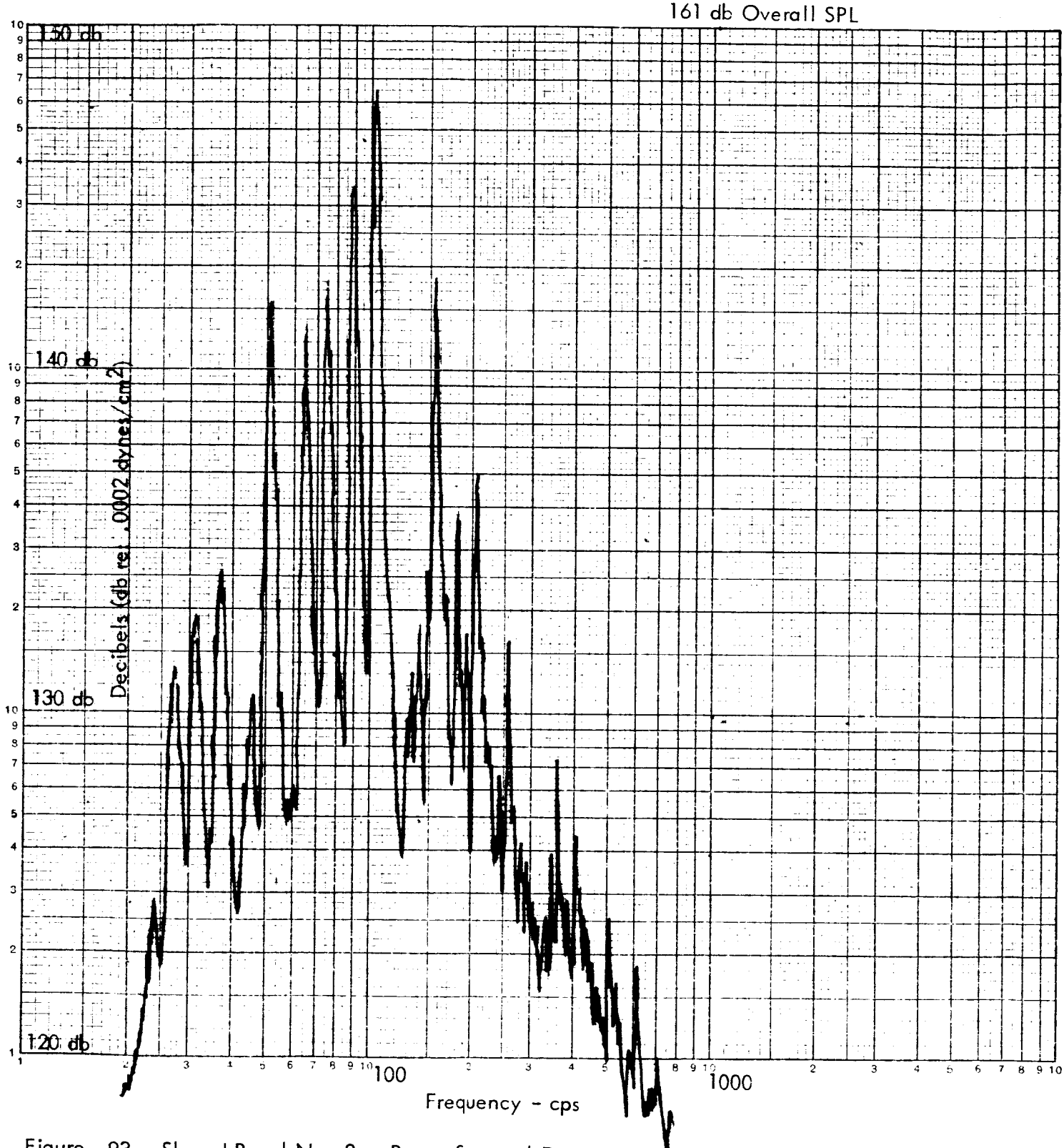


Figure 93 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 1

Date : 19 April 1963
Run No. : 1
Track No. : 1
Filter Bandwidth : 10 cps Average time 12 seconds

160 db Overall SPL

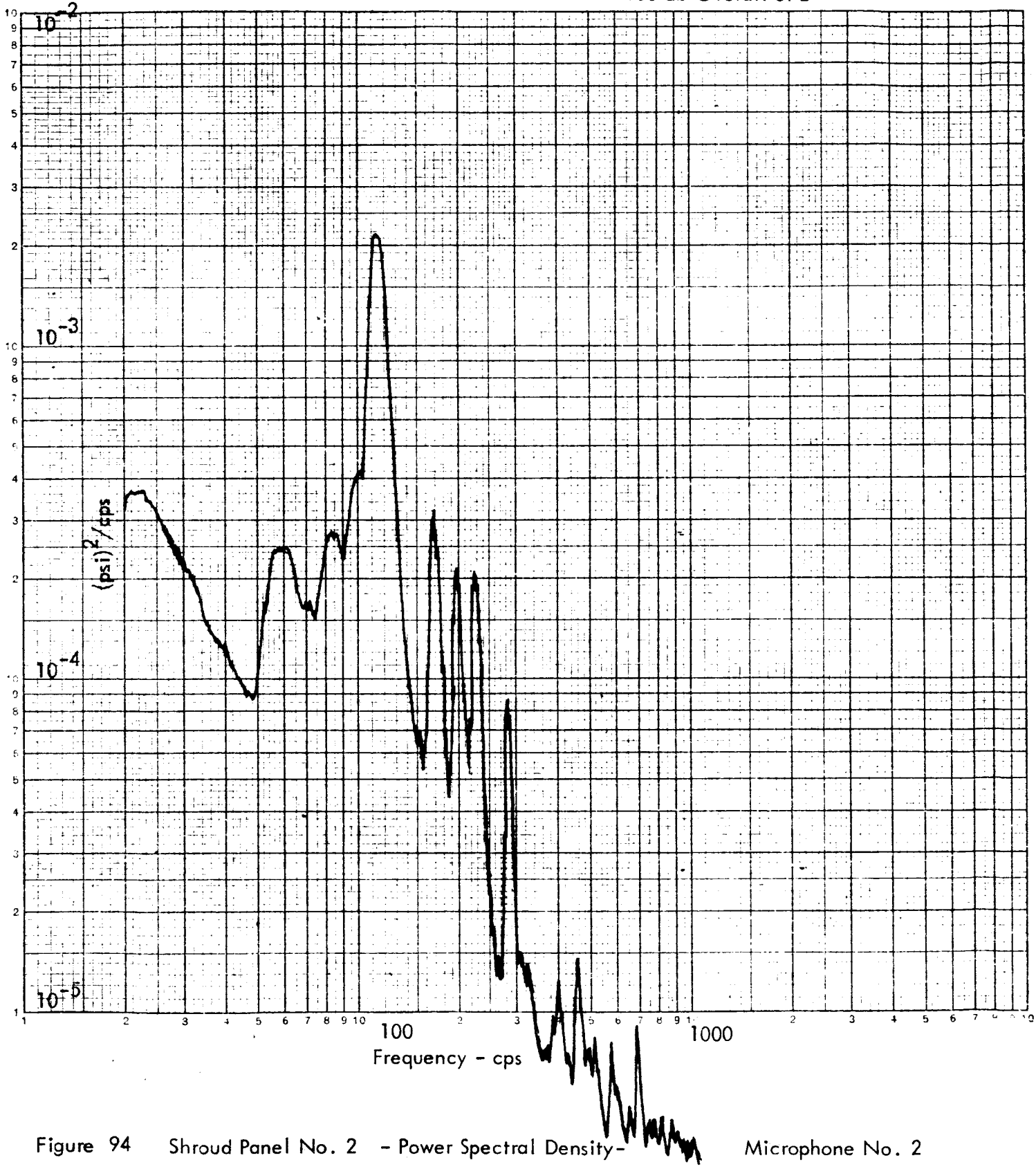


Figure 94 Shroud Panel No. 2 - Power Spectral Density- Microphone No. 2

Date : 19 April 1963
Run No. : 1
Track No. : 3
Filter Bandwidth : 10 cps Average time 12 seconds

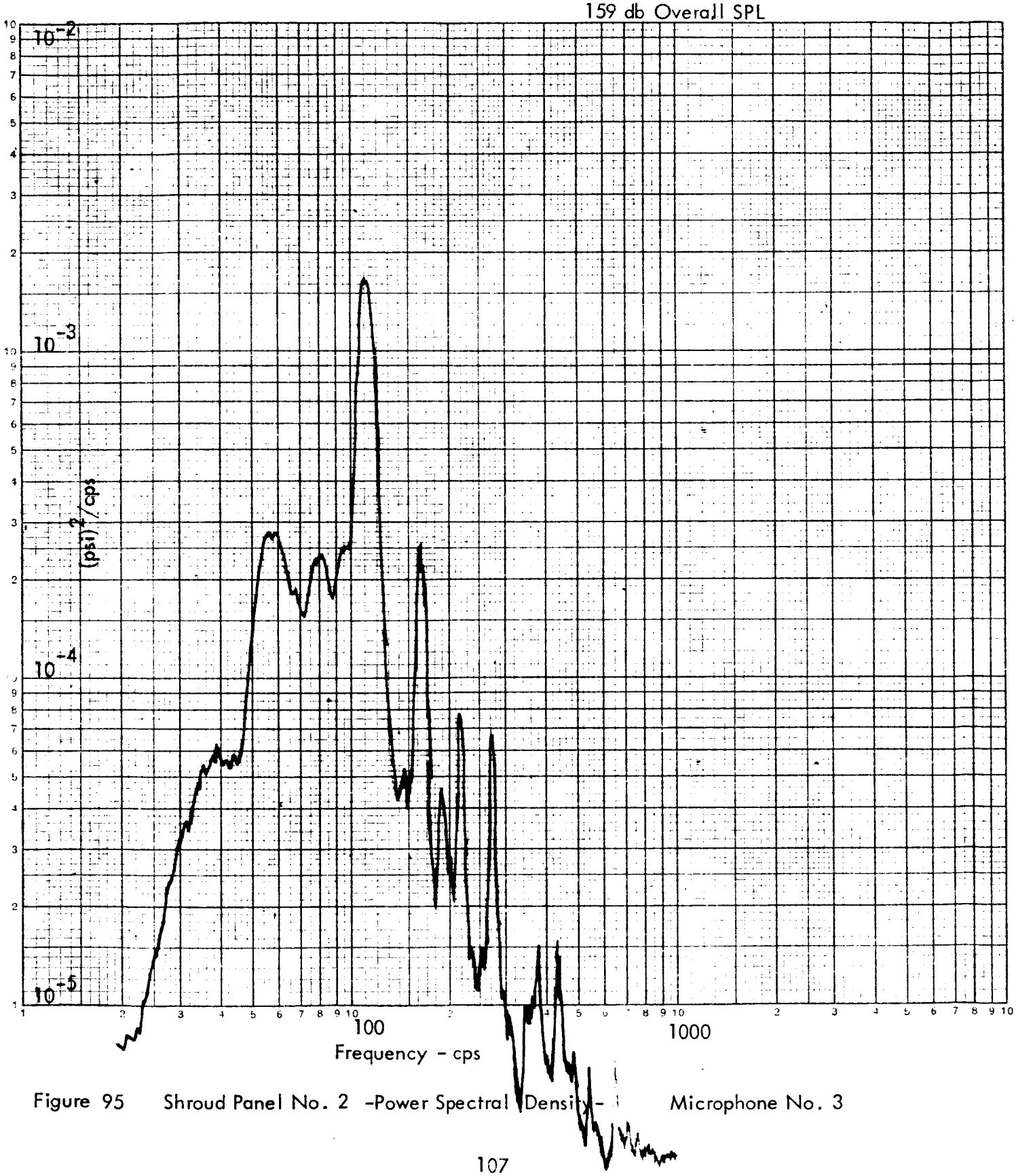


Figure 95 Shroud Panel No. 2 -Power Spectral Density- Microphone No. 3

Date : 19 April 1963
Run No. : 1
Track No. : 9
Filter Bandwidth : 10 cps Average time 12 seconds

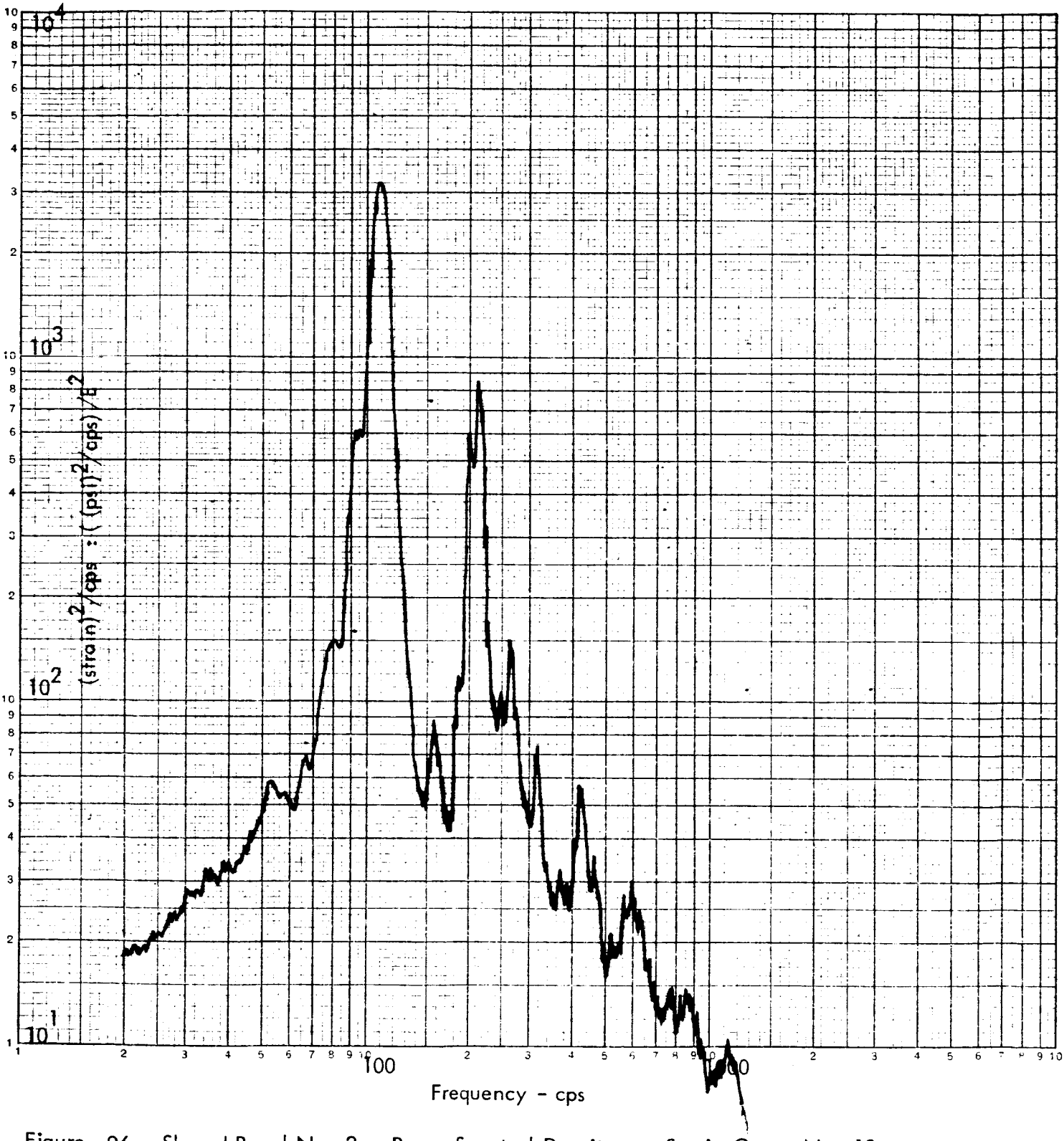


Figure 96 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 12

Date : 19 April 1963
Run No. : 1
Track No. : 9
Filter Bandwidth : 2 cps Average time 20 seconds

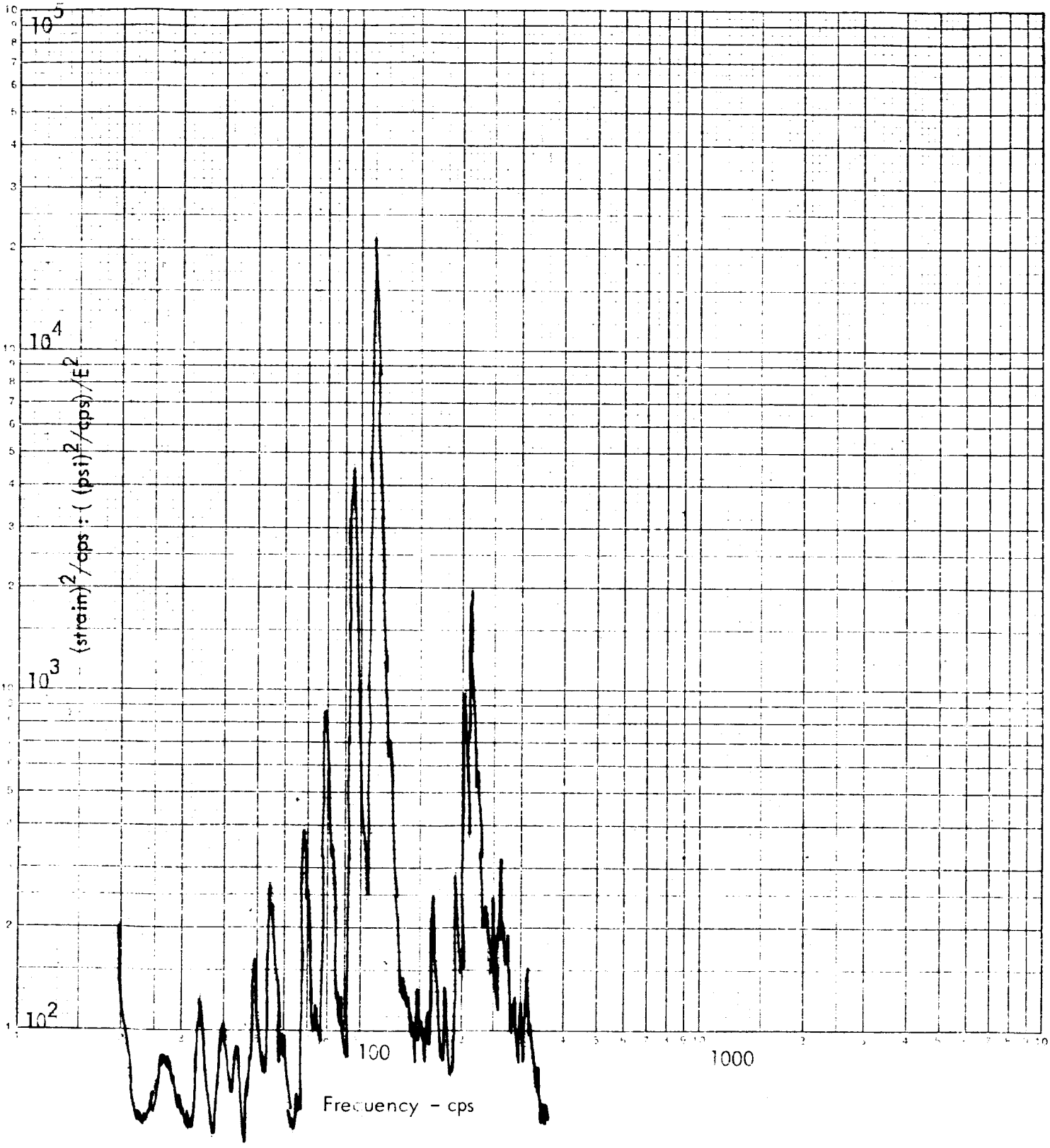


Figure 97 Shroud Panel No. 2 -Power Spectral Density- Strain Gauge No. 12

Date : 22 April 1963
Run No. : 1
Track No. : 1
Filter Bandwidth : 10 cps Average time 12 seconds

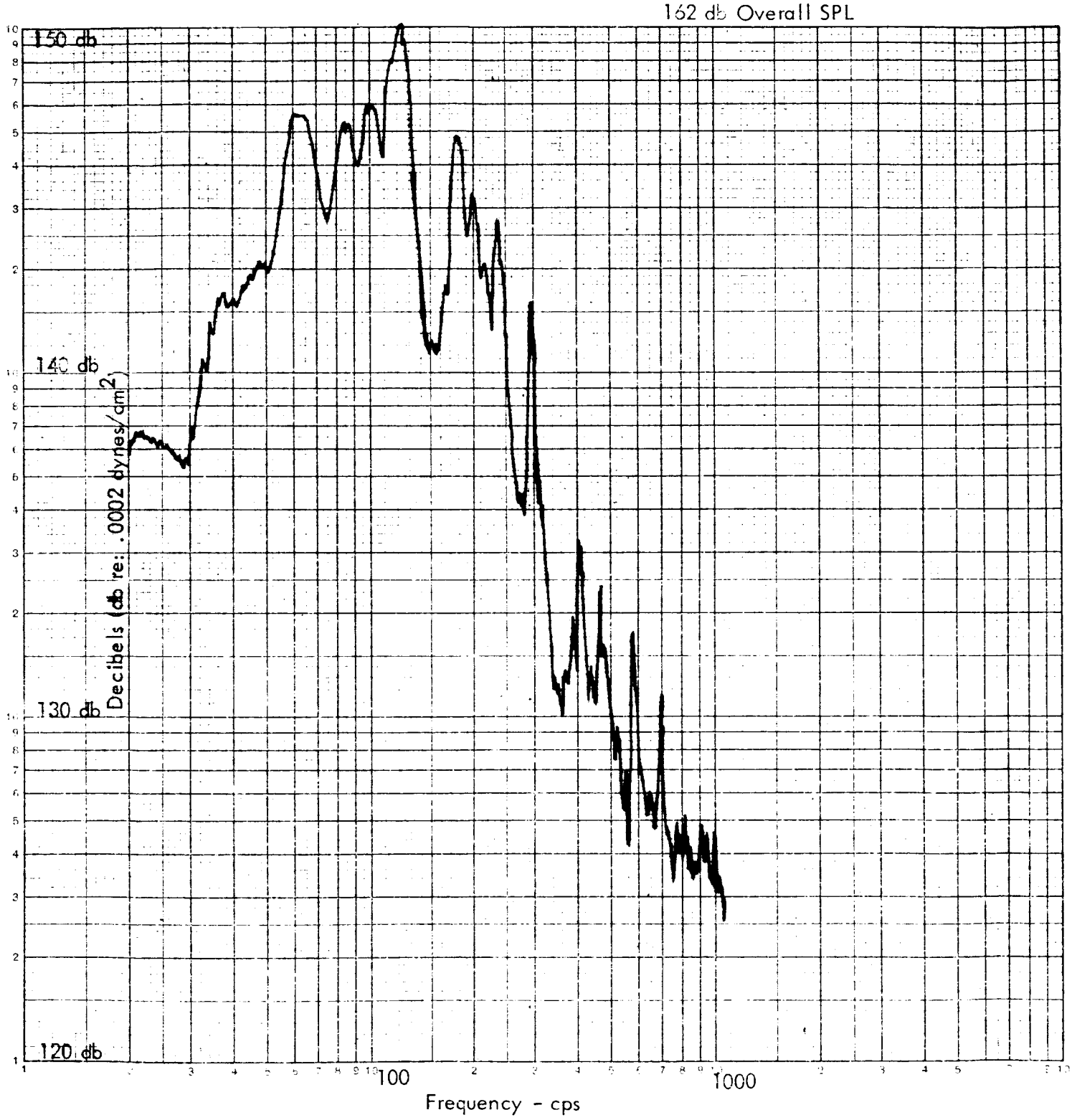


Figure 98 Sand Box - Power Spectral Density - Microphone No. 1

Date : 22 April 1963
Run No. : 1
Track No. : 1
Filter Bandwidth : 2 cps Average time 20 seconds

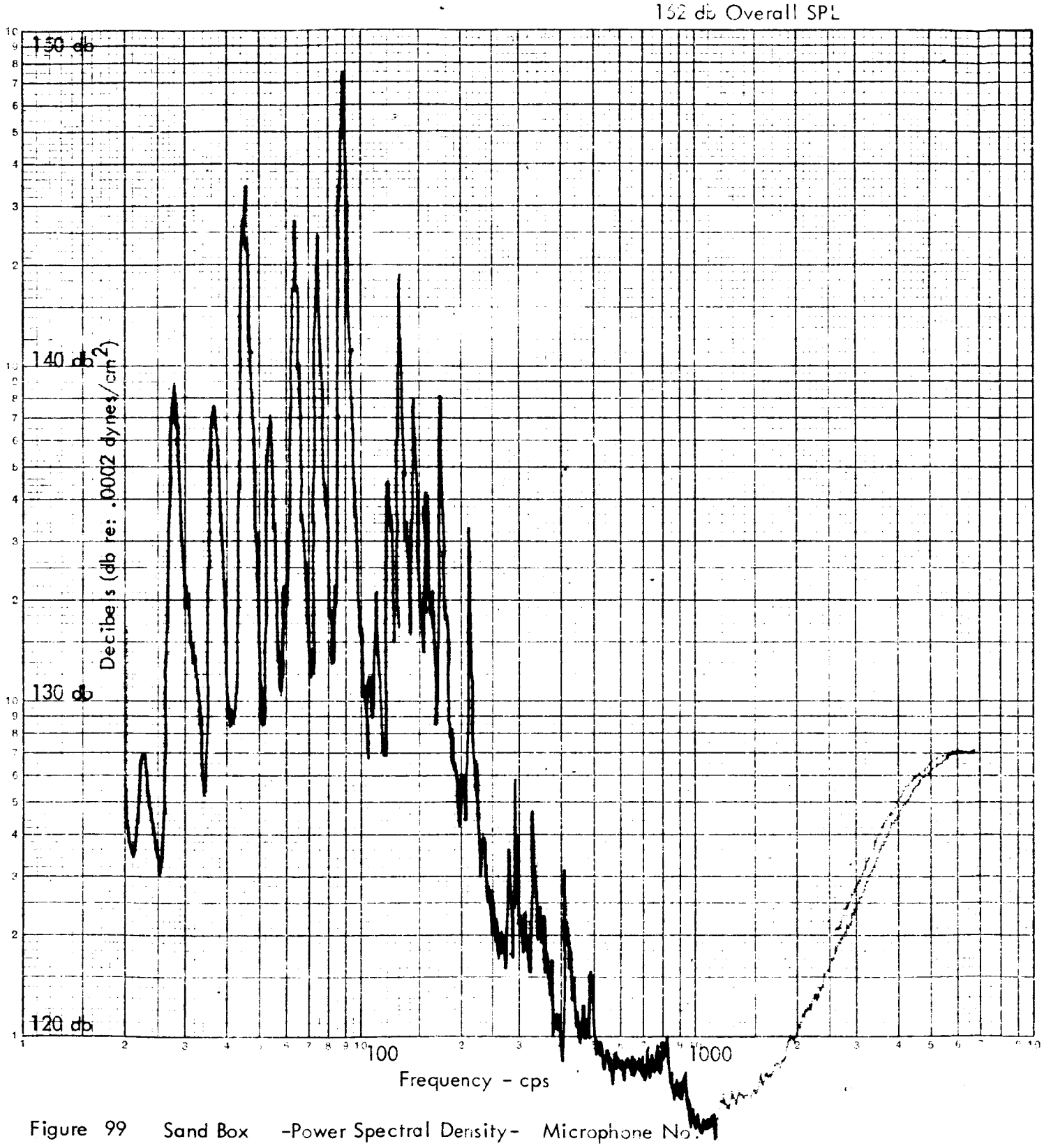


Figure 99 Sand Box -Power Spectral Density- Microphone No. 1

Date : 8 May 1963
Run No. : 0
Track No. : 6
Filter Bandwidth : 2 cps

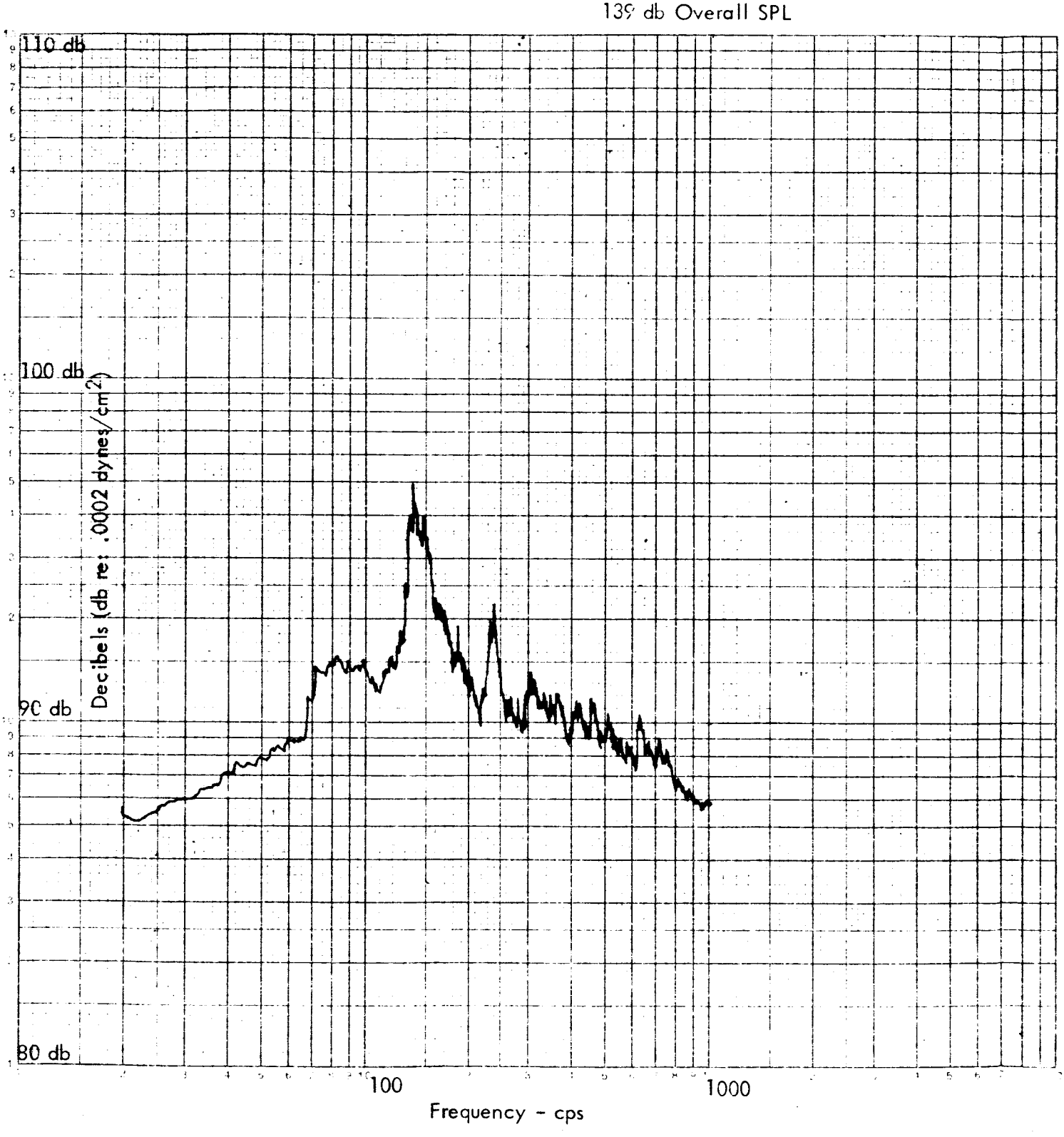


Figure No. 100 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 1

Date : 8 May 1963
Run No. : 0
Track No. : 7
Filter Bandwidth : 2 cps

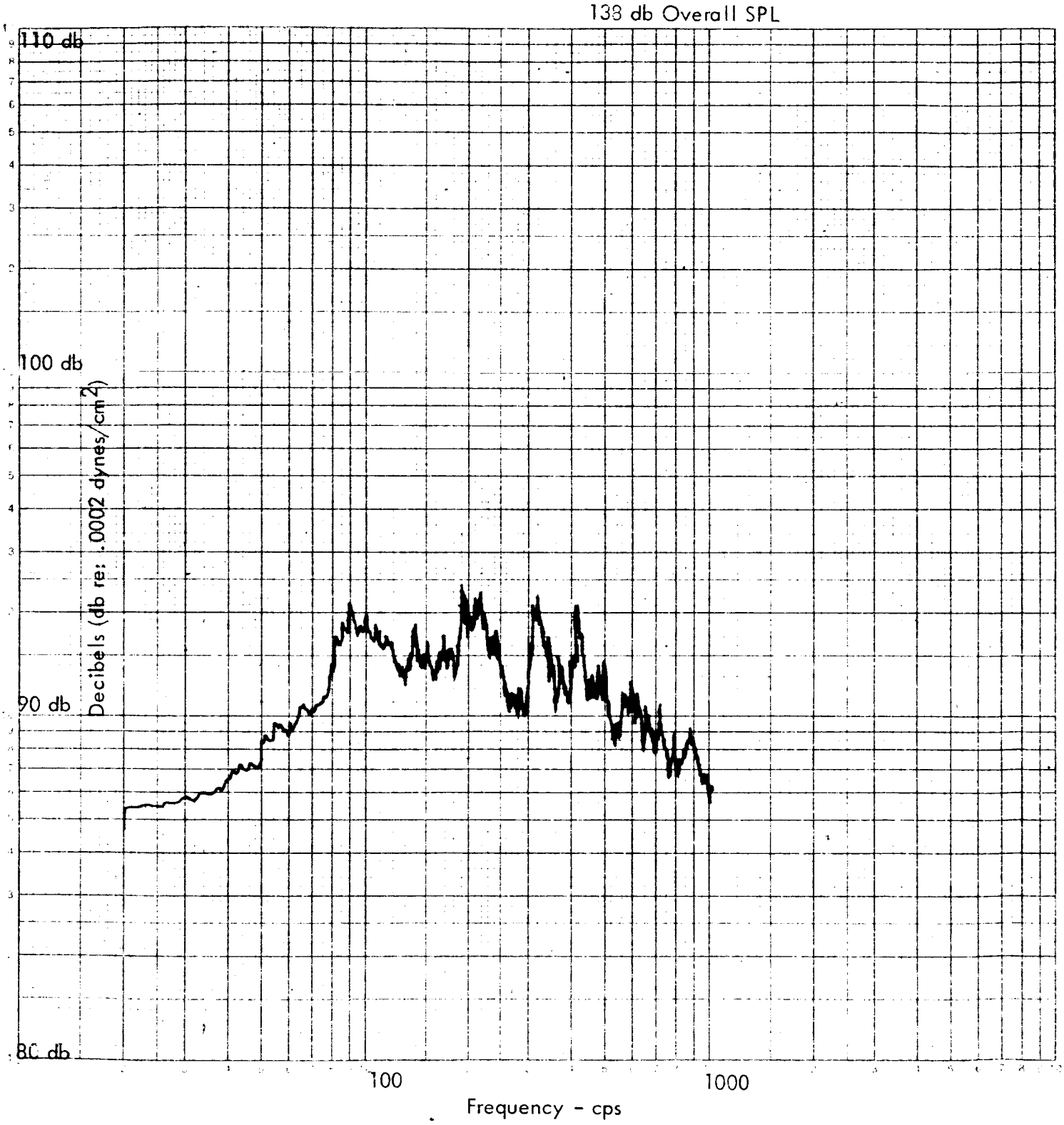


Figure No. 101 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 2

Date : 8 May 1963
Run No. : 0
Track No. : 8
Filter Bandwidth: 2 cps

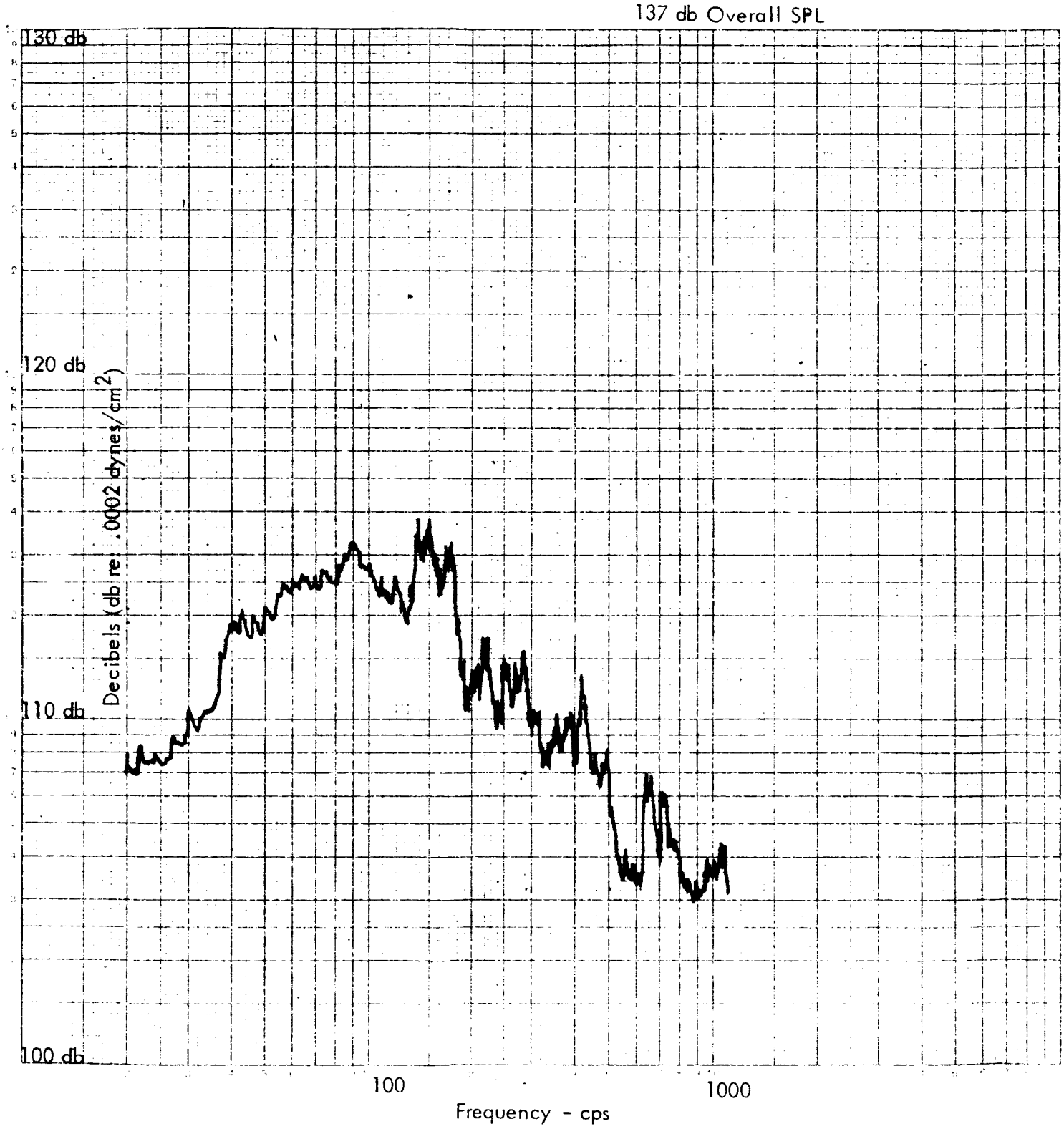


Figure No. 102 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 3

Date : 8 May 1963
Run No. : 0
Track No. : 1
Filter Bandwidth : 2 cps

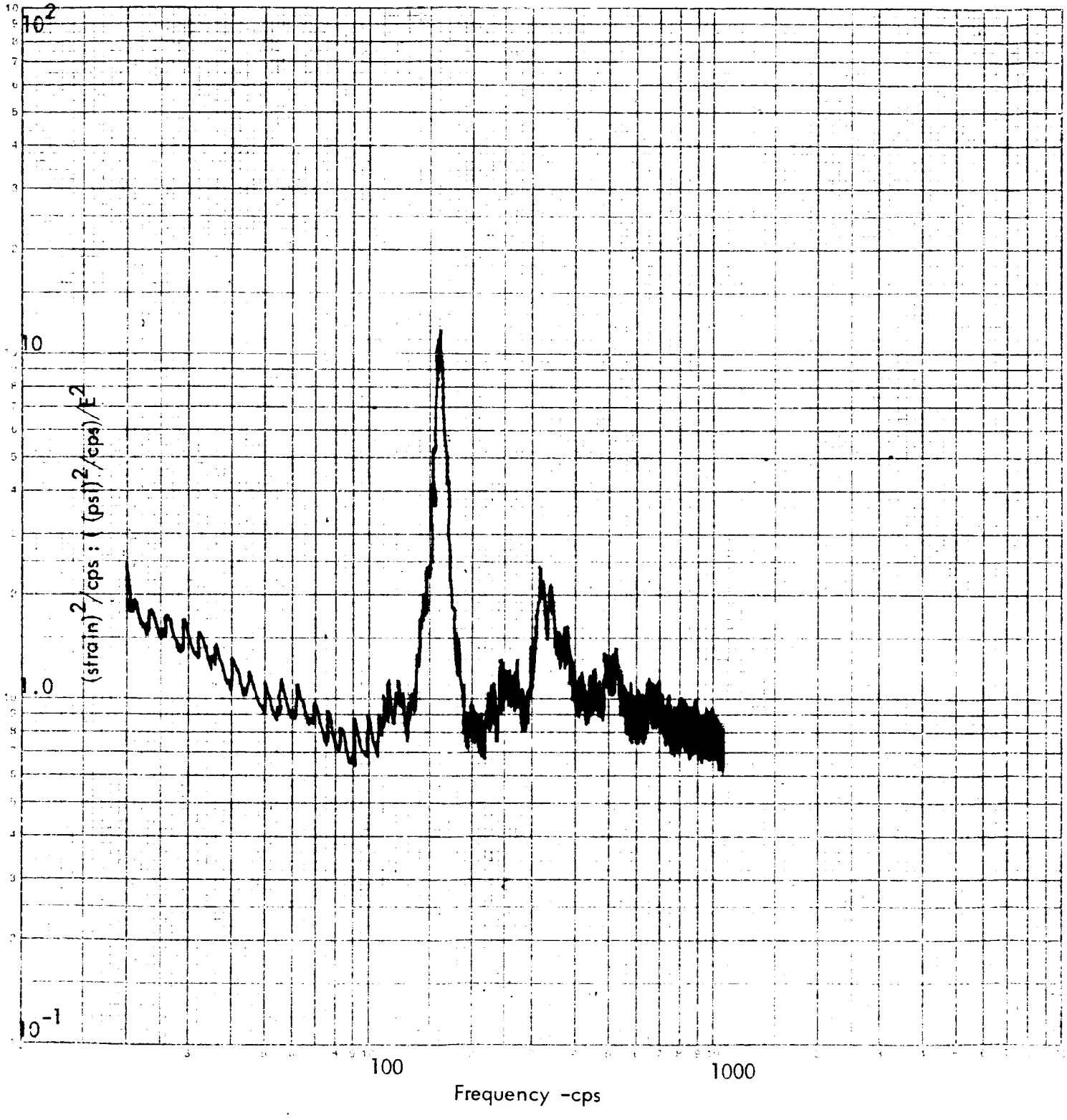


Figure No. 103 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 2

Date : 8 May 1963
Run No. : 0
Track No. : 2
Filter Bandwidth : 2 cps

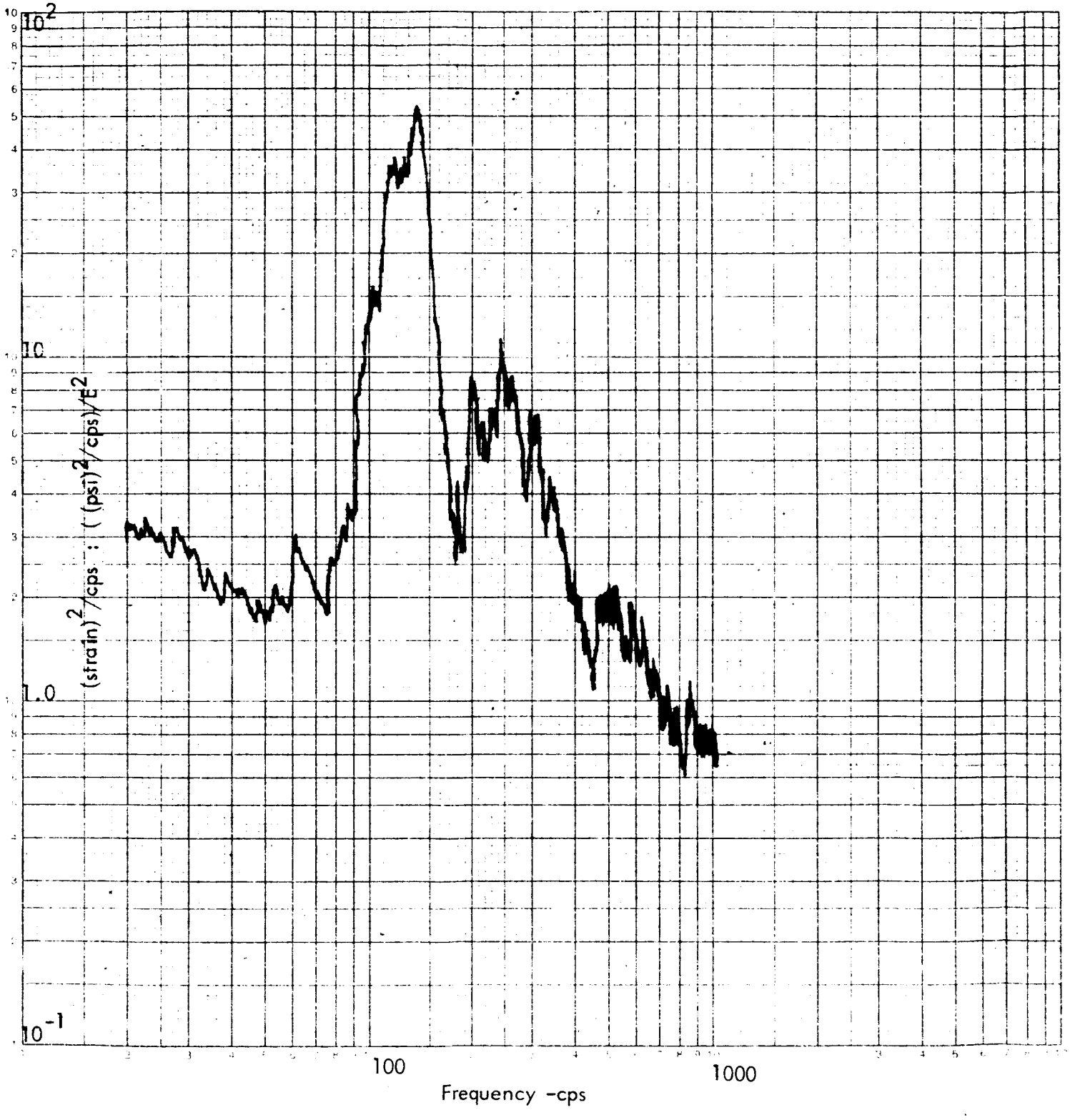


Figure No. 104 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 8

Date : 8 May 1963
Run No. : 0
Track No. : 3
Filter Bandwidth : 2 cps

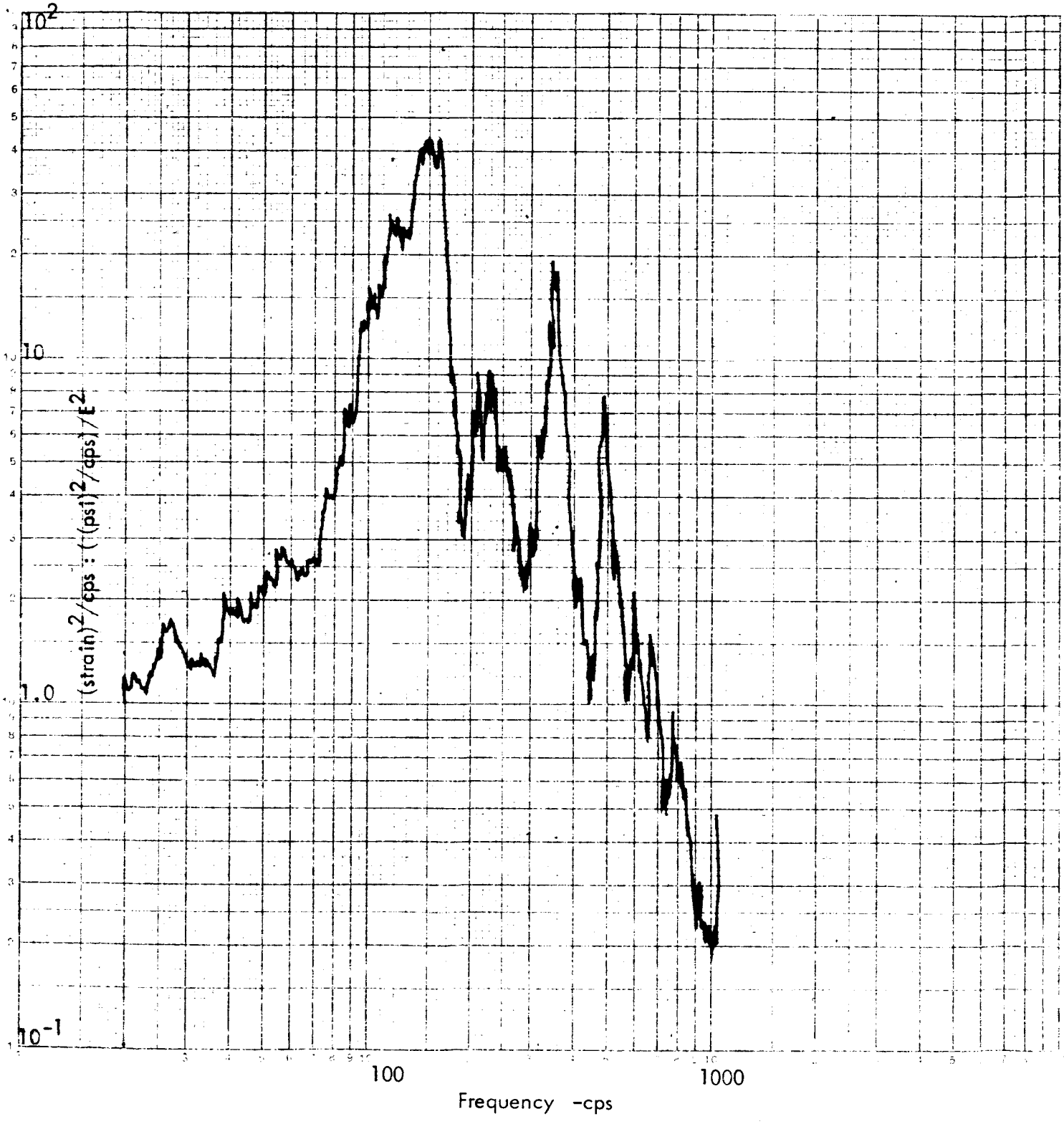


Figure No. 105 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 11

Date : 8 May 1963
Run No. : 0
Track No. : 4
Filter Bandwidth : 2 cps

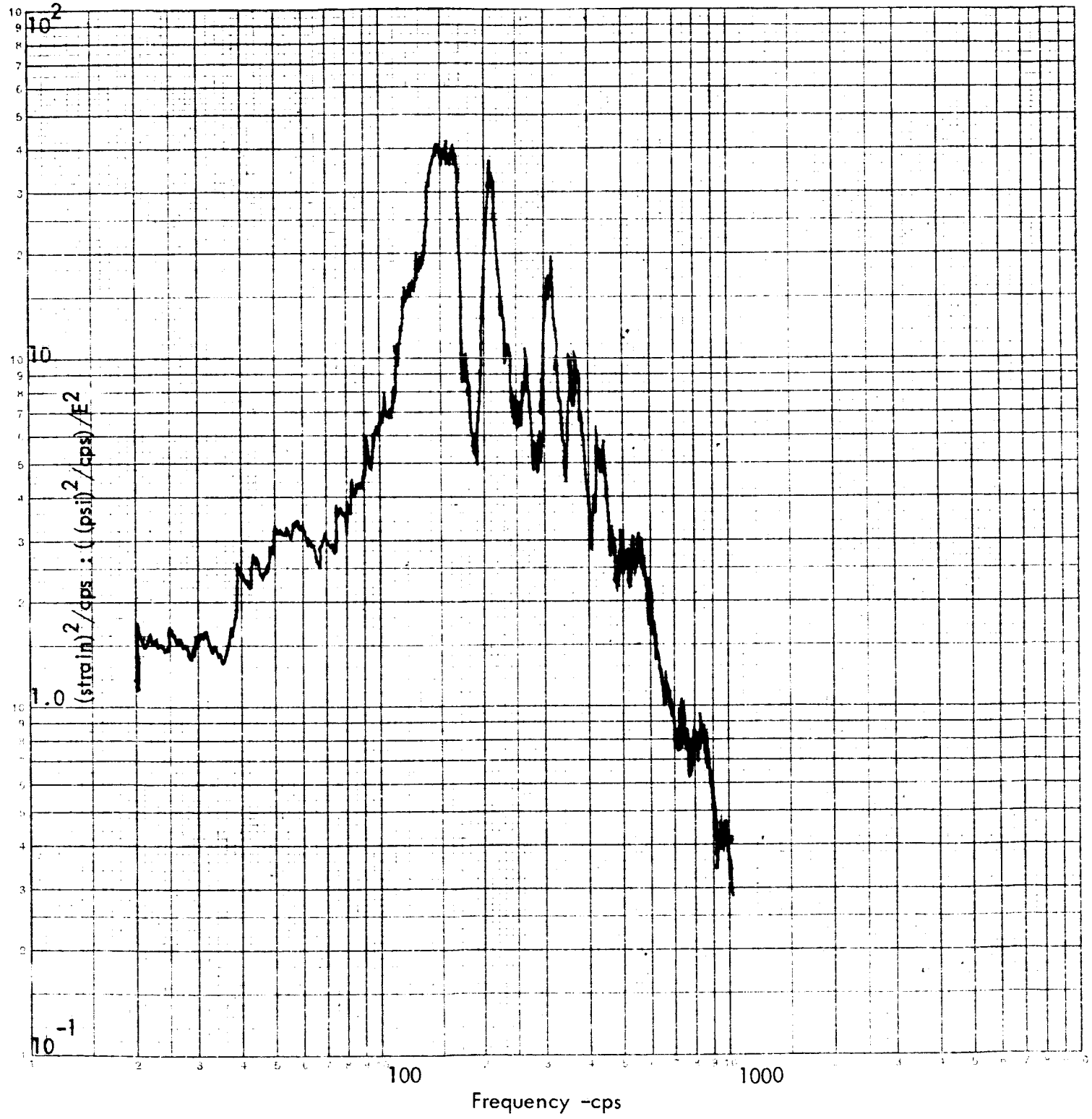


Figure No. 106 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 12

Date : 8 May 1963
Run No. : 0
Track No. : 5
Filter Bandwidth : 2 cps

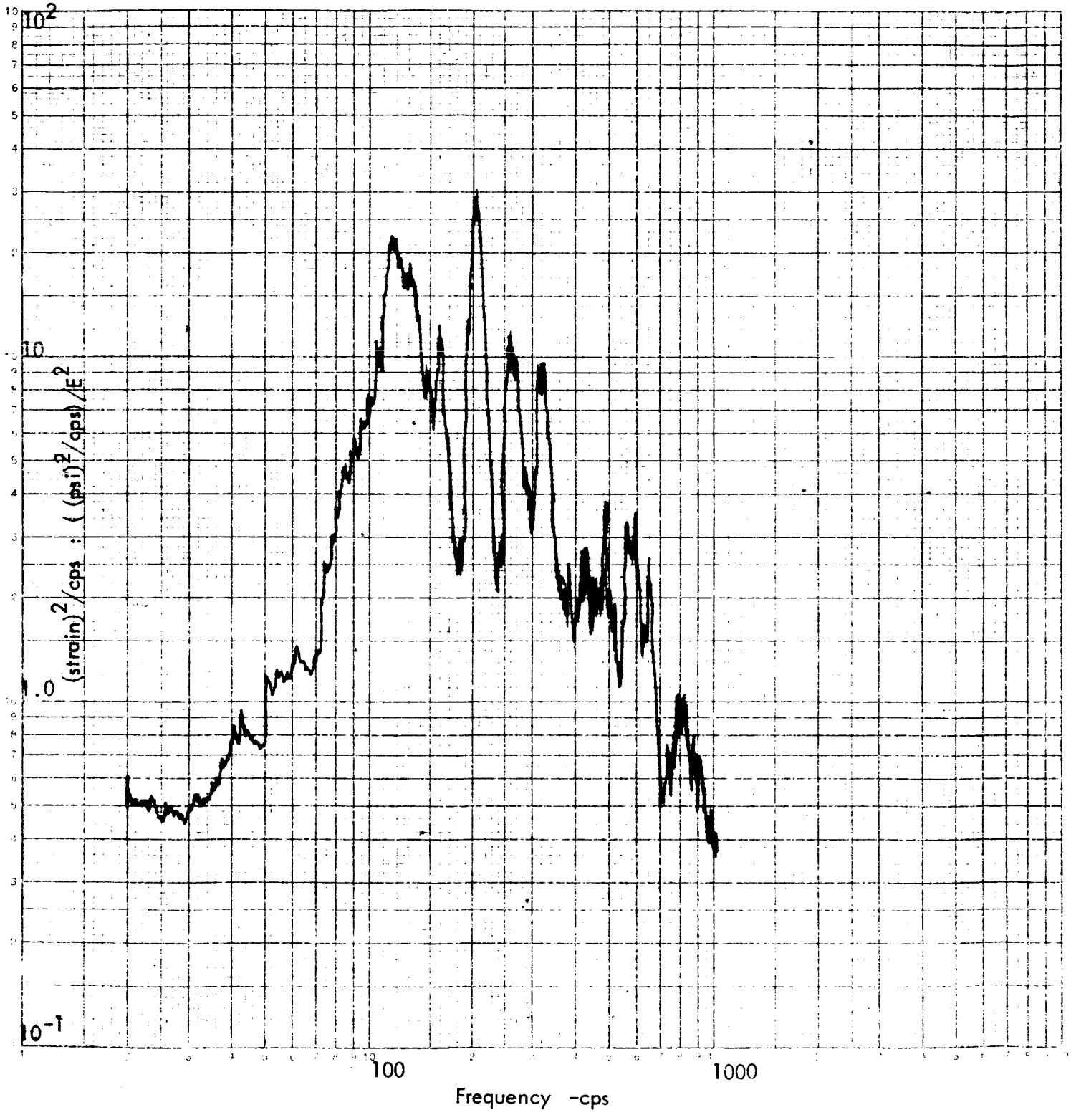


Figure No. 107 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 13

Date : 8 May 1963
Run No. : 0
Track No. : 9
Filter Bandwidth : 2 cps

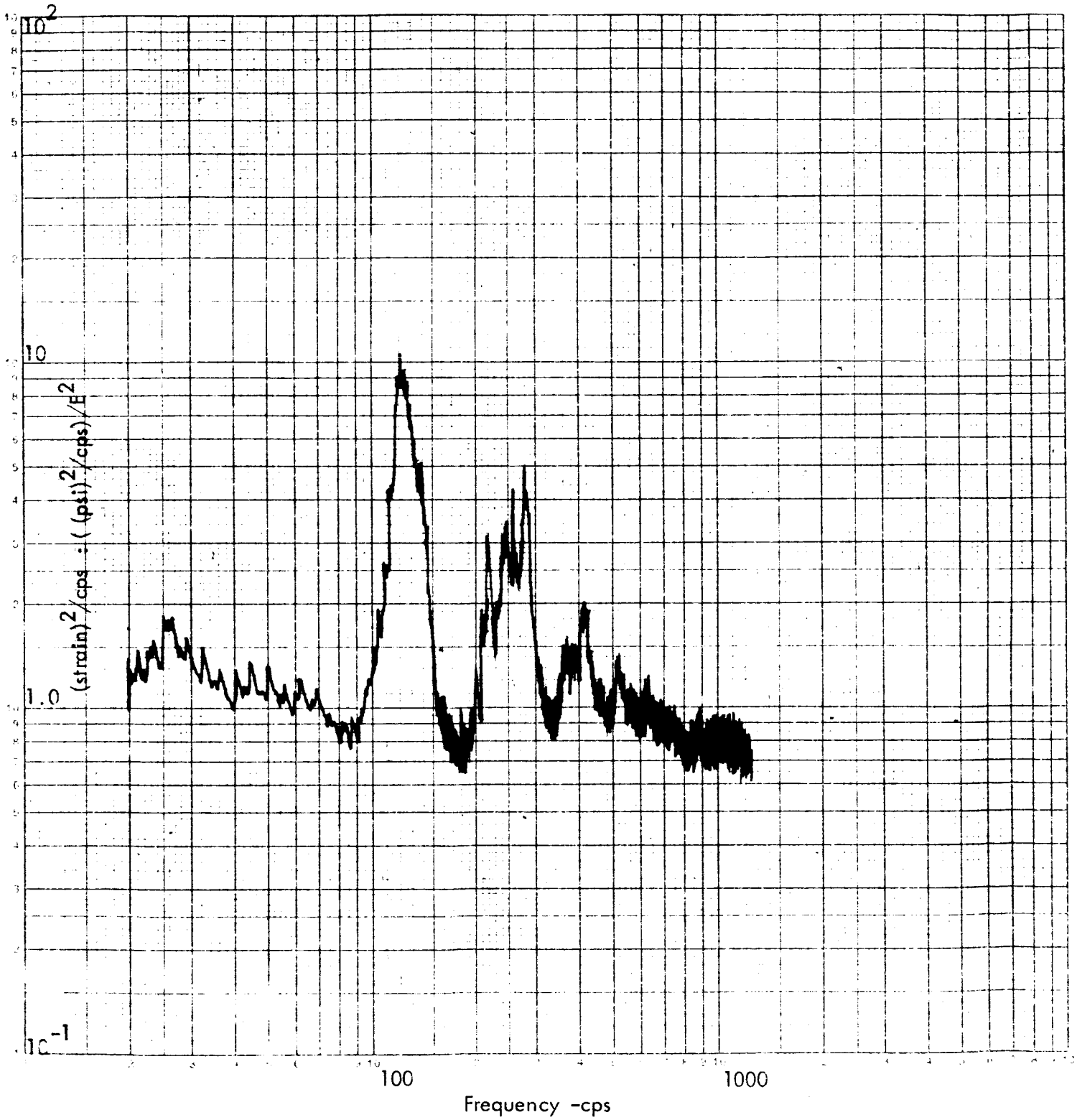


Figure No. 108 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 14

Date : 27 May 1963

Filter Bandwidth : 2 cps
Run No. 1

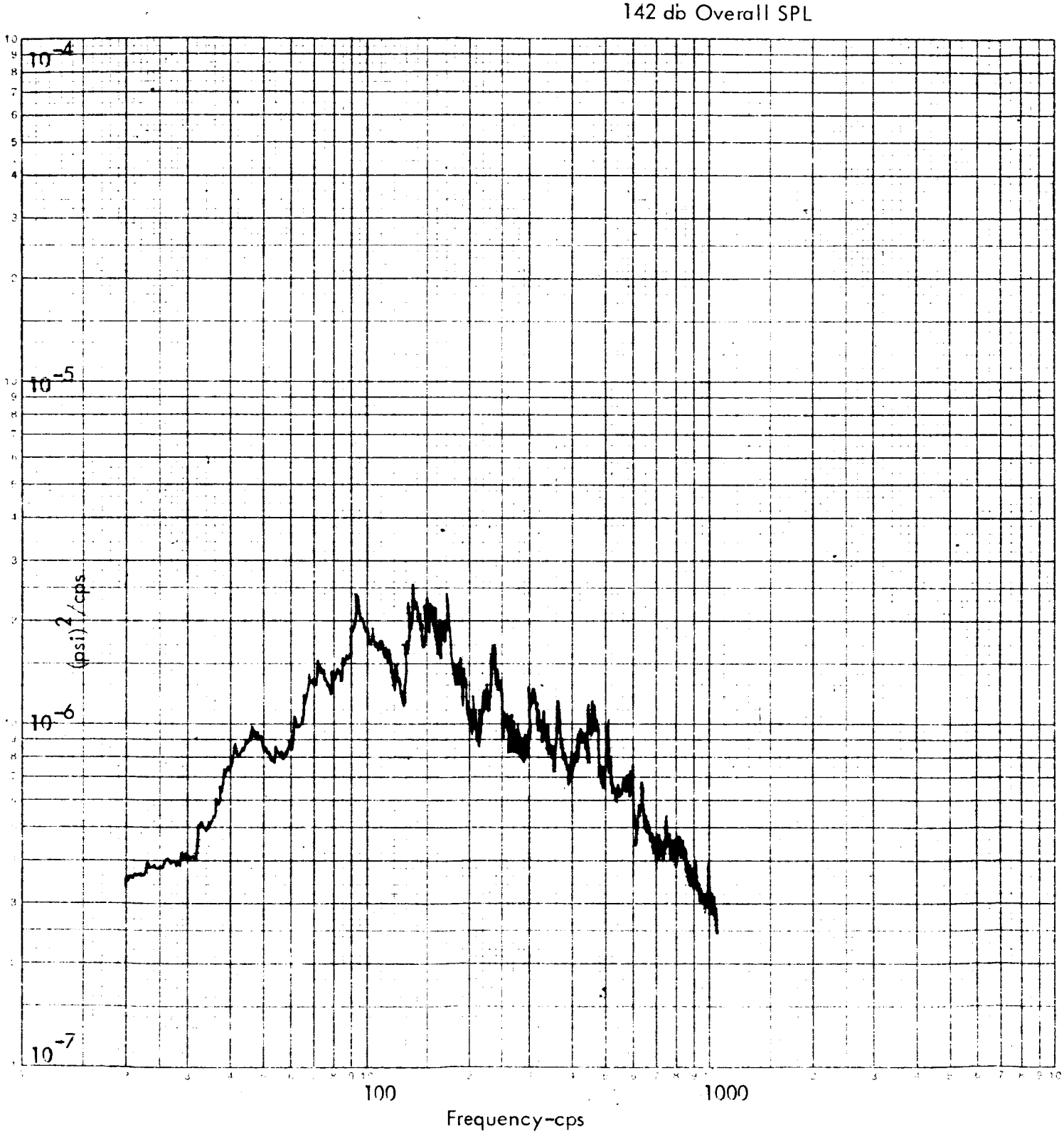


Figure 109 Shroud Panel No. 3-Power Spectral Density- Microphone No. 1

Date : 27 May 1963

Filter Bandwidth : 2 cps

Run No. 1

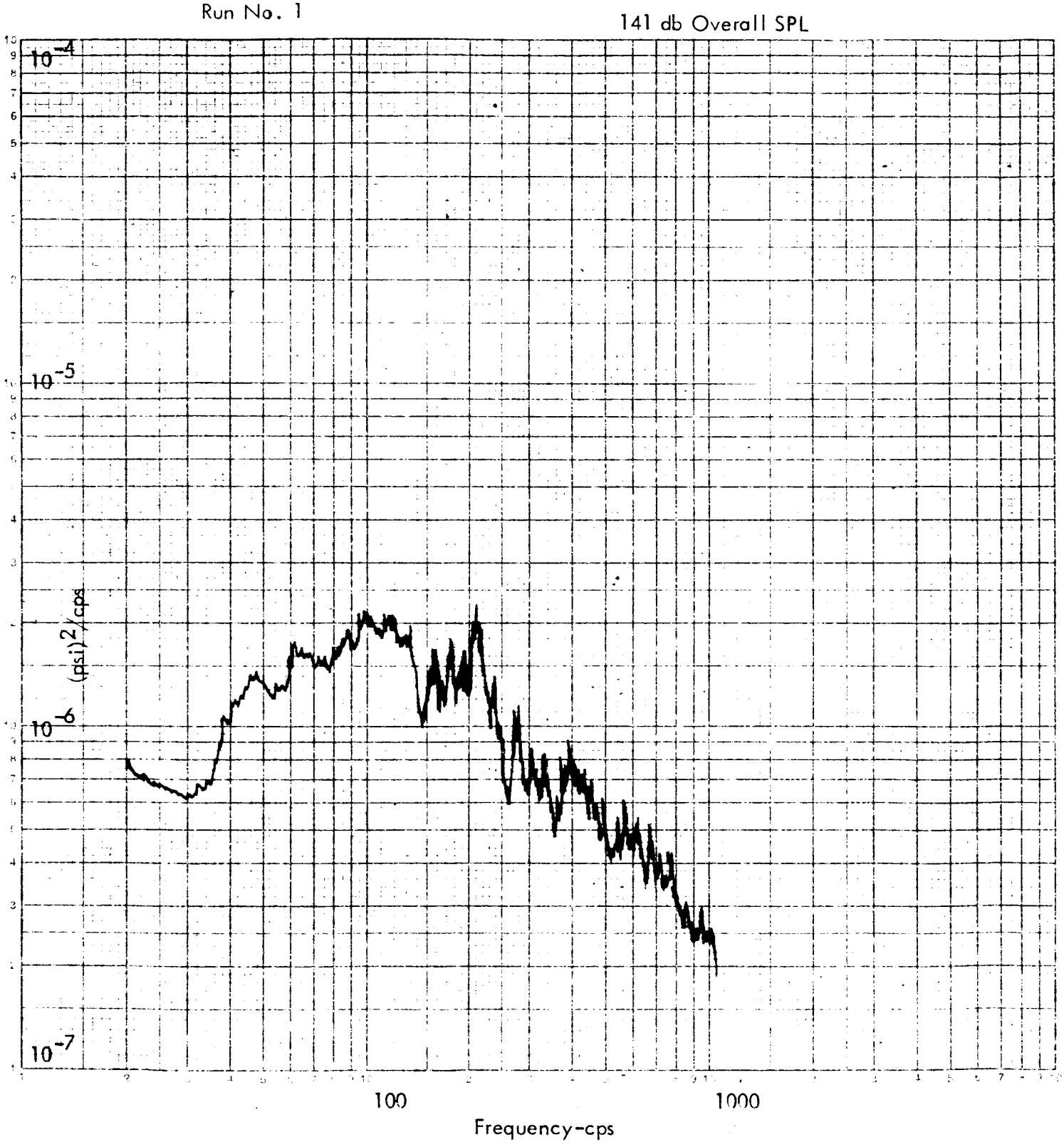


Figure 110 Shroud Panel No. 3 - Power Spectral Density- Microphone No. 2

Date : 27 May 1963

Filter Bandwidth : 2 cps
Run No. 1

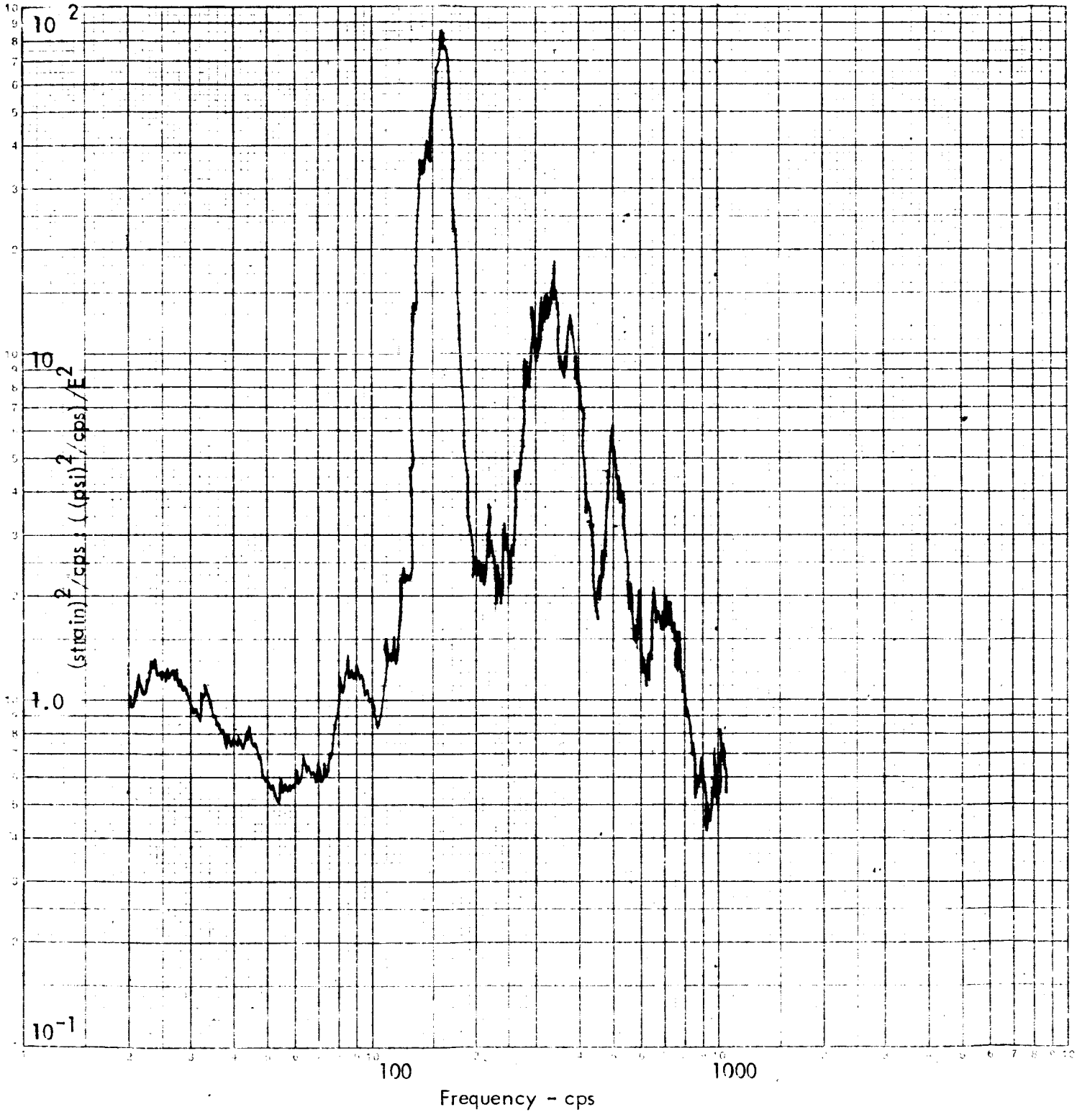


Figure 111 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 2

Date : 27 May 1963

Filter Bandwidth : 2 cps
Run No. 1

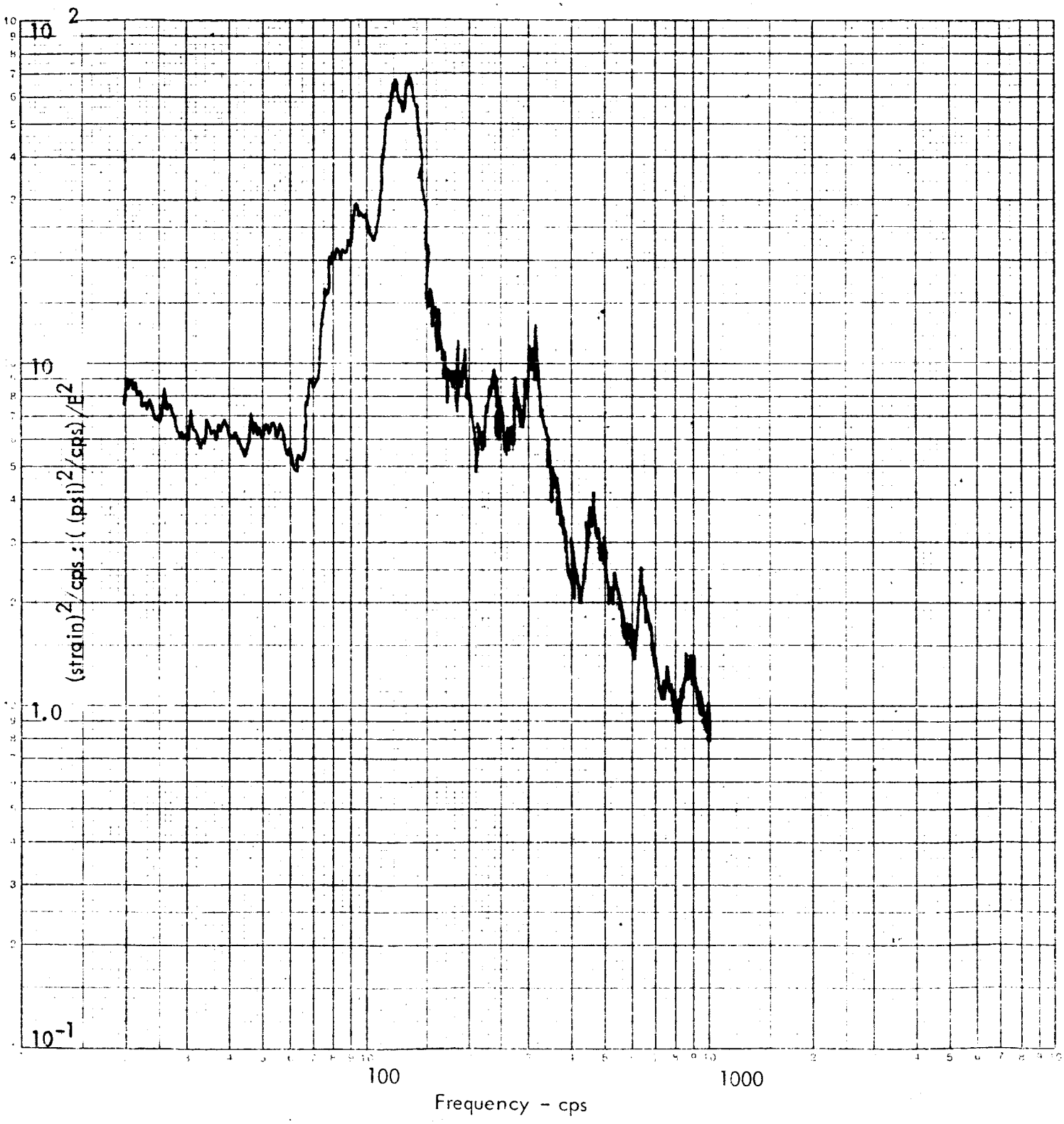


Figure 112 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 3

Date :27 May 1963

Filter Bandwidth :2 cps
Run No. 1

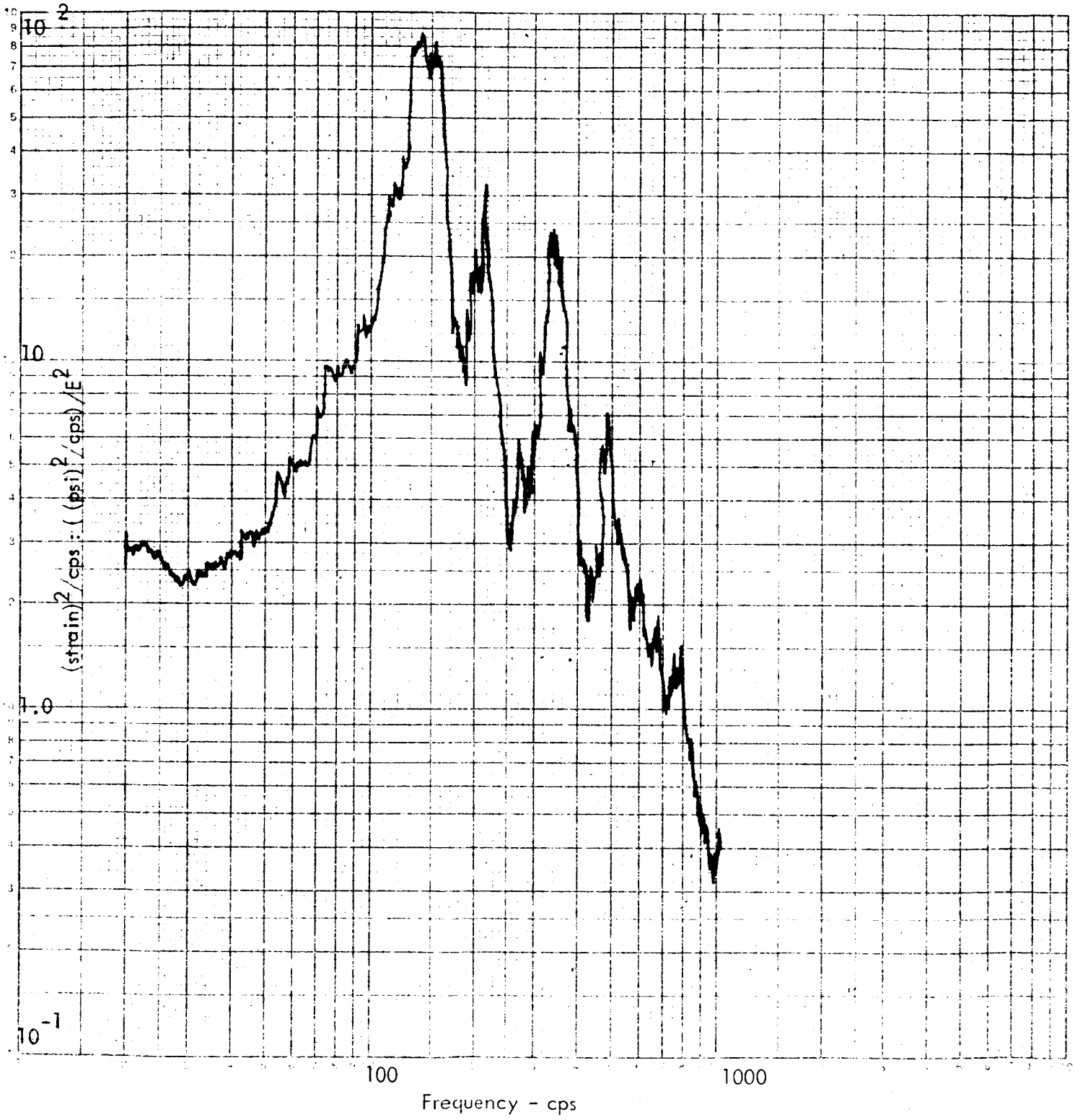


Figure 113 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 11

Date : 27 May 1963

Filter Bandwidth : 2 cps
Run No. 1

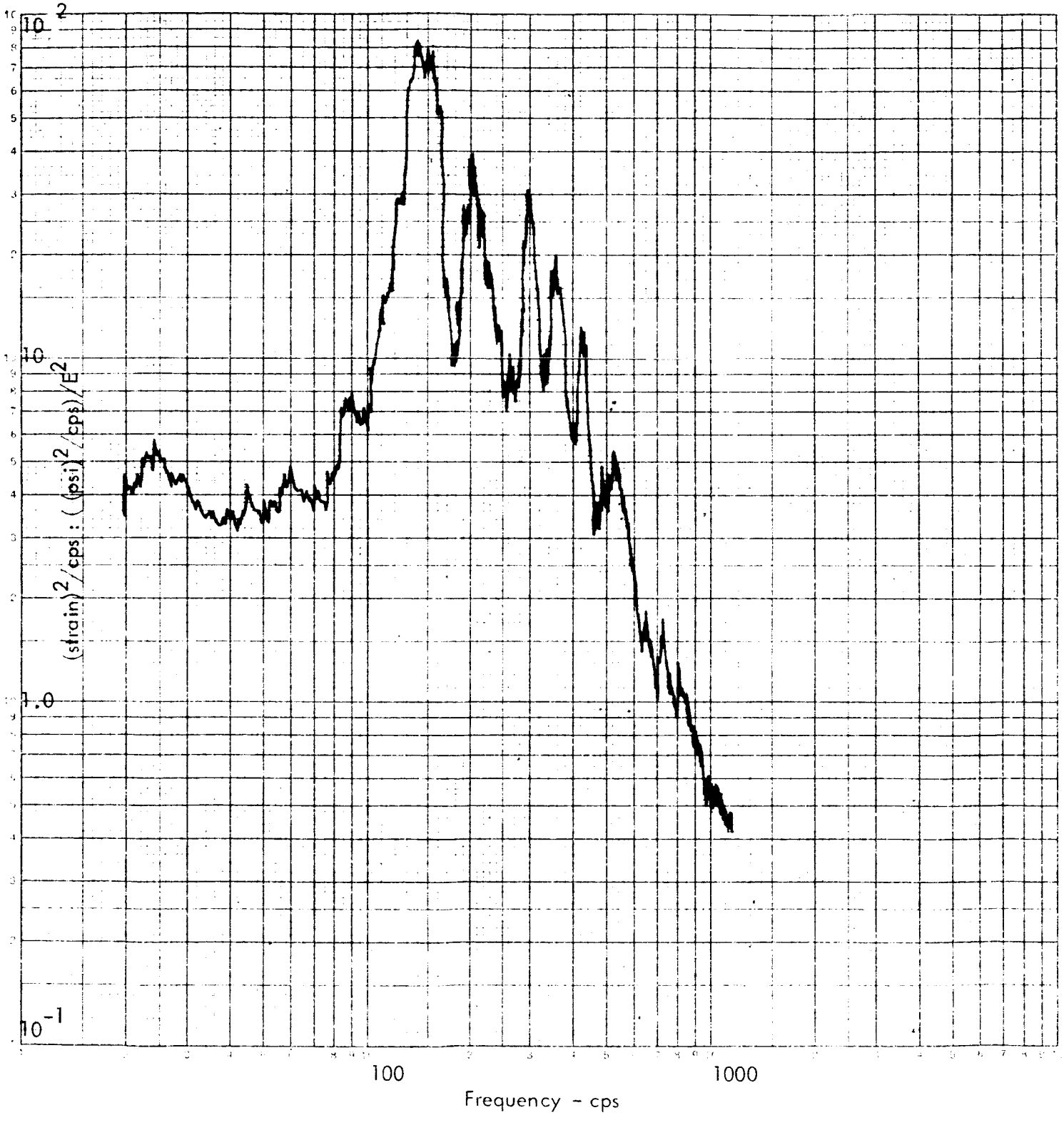


Figure 114 Shroud Panel No. 3 - Power Spectral Density - Strain Gauge No. 12

Date : 27 May 1963

Filter Bandwidth : 2 cps
Run No. 1

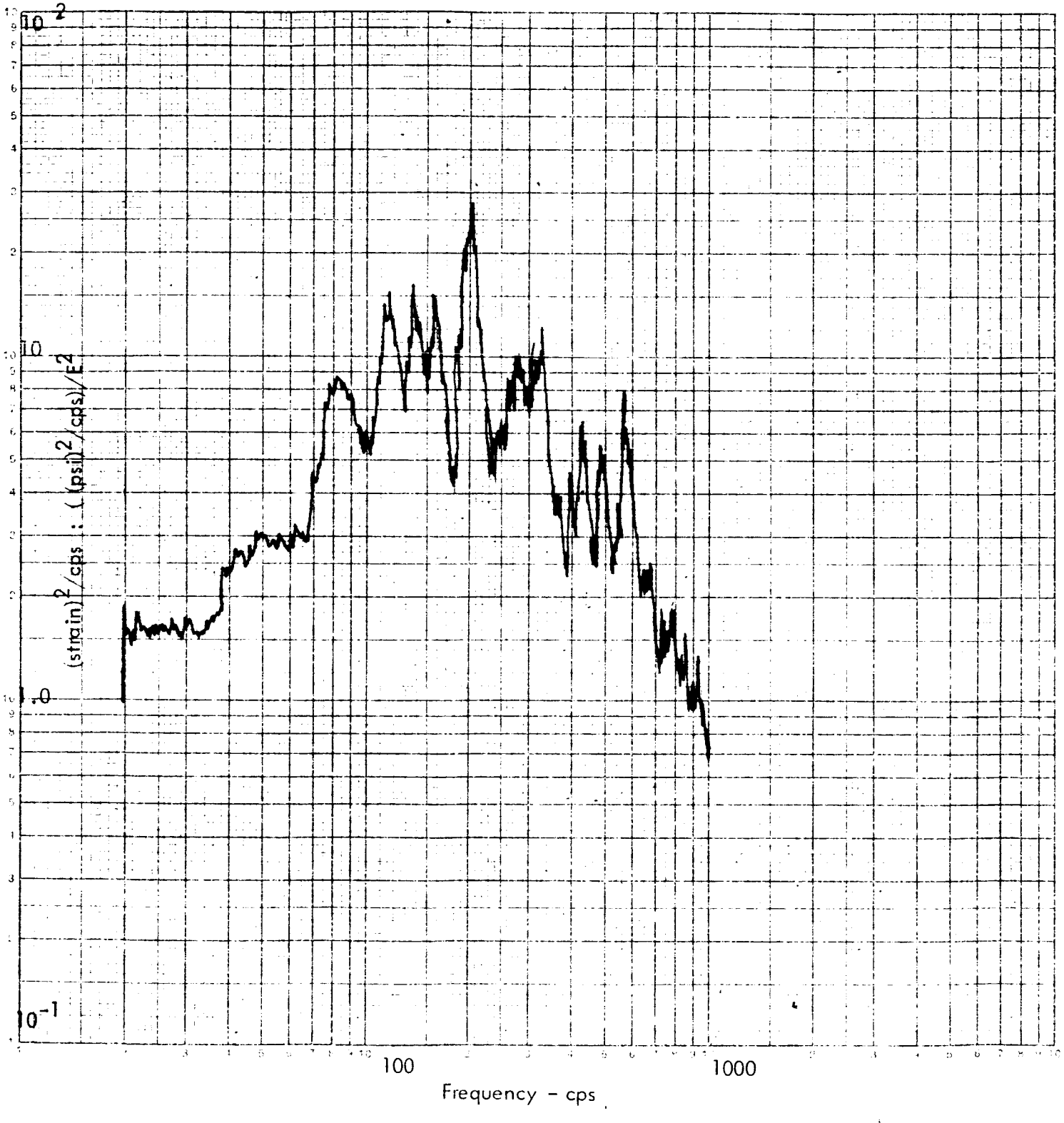


Figure 115 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 13

Date : 27 May 1963

Filter Bandwidth : 2 cps
Run No. 1

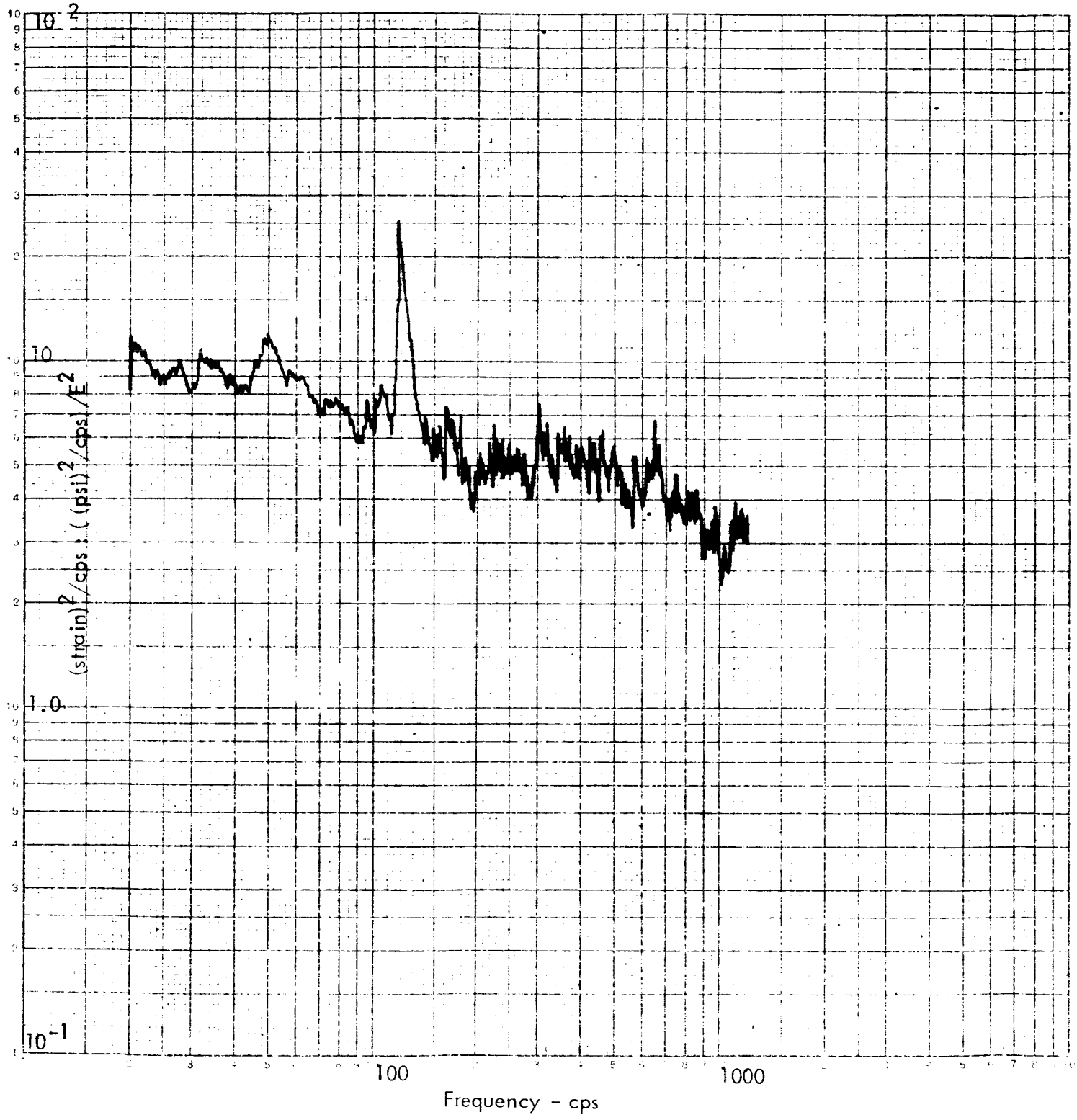


Figure 116 Shroud Panel No. 3 - Power Spectral Density - Strain Gauge No. 14

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 2

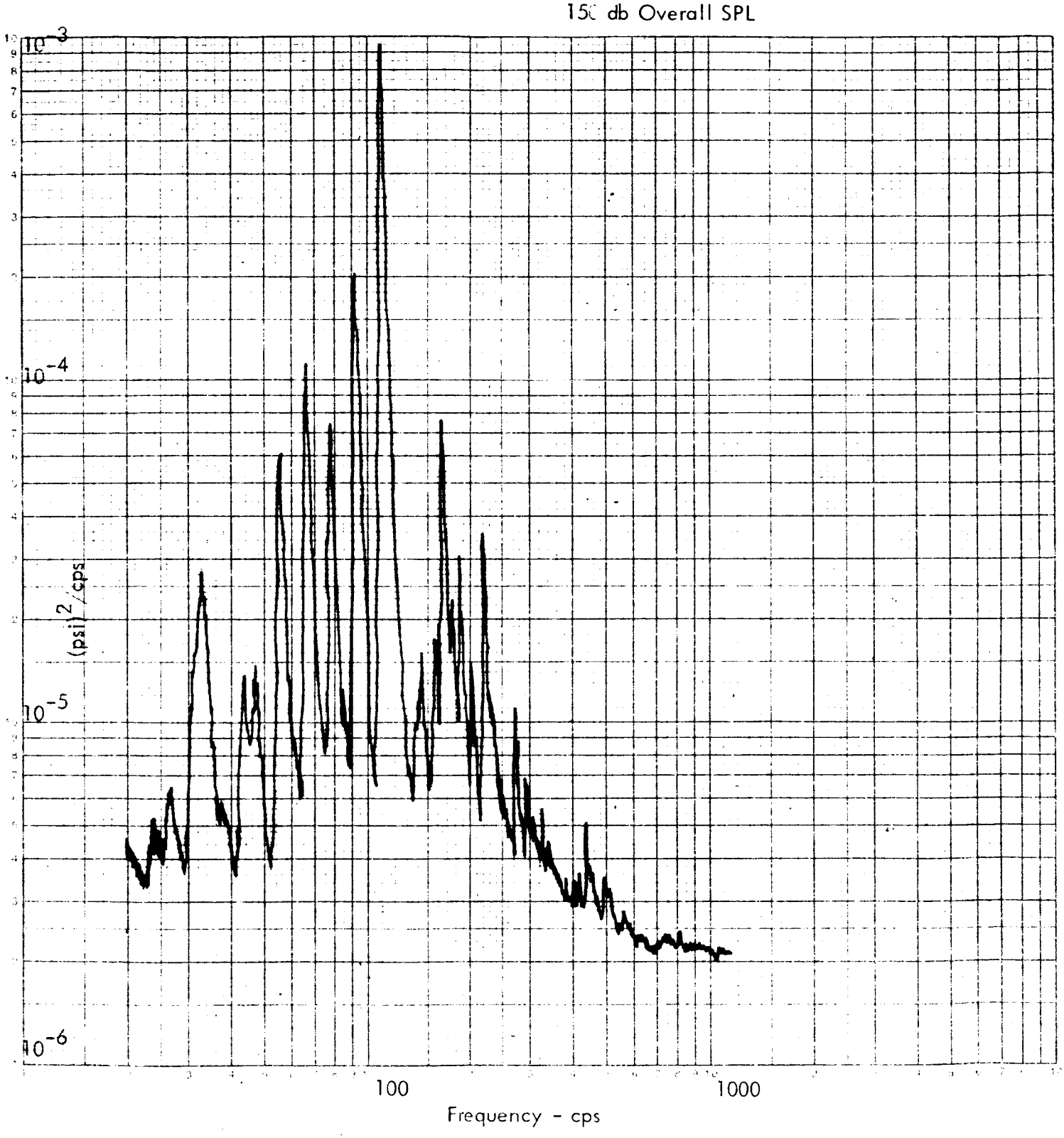


Figure 117 Shroud Panel No. 3 - Power Spectral Density - Microphone No. 1

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 2

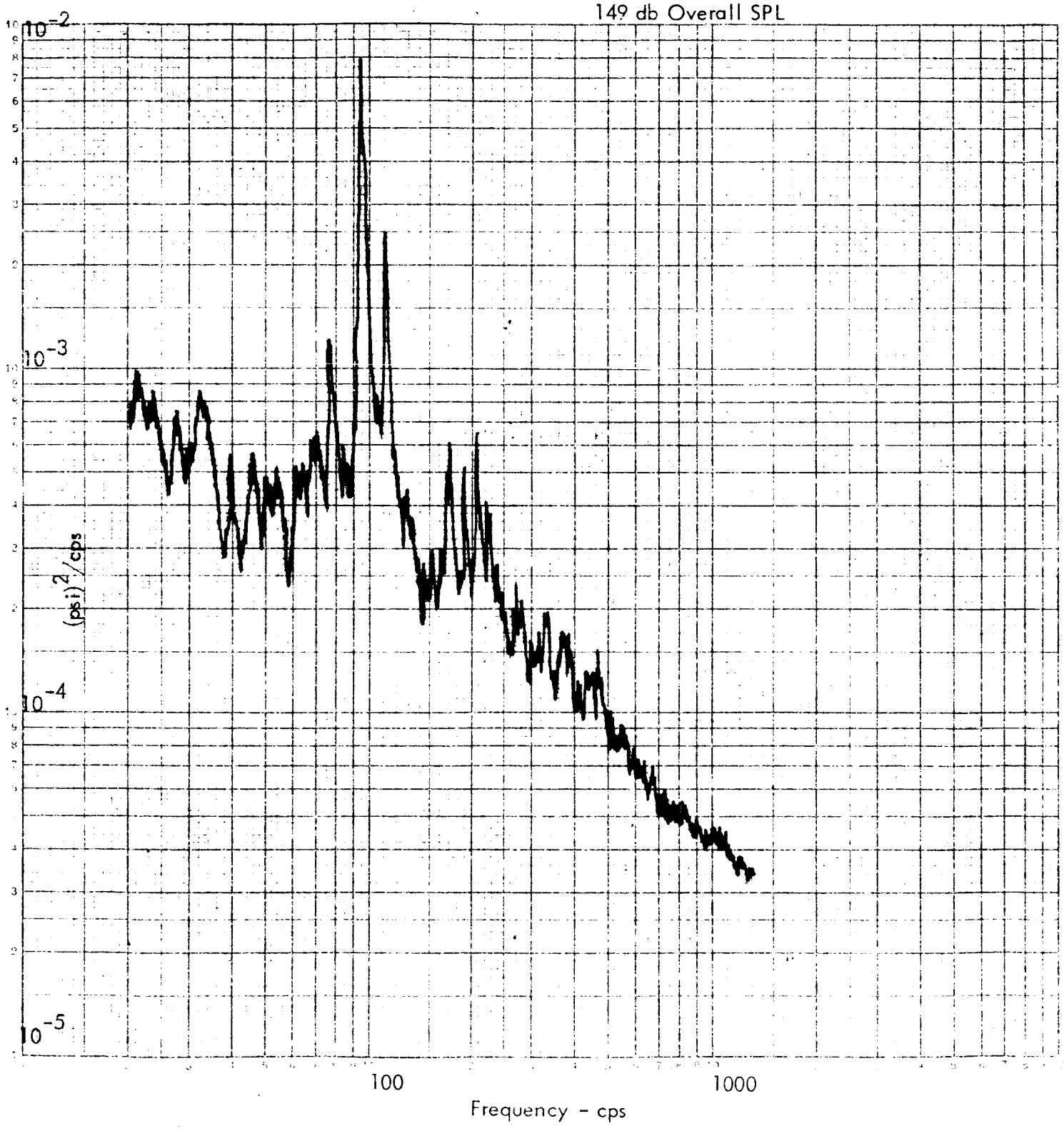


Figure 118 Shroud Panel No. 3 - Power Spectral Density- Microphone No. 2

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 2

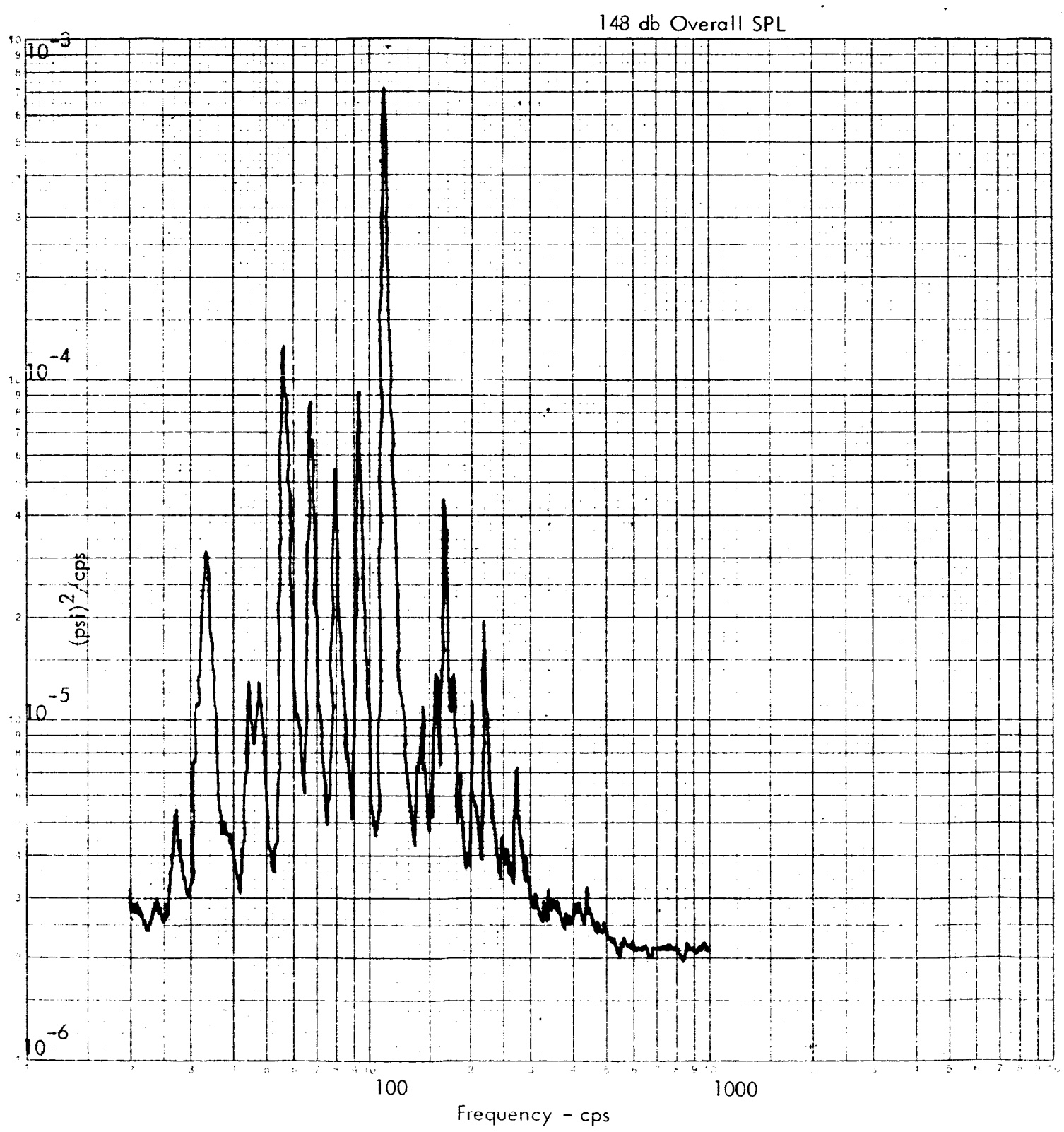


Figure 119 Shroud Panel No. 3 - Power Spectral Density- Microphone No. 3

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 2

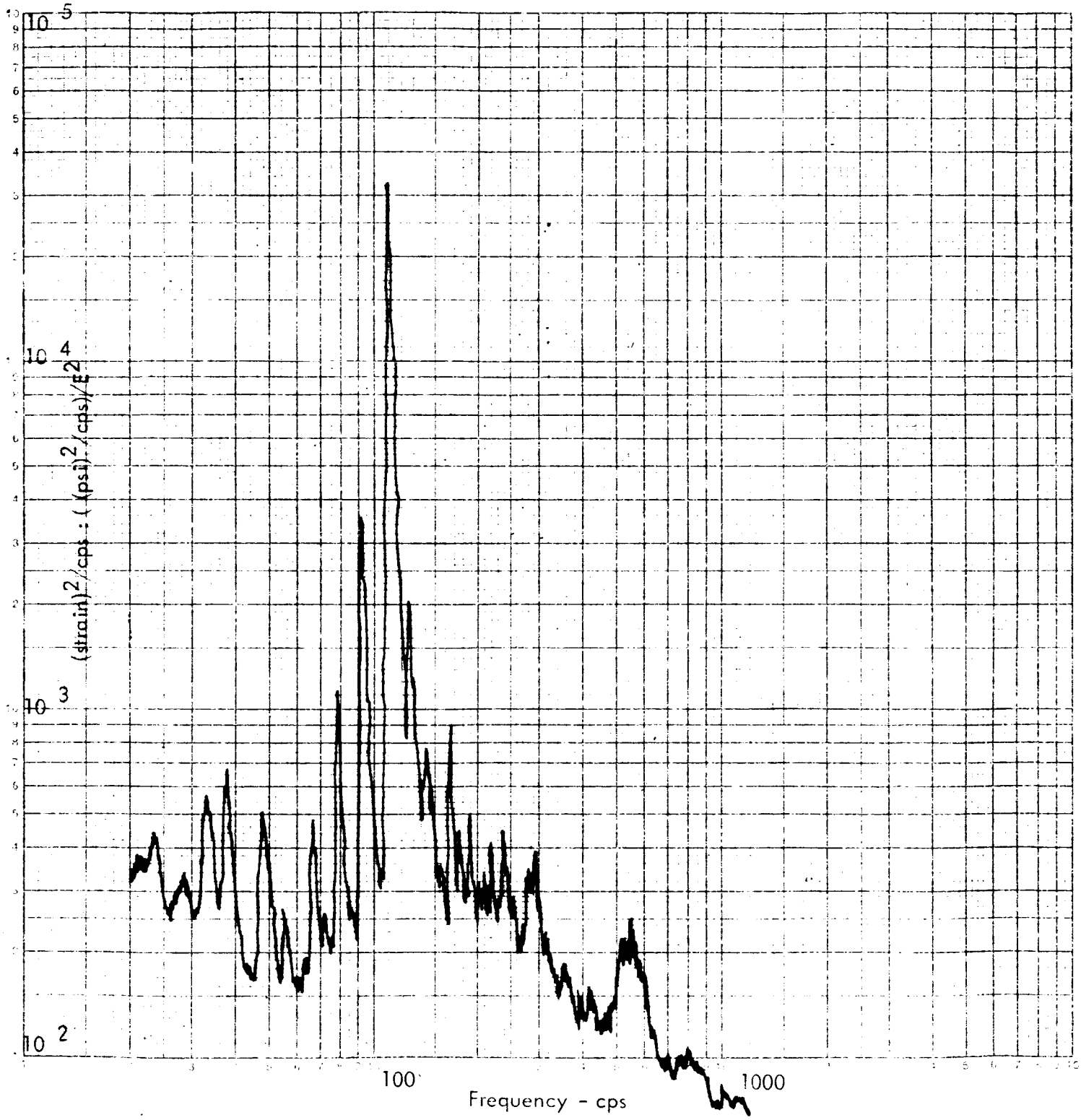


Figure 120 Shroud Panel No. 3 - Power Spectral Density- Strain Gauge No. 12

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 2

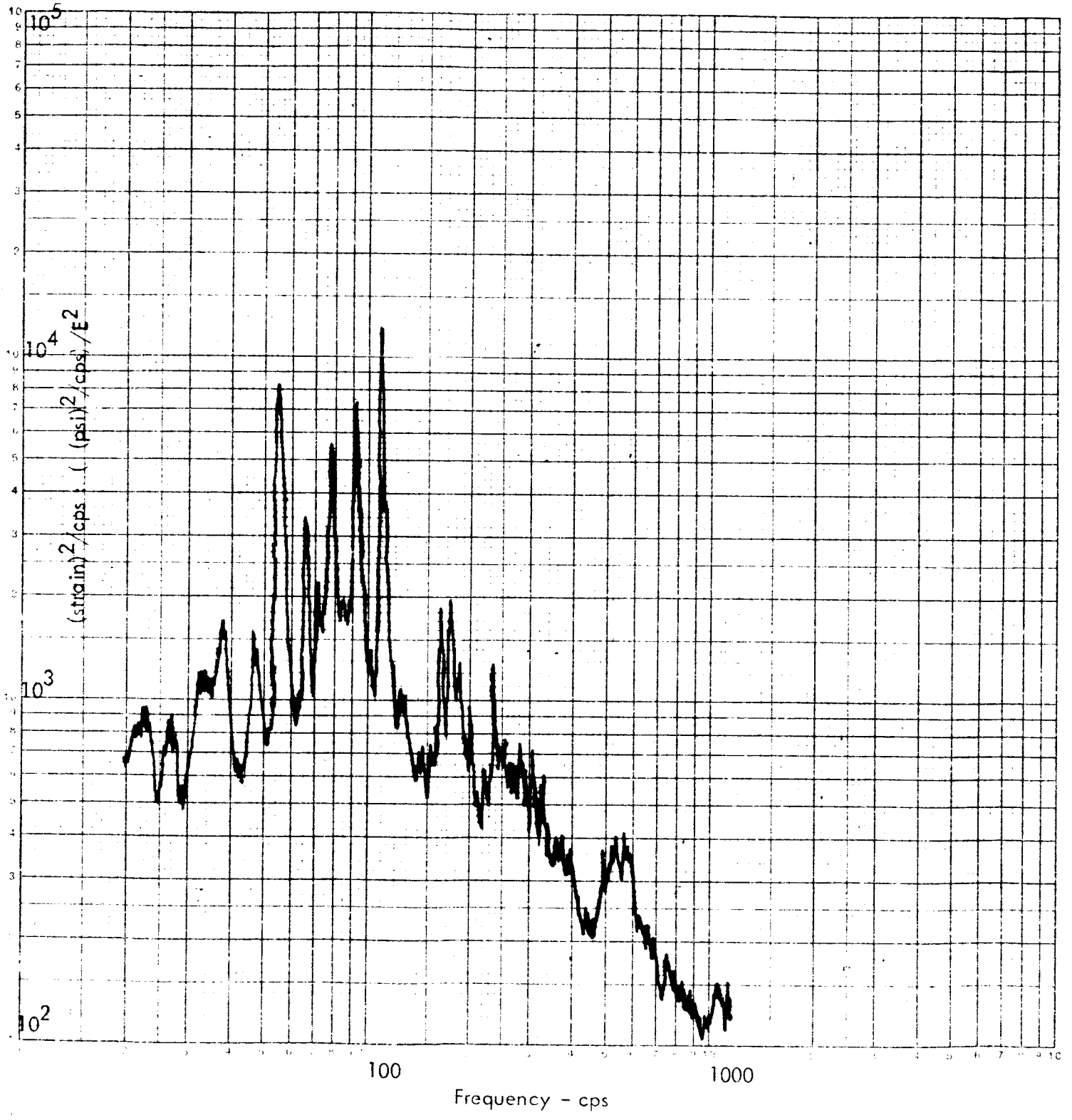


Figure 121 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 13

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 2

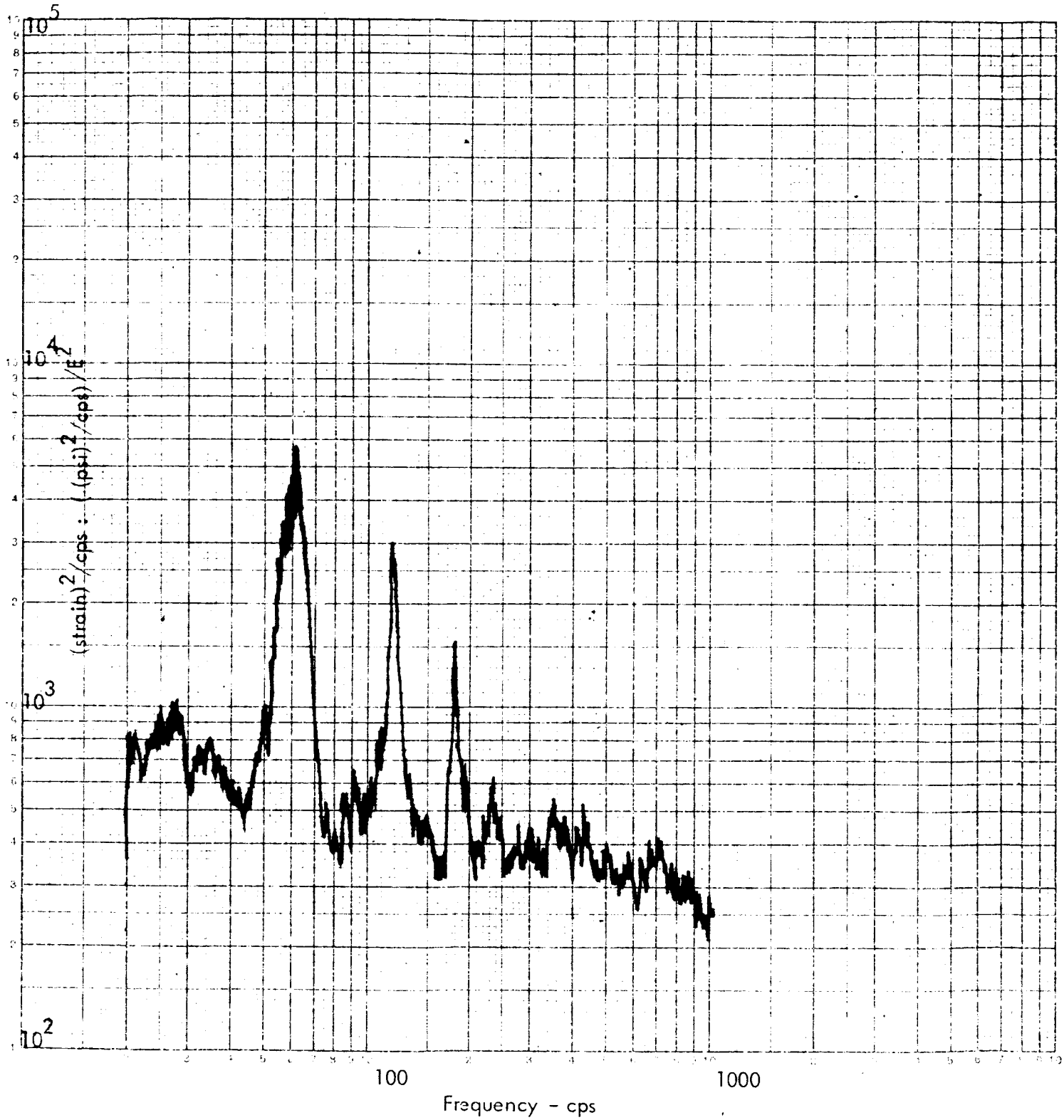


Figure 122 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 14

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 3

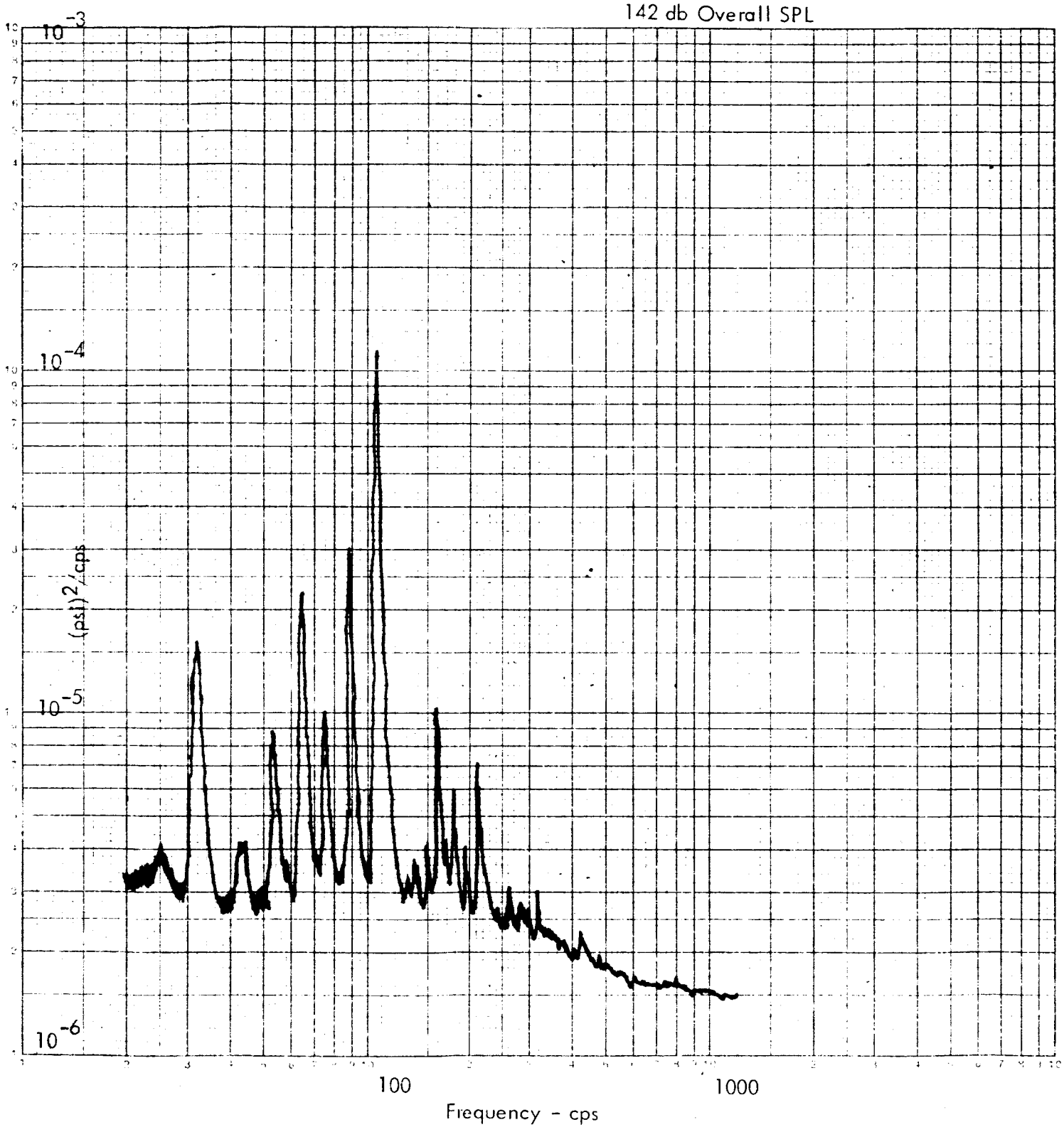


Figure 123 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 1

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 3

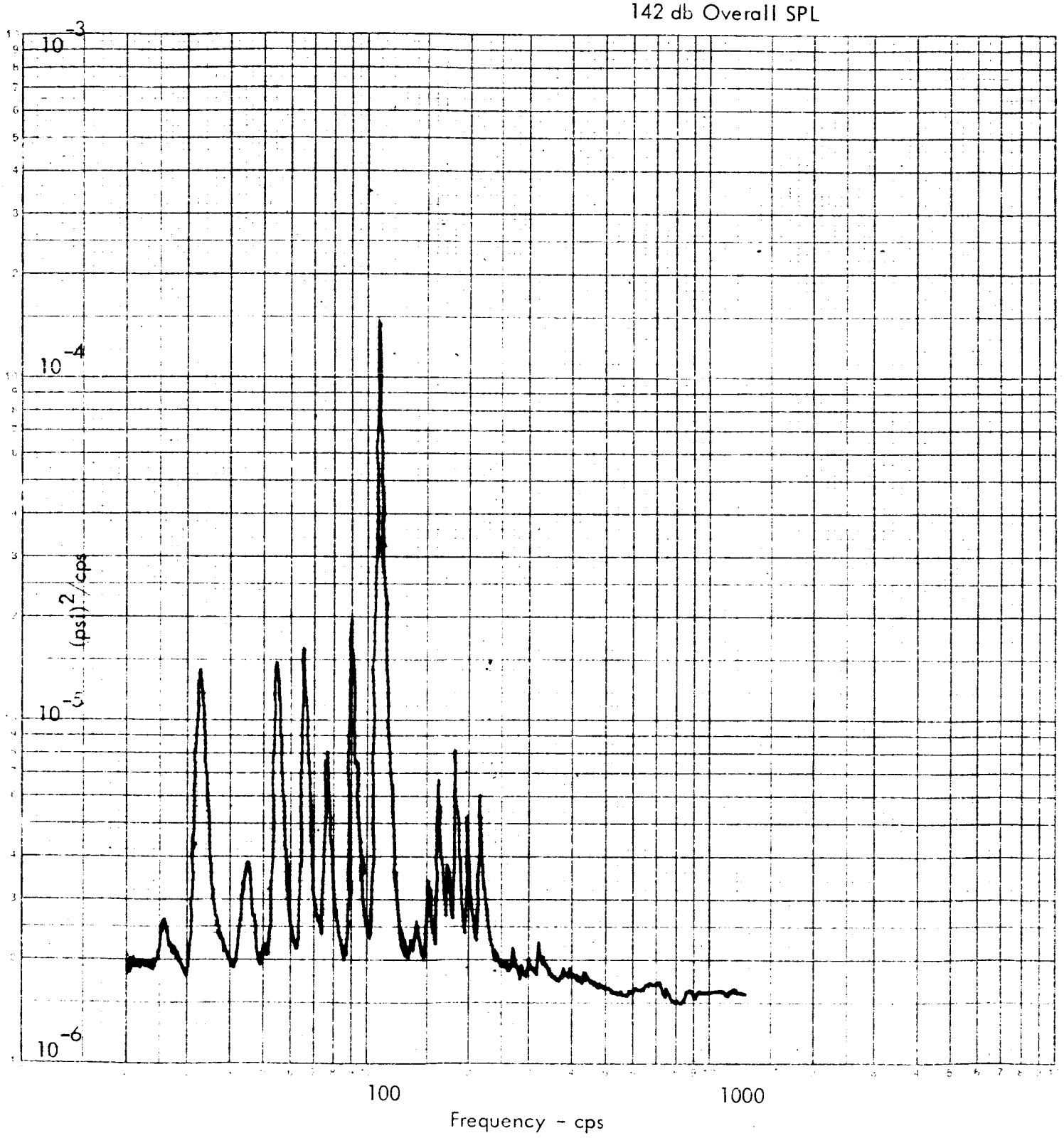


Figure 124 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 2

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 3

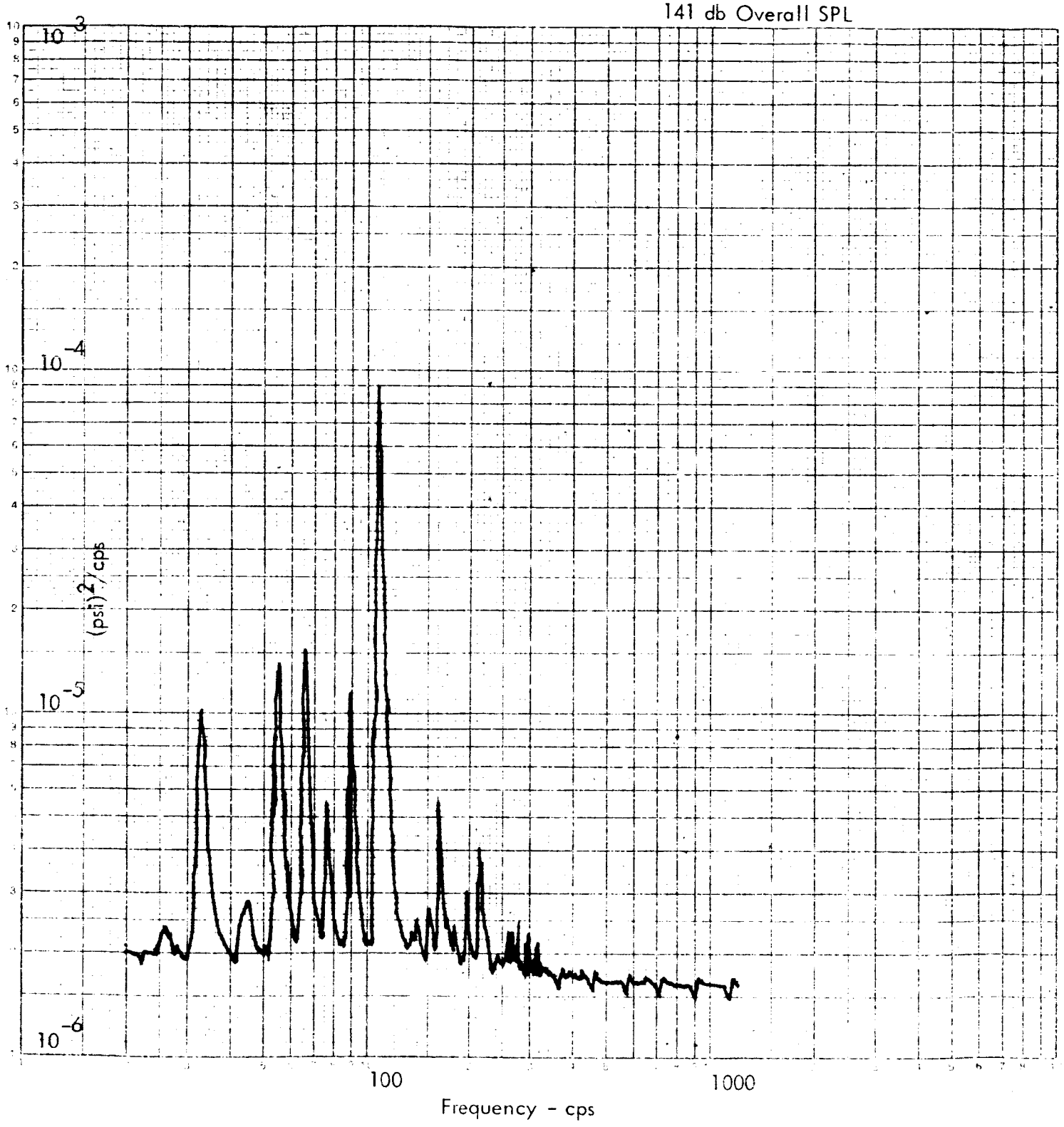


Figure 125 Shroud Panel No. 3 - Power Spectral Density - Microphone No. 3

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 3

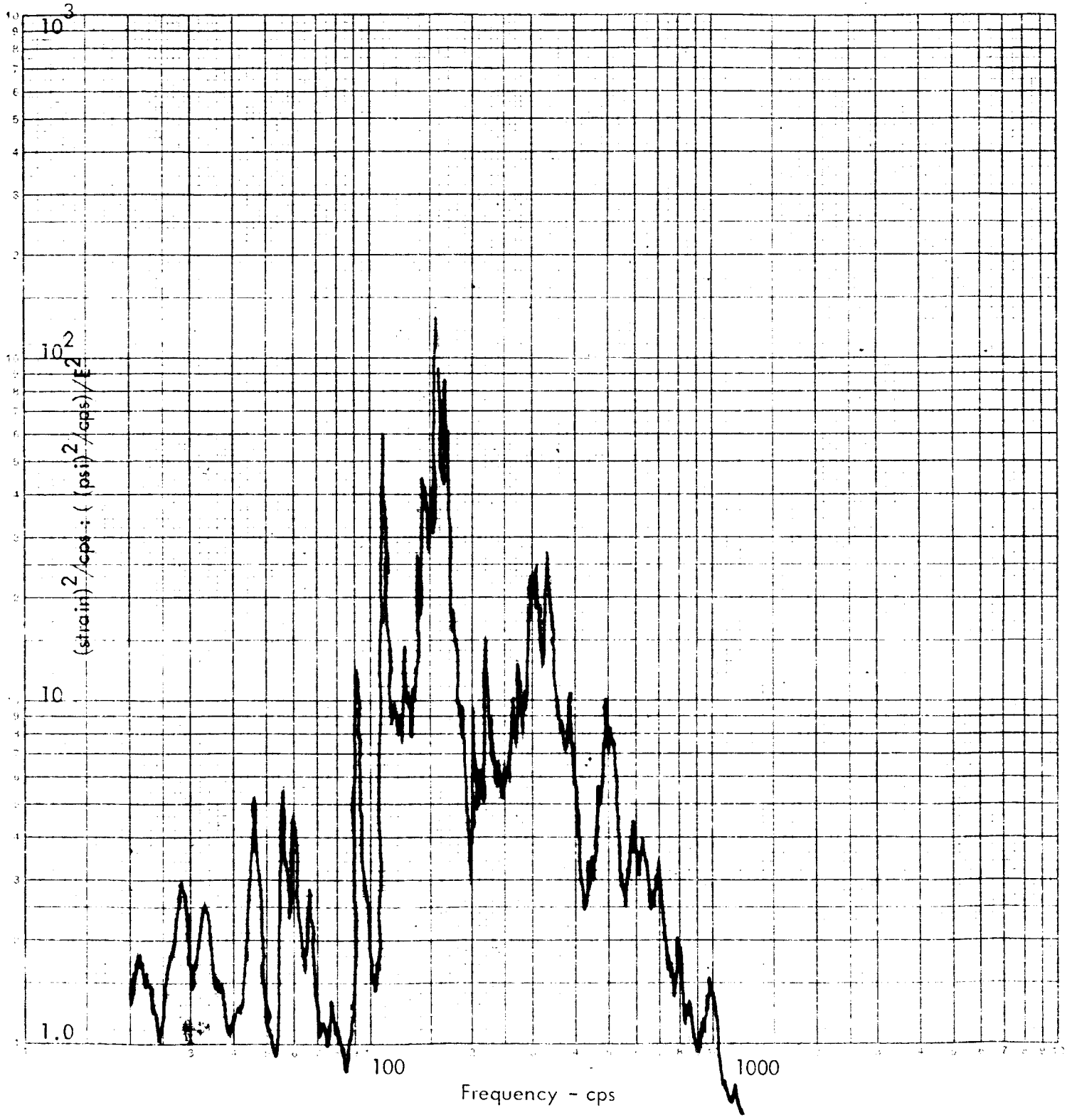


Figure 126 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 2

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 3

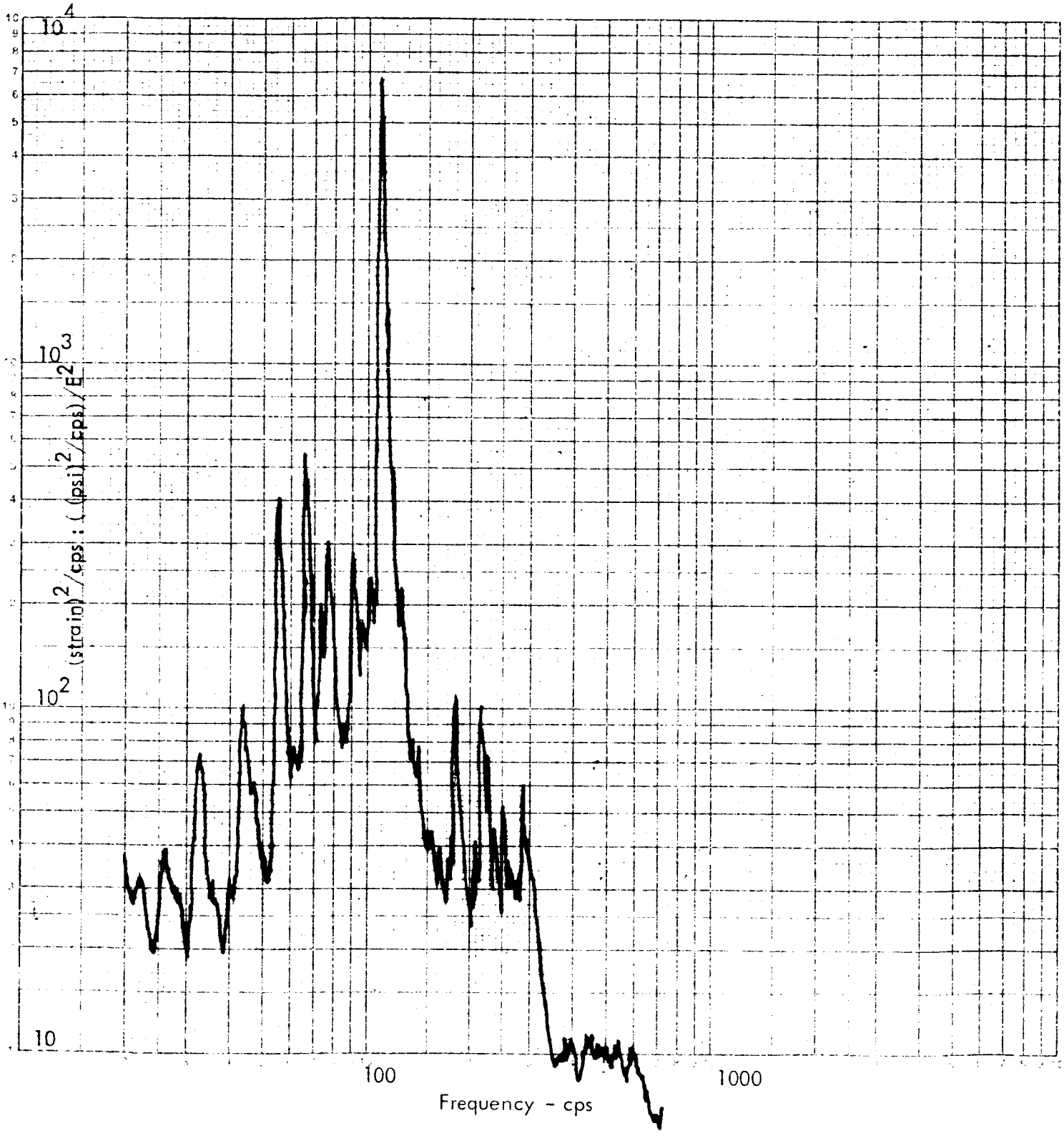


Figure 127 Shroud Panel No. 3 - Power Spectral Density - Strain Gauge No. 8

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 3

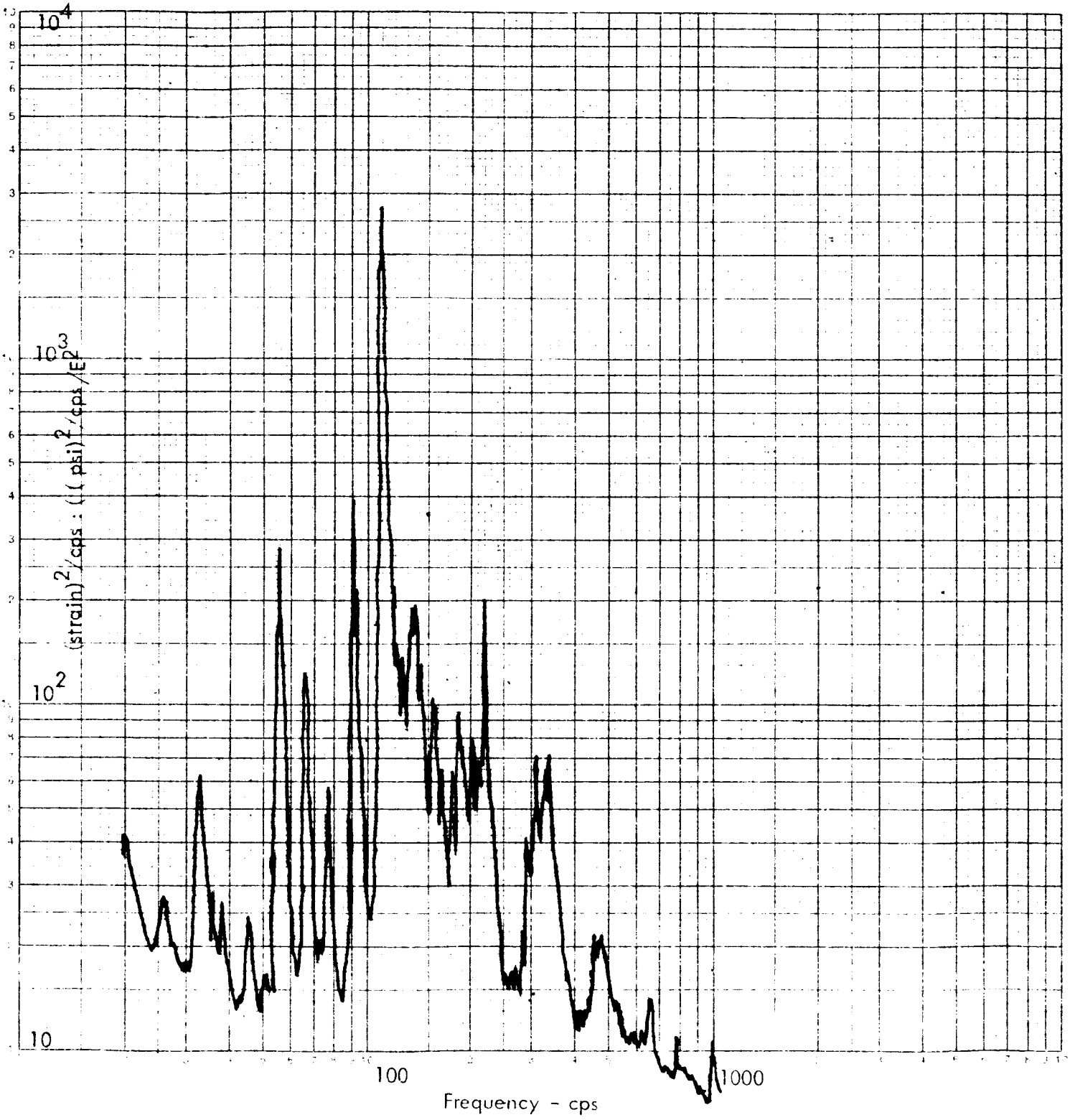


Figure 128 Shroud Panel No. 3 - Power Spectral Density - Strain Gauge No. 11

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 3

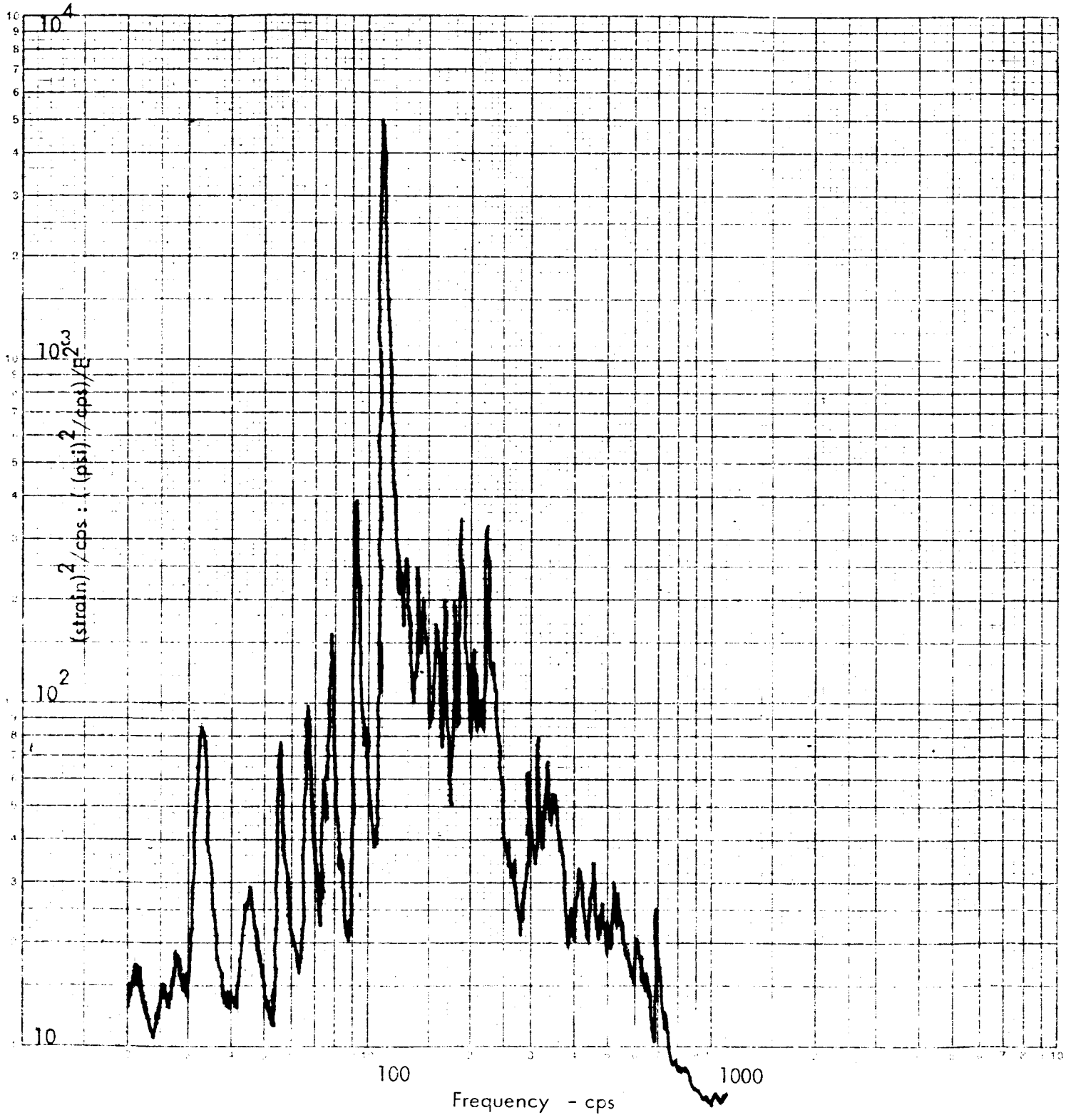


Figure 129 Shroud Panel No. 3 - Power Spectral Density- Strain Gauge No. 12

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 3

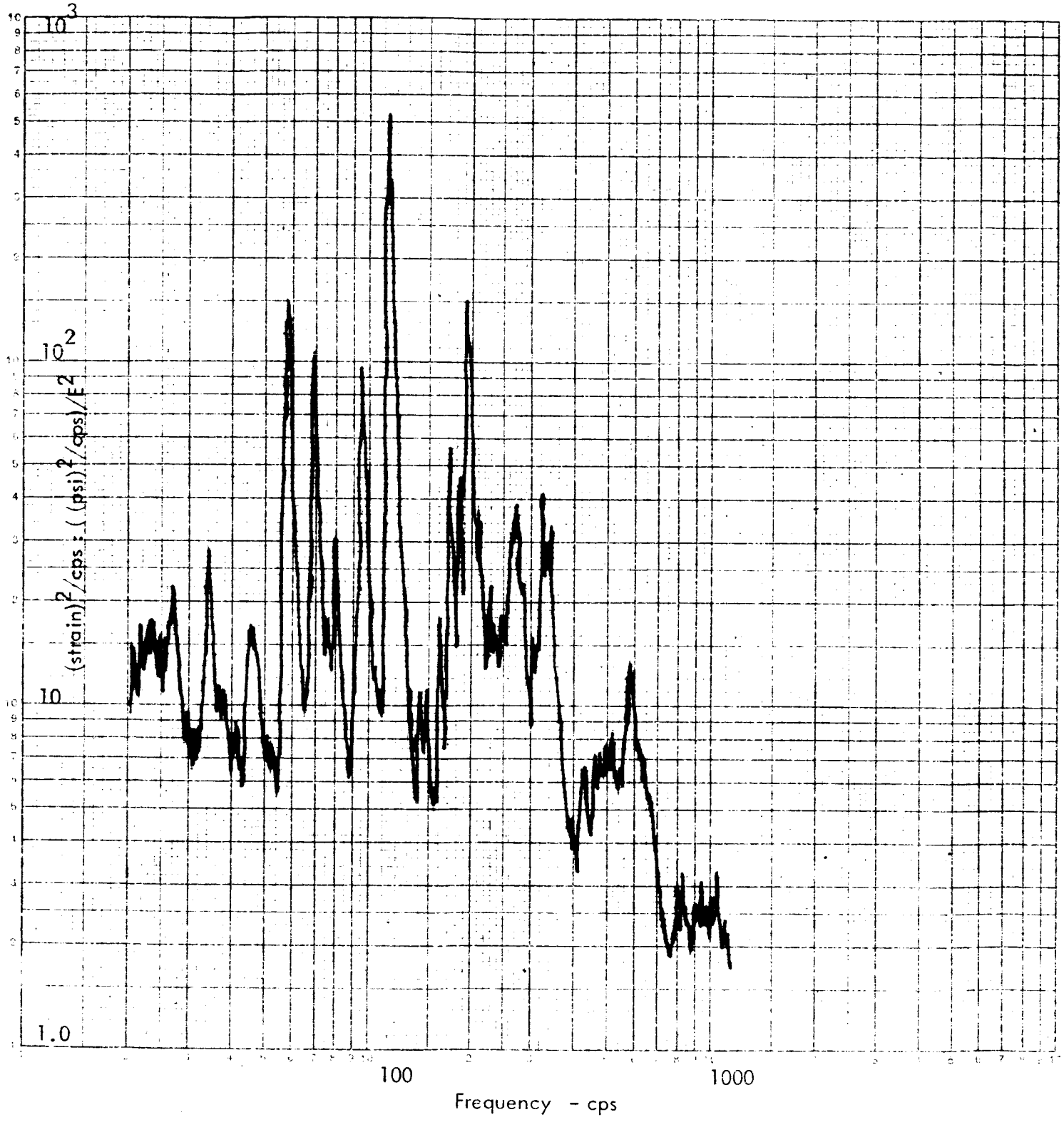


Figure 130 Shroud Panel No. 3 - Power Spectral Density- Strain Gauge No. 13

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 3

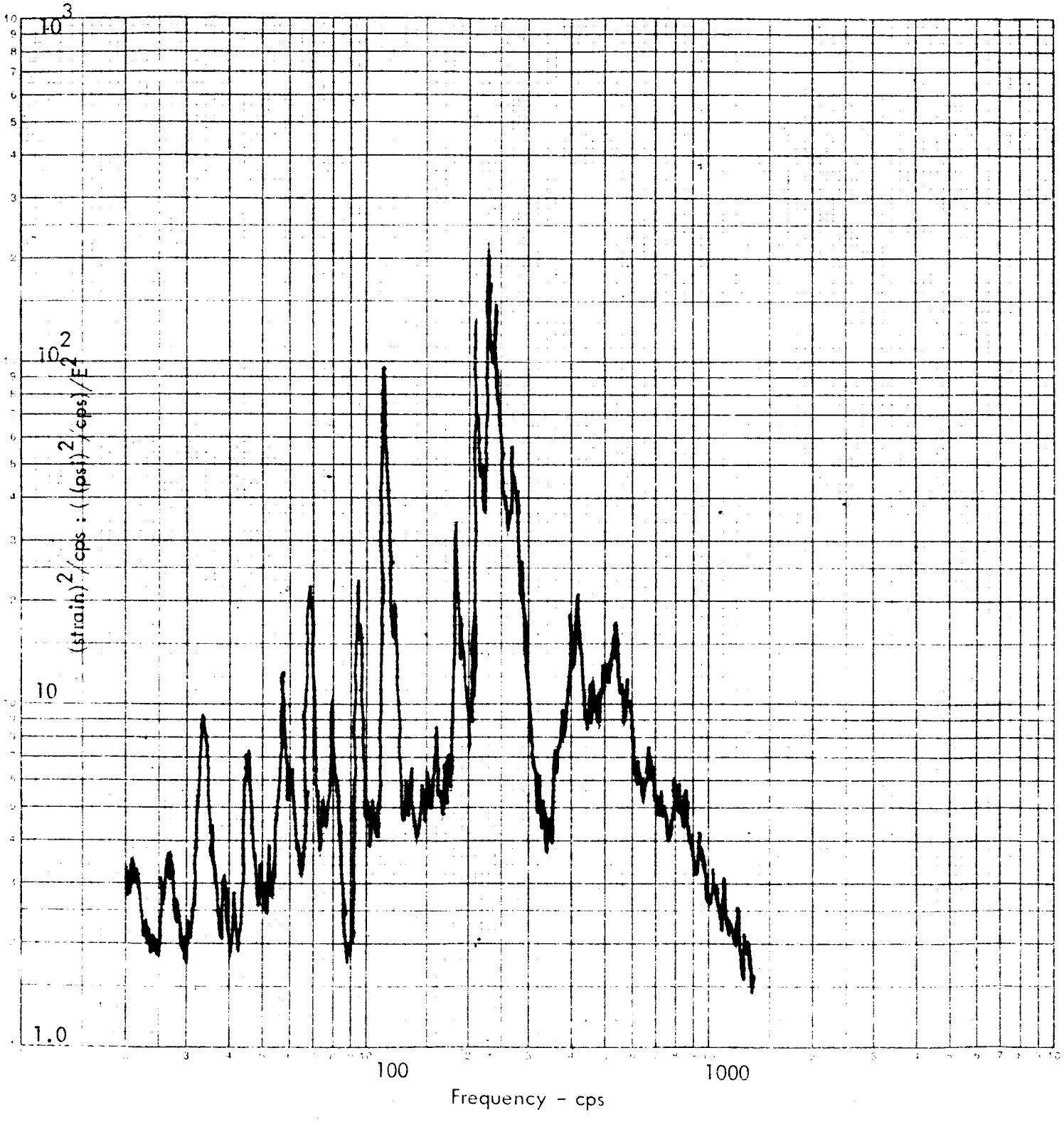


Figure 131 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 14

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 4

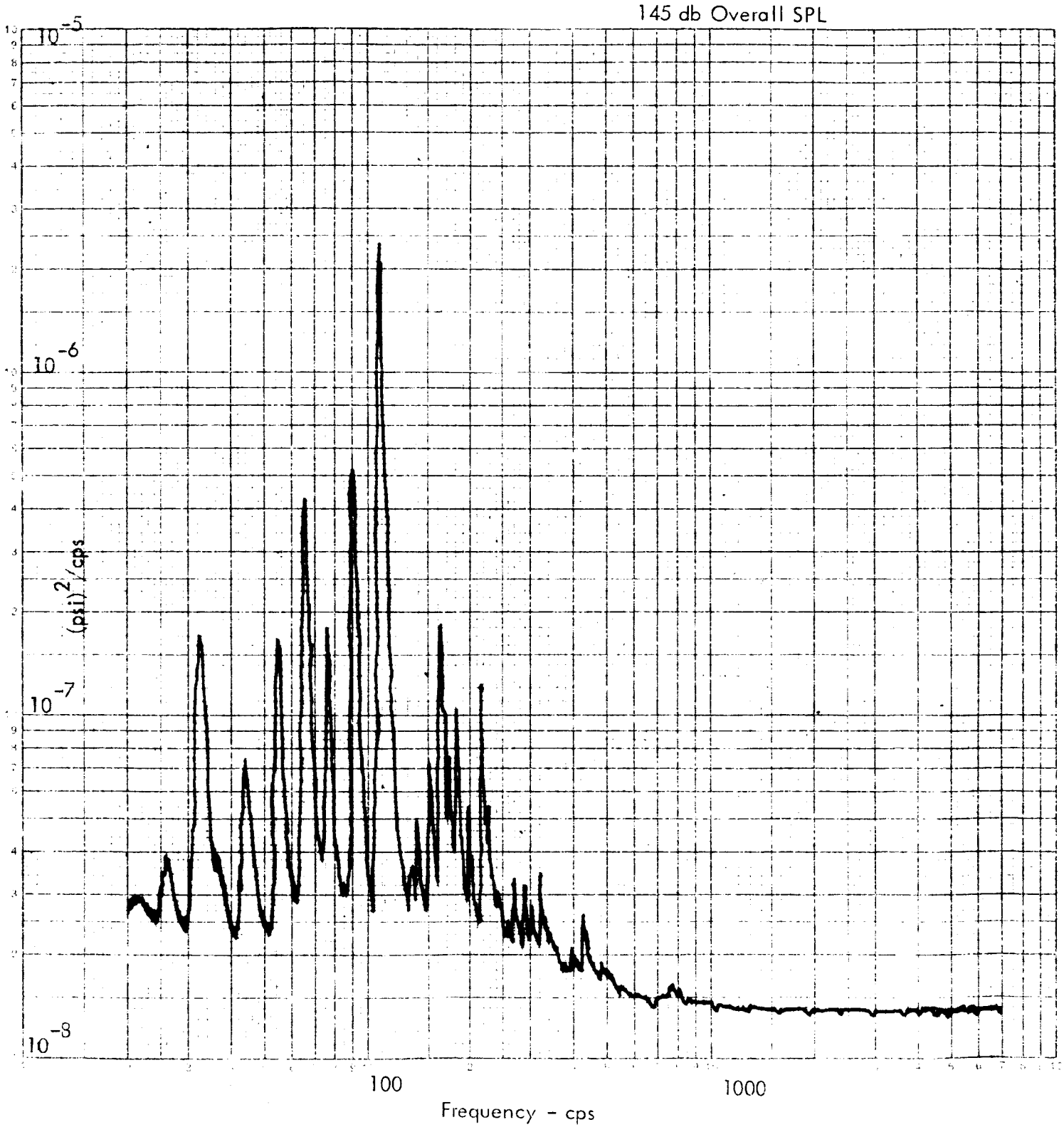


Figure 132 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 1

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 4

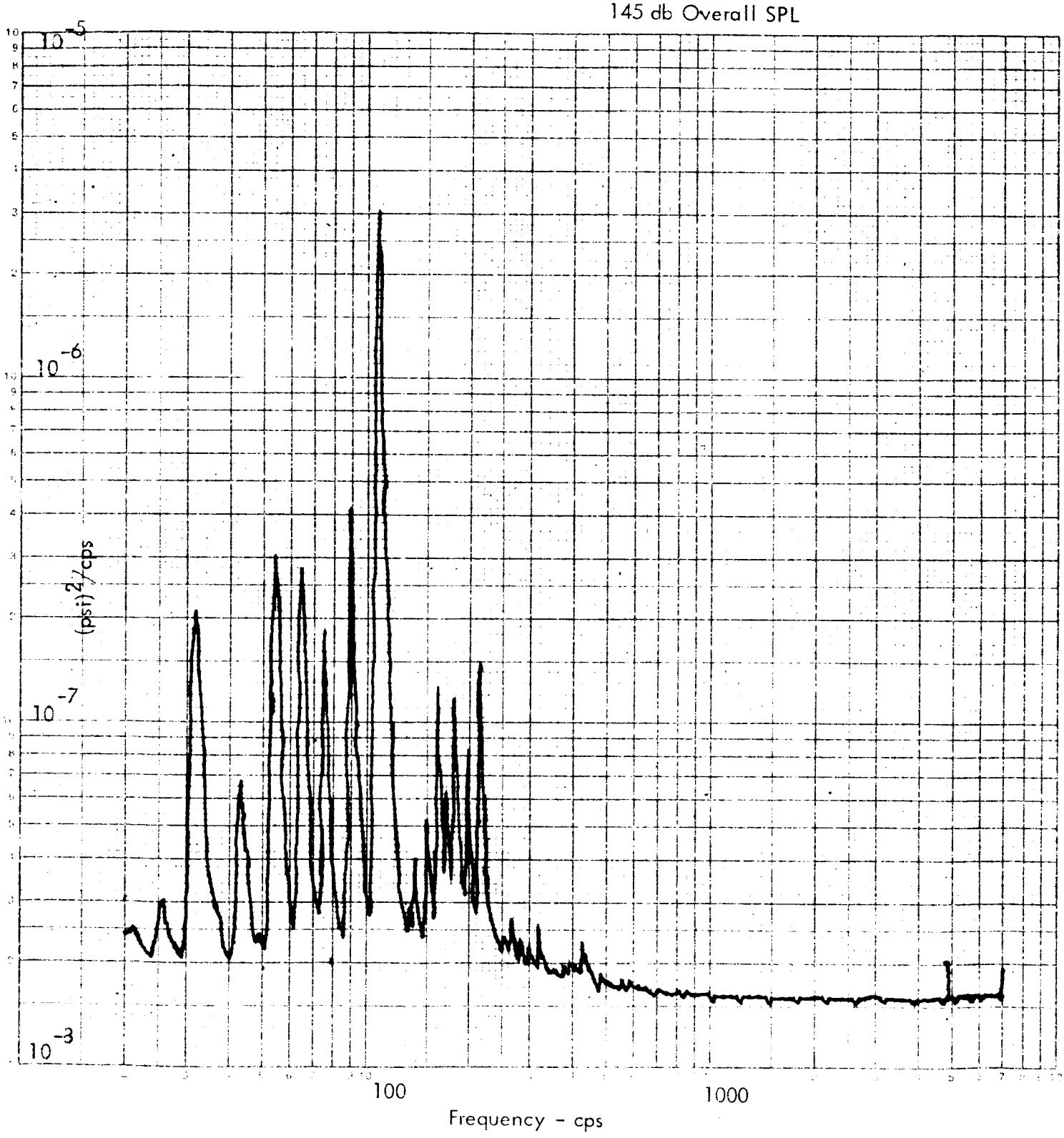


Figure 133 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 2

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 4

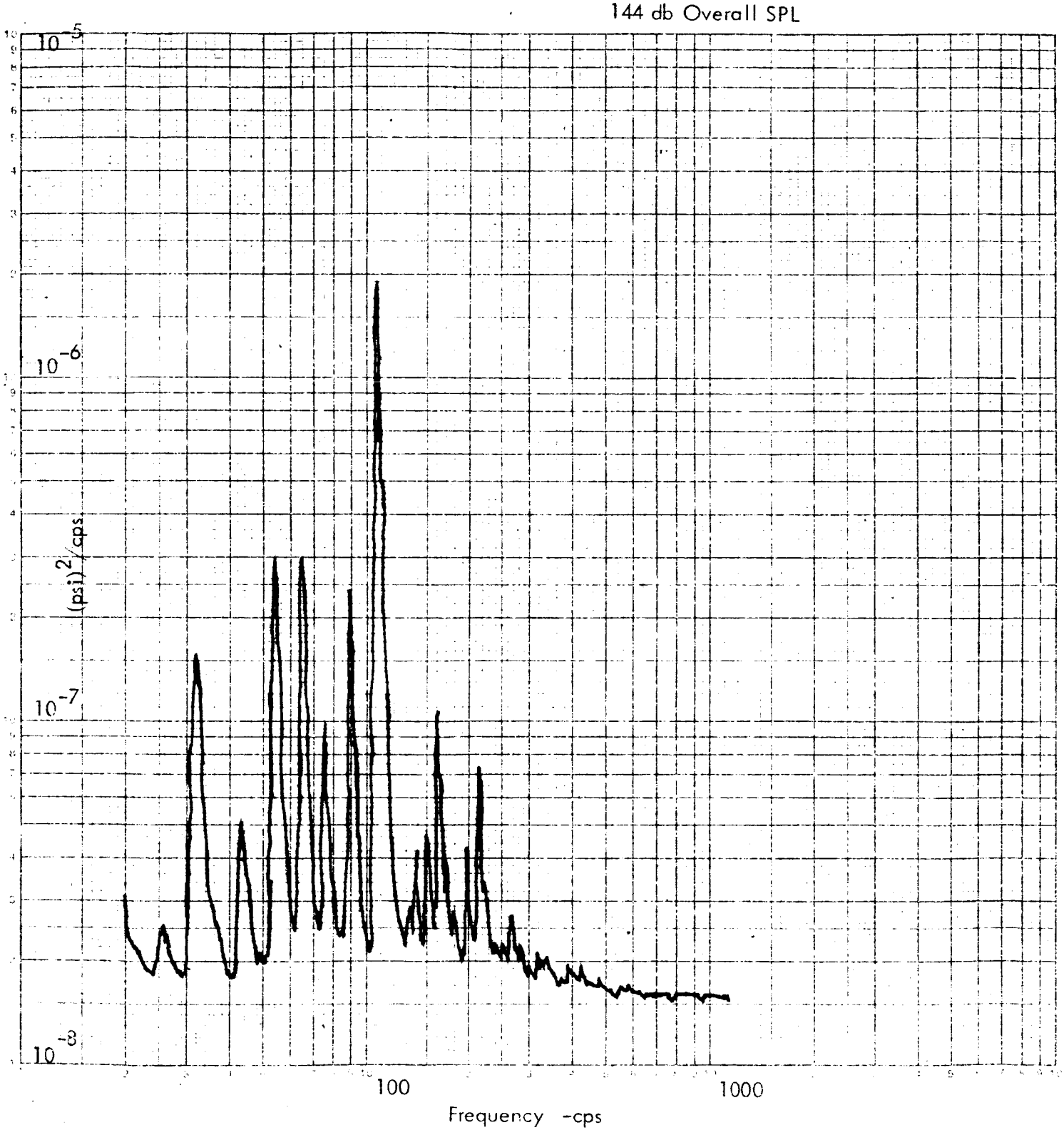


Figure 134 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 3

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 4

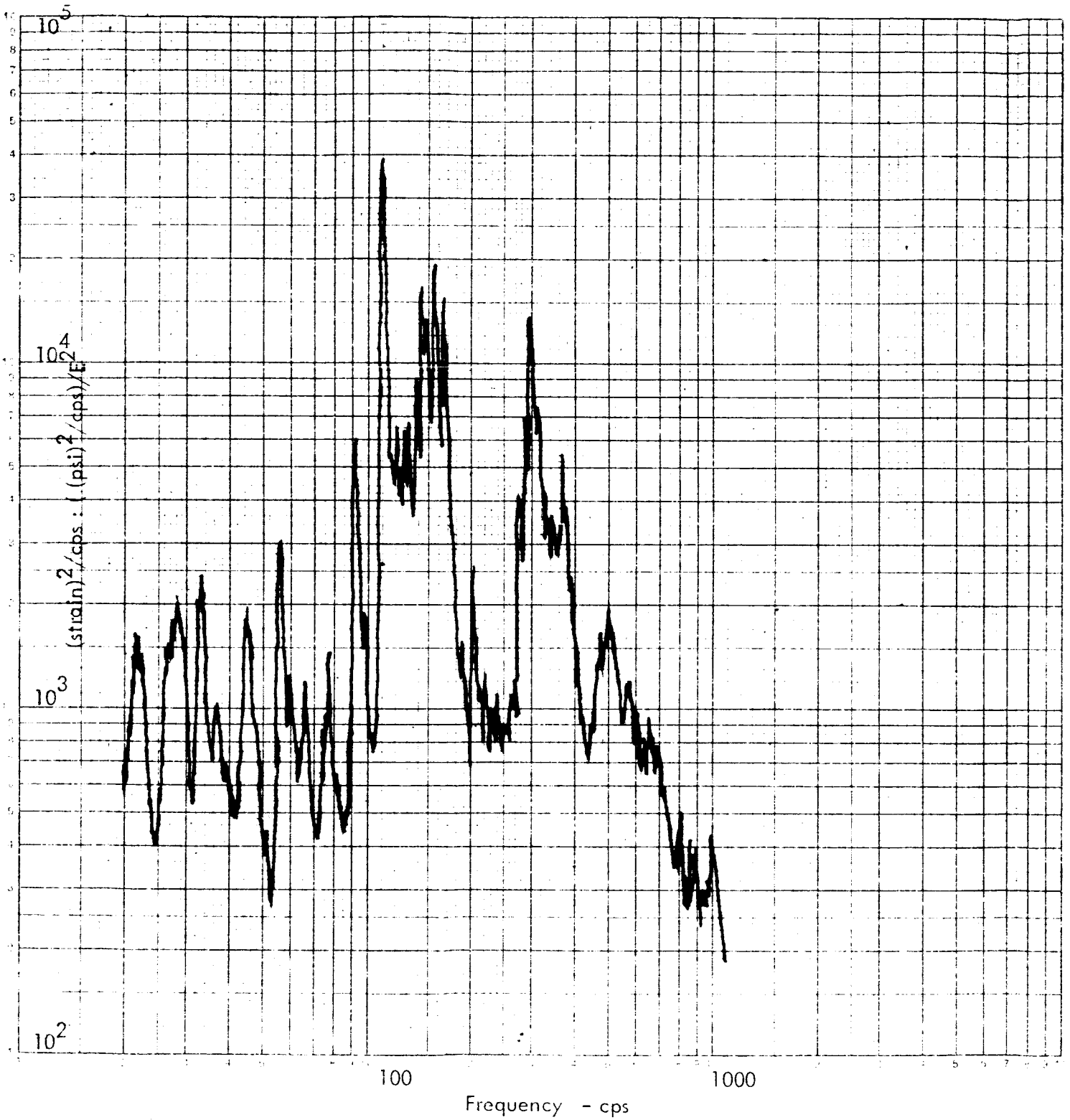


Figure 135 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 2

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 4

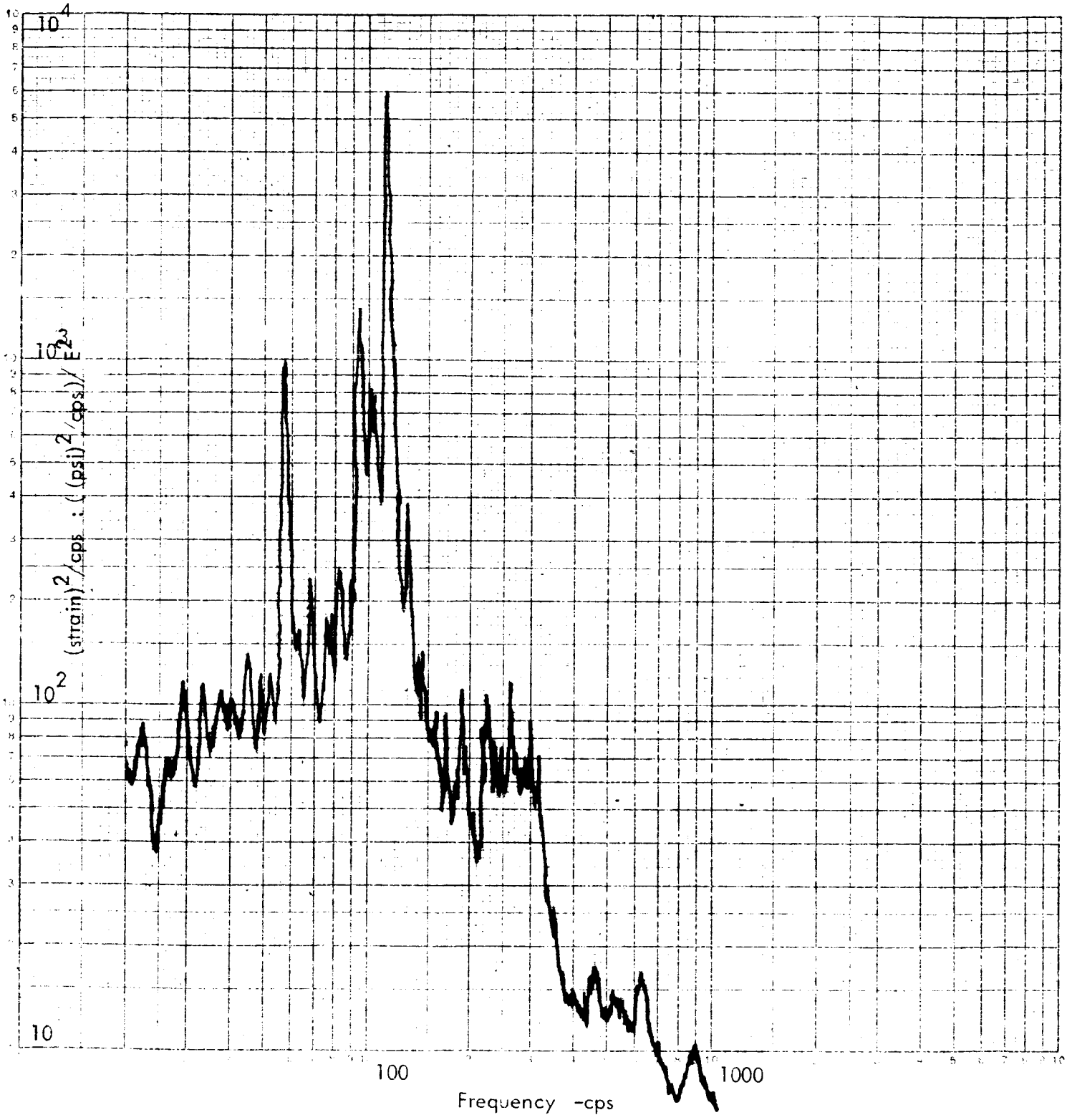


Figure 136 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 3

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 4

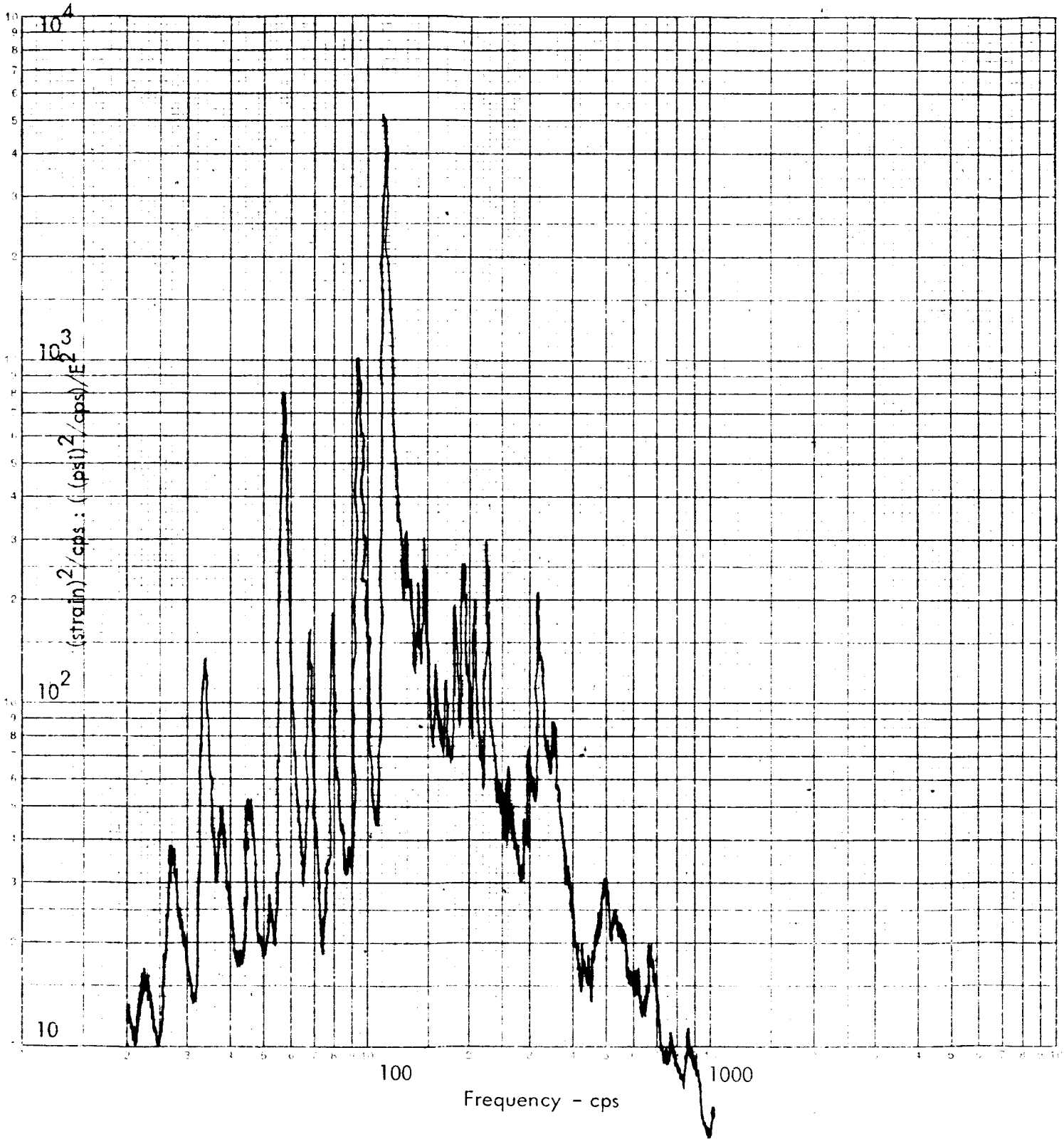


Figure 137 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 11

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 4

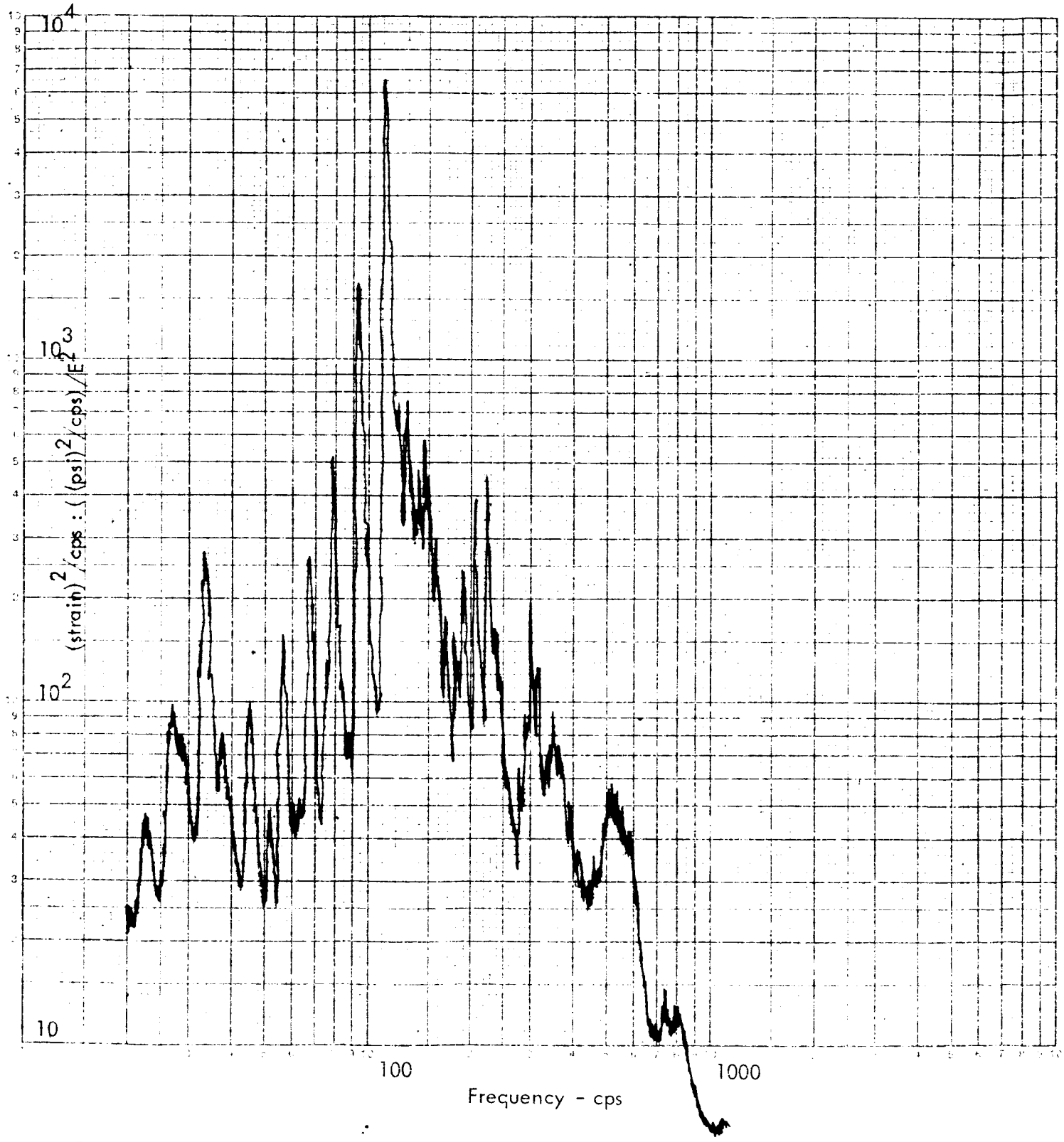


Figure 138 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 12

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 4

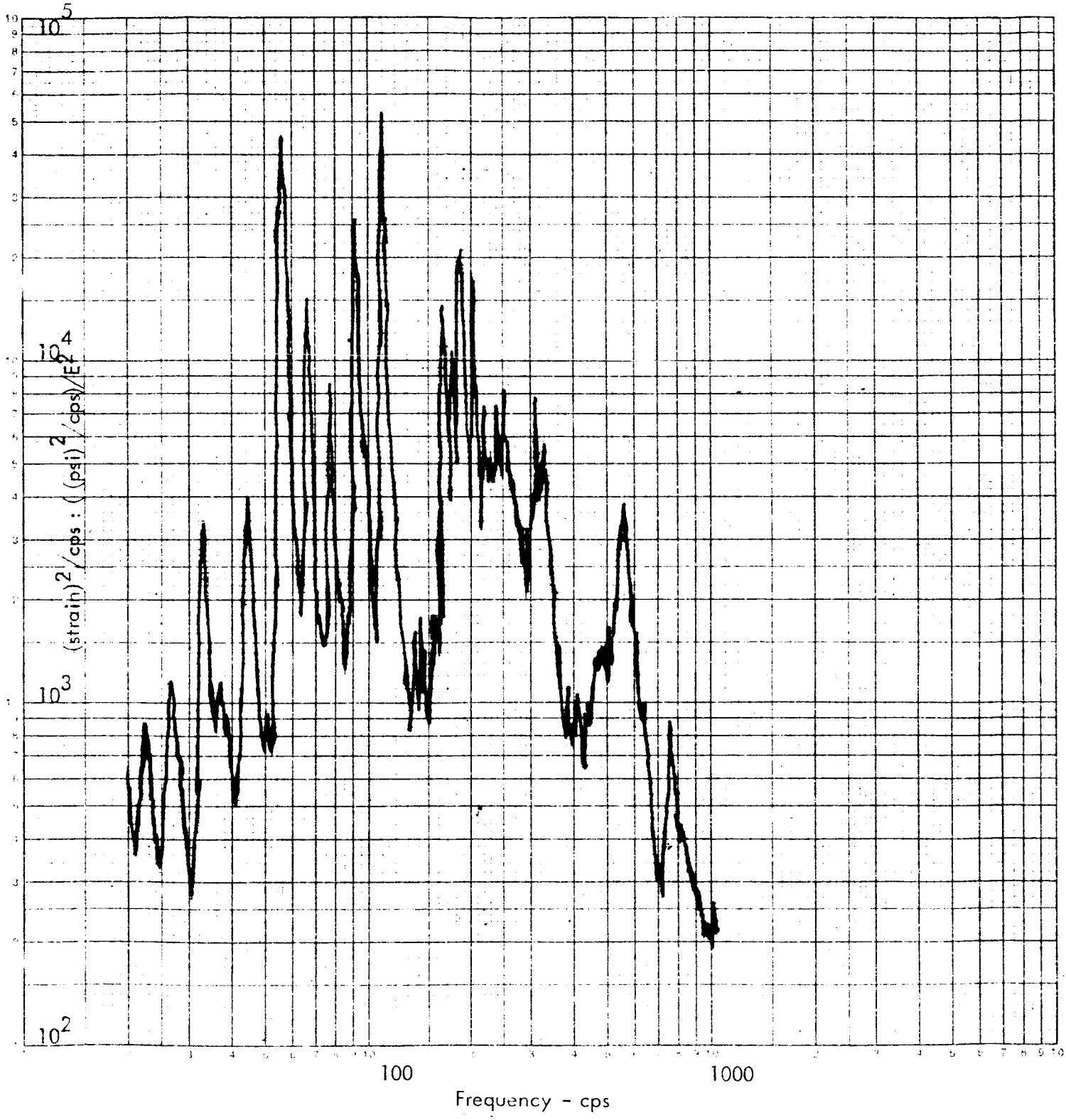


Figure 139 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 13

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 4

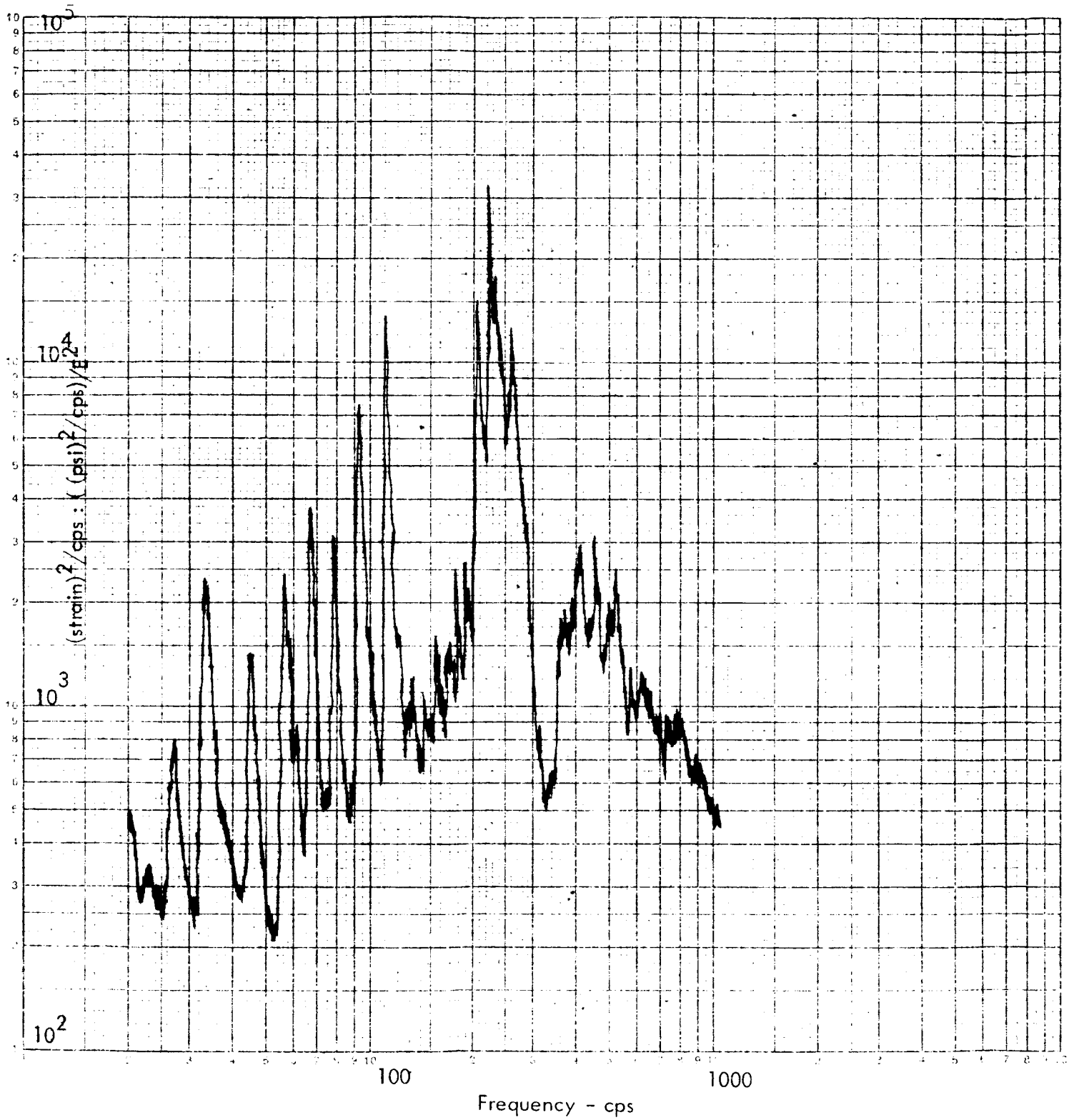


Figure 140 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 14

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 5

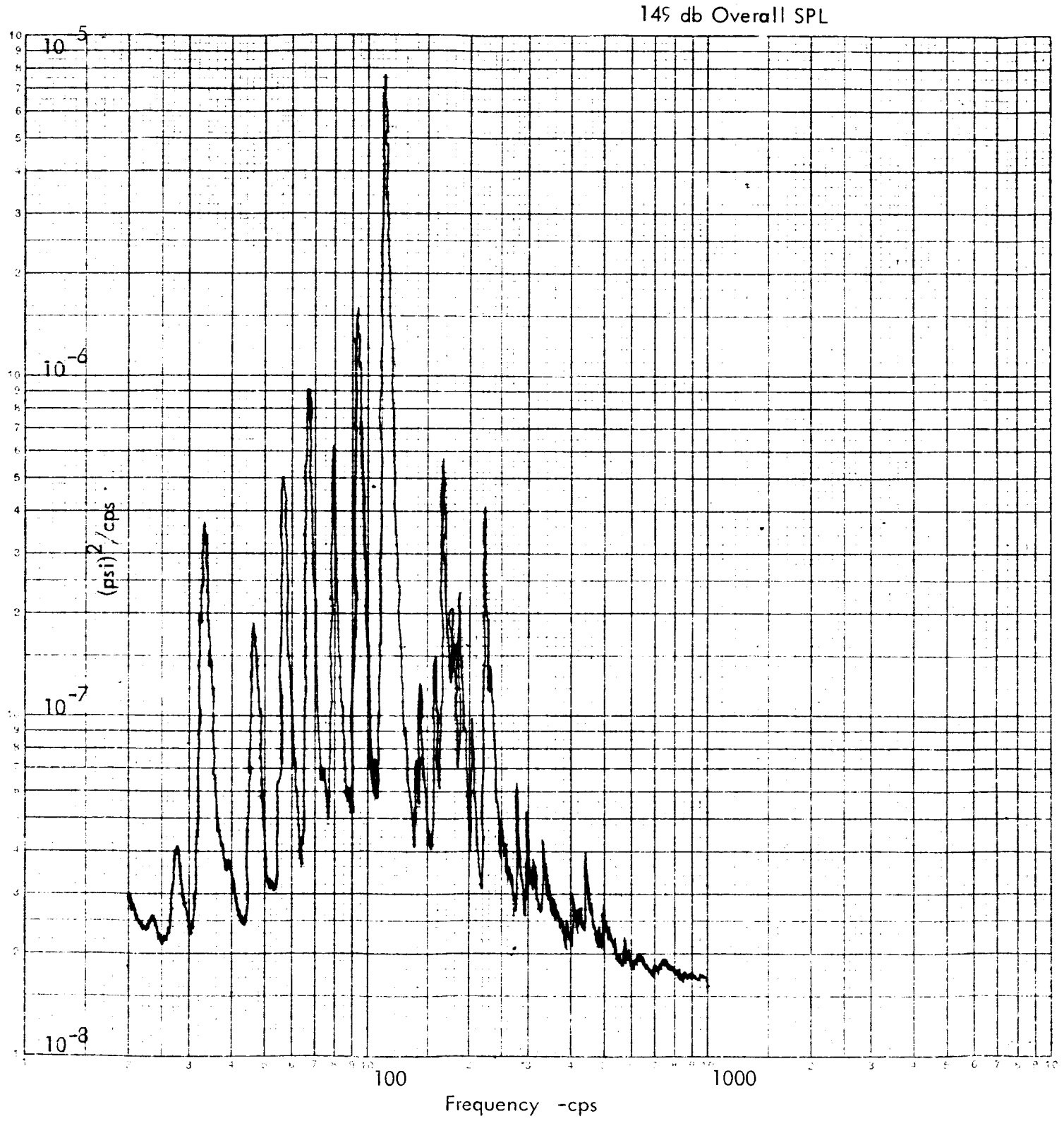


Figure 141 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 1

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 5

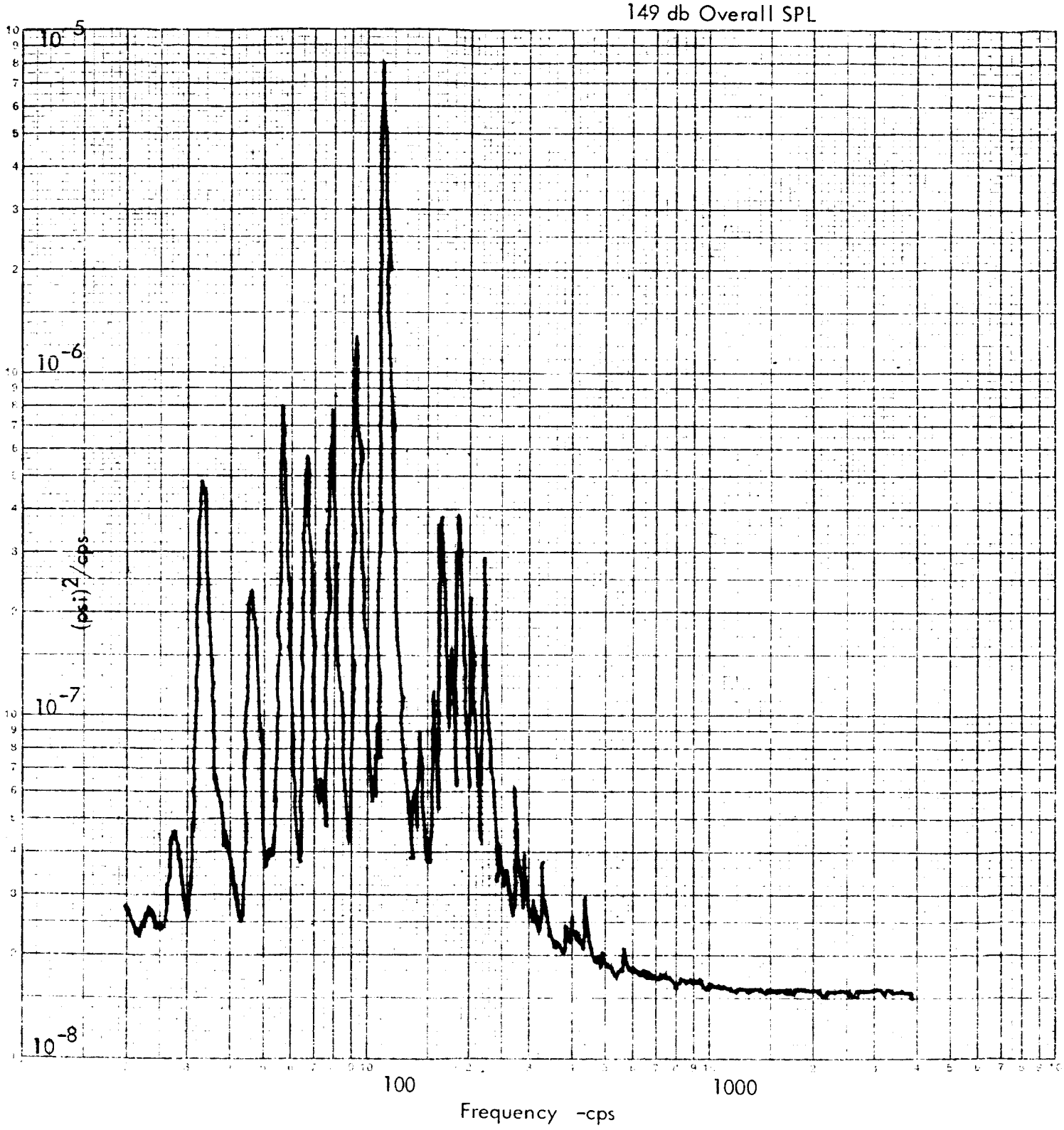


Figure 142 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 2

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 5

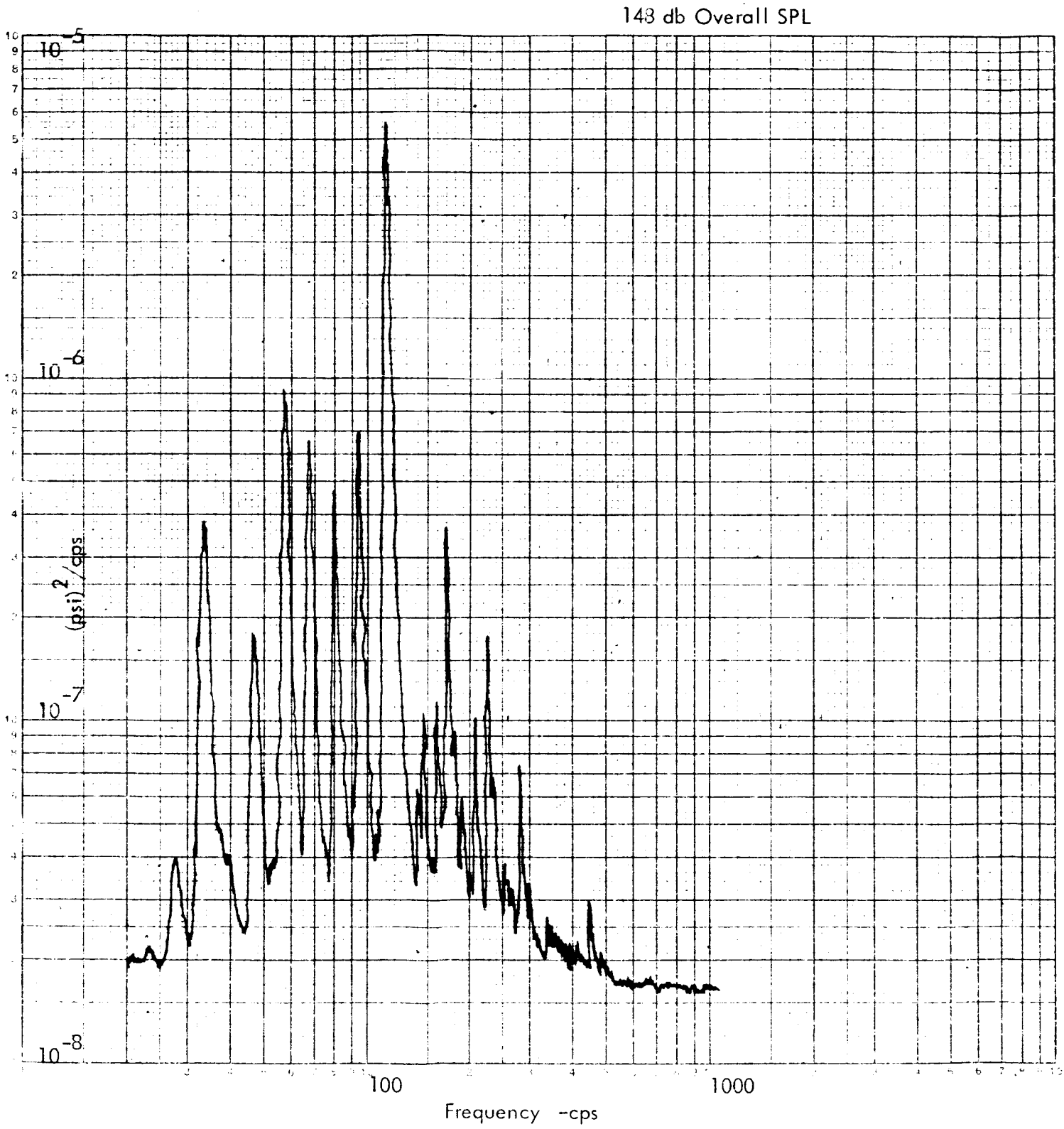


Figure 143 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 3

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 5

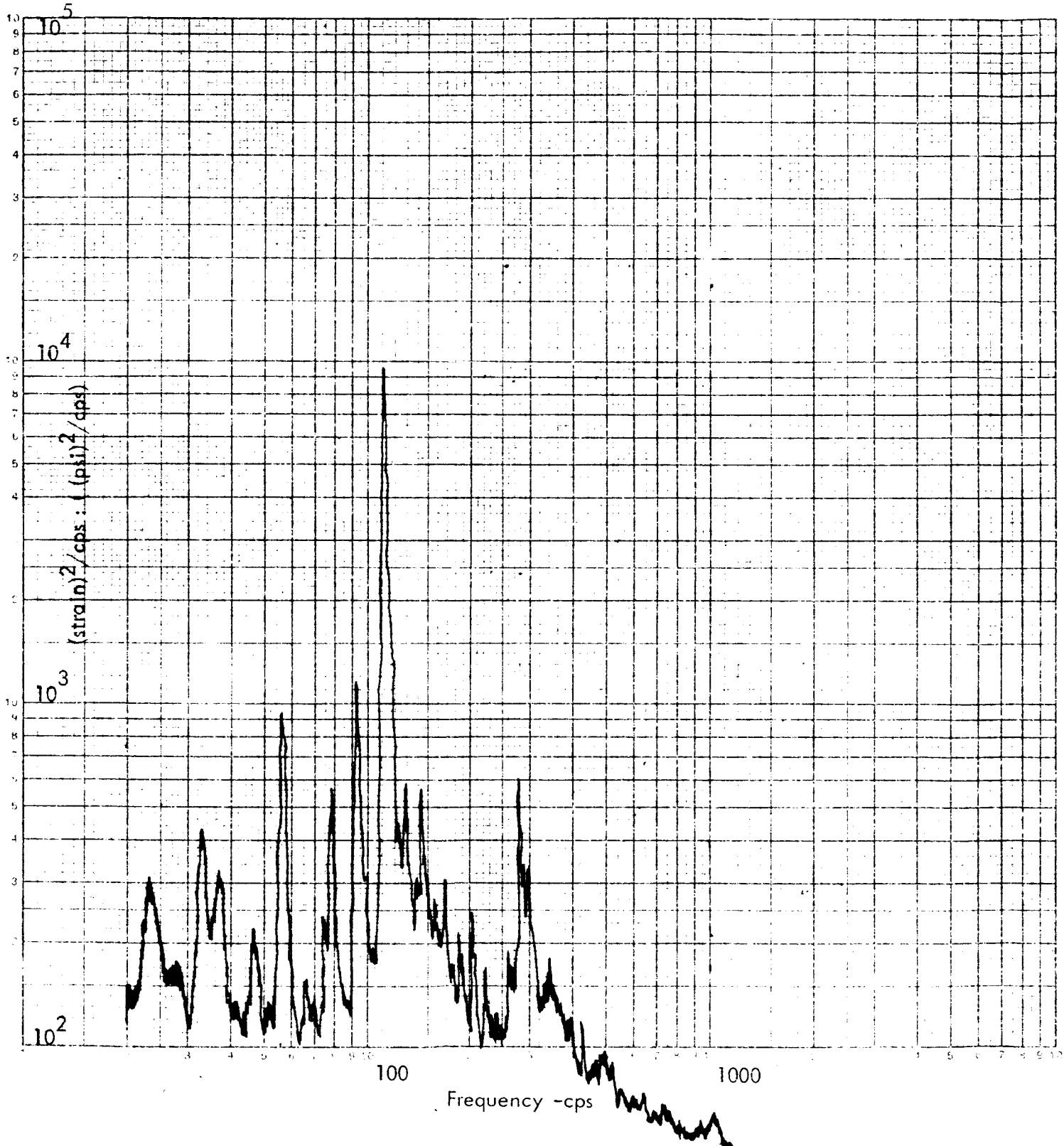


Figure 144 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 2

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 5
(No Good)

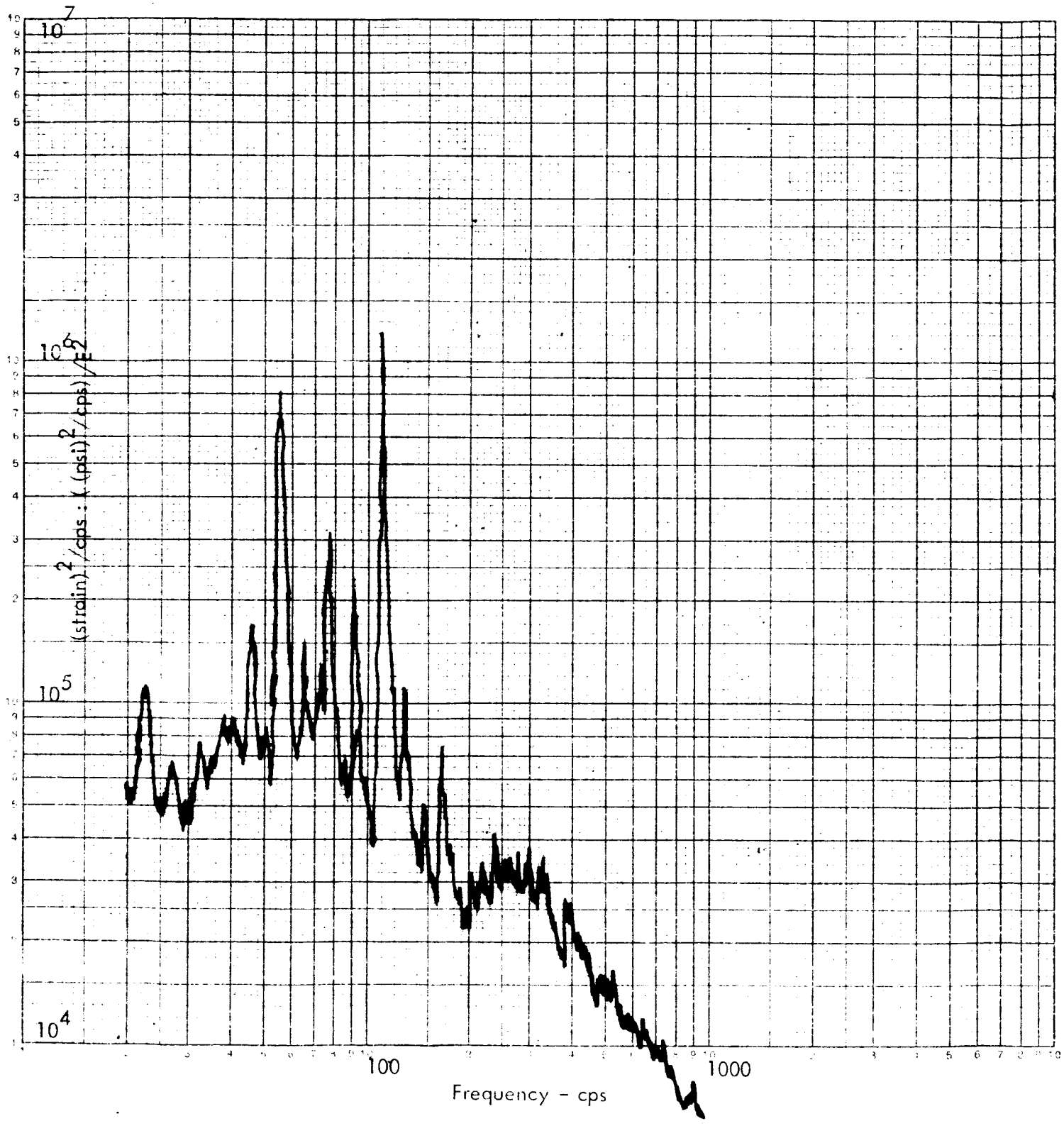


Figure 145 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 8

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 5

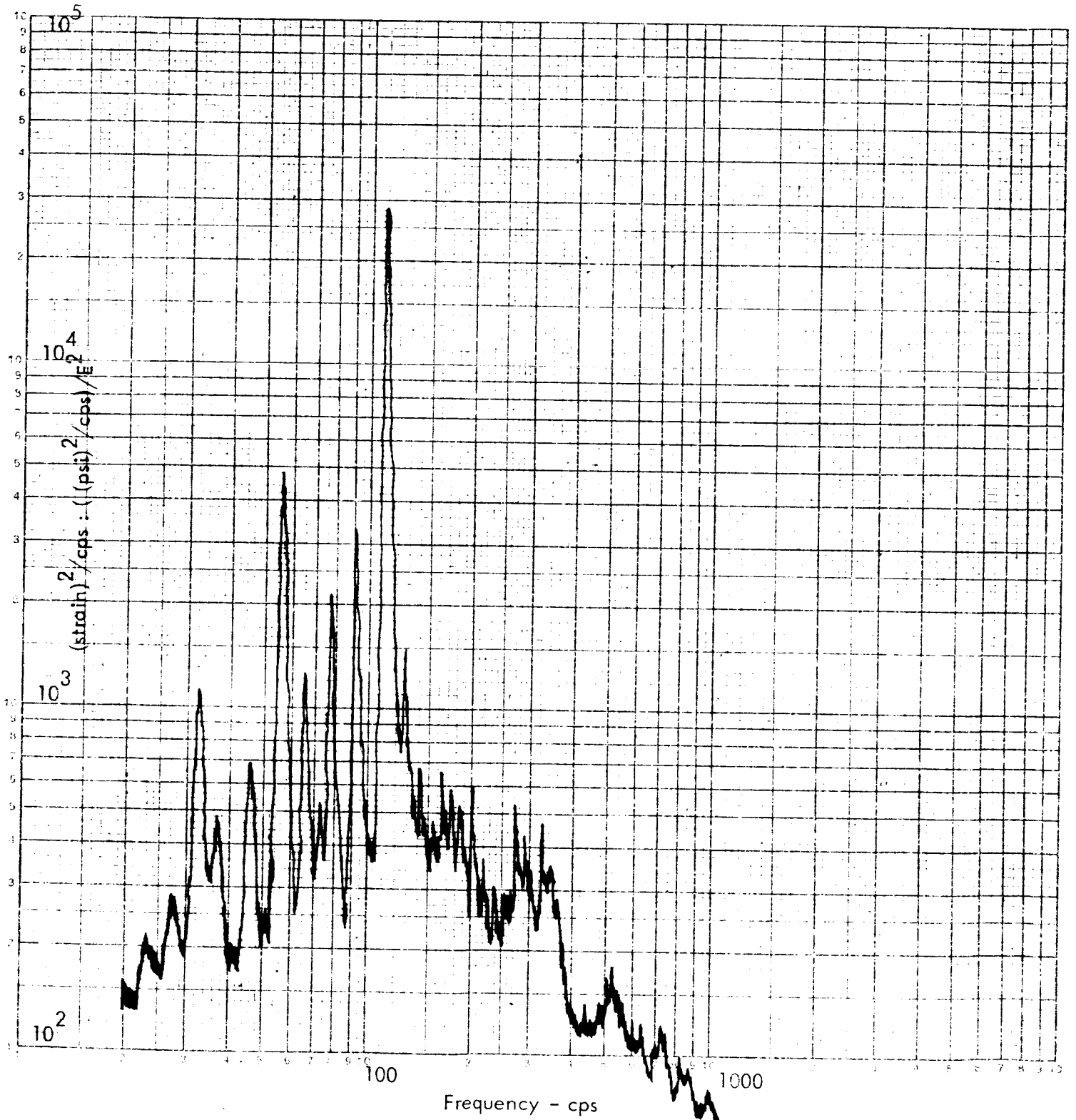


Figure 146 Shroud Panel No. 3 - Power Spectral Density- Strain Gauge No. 11

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 5

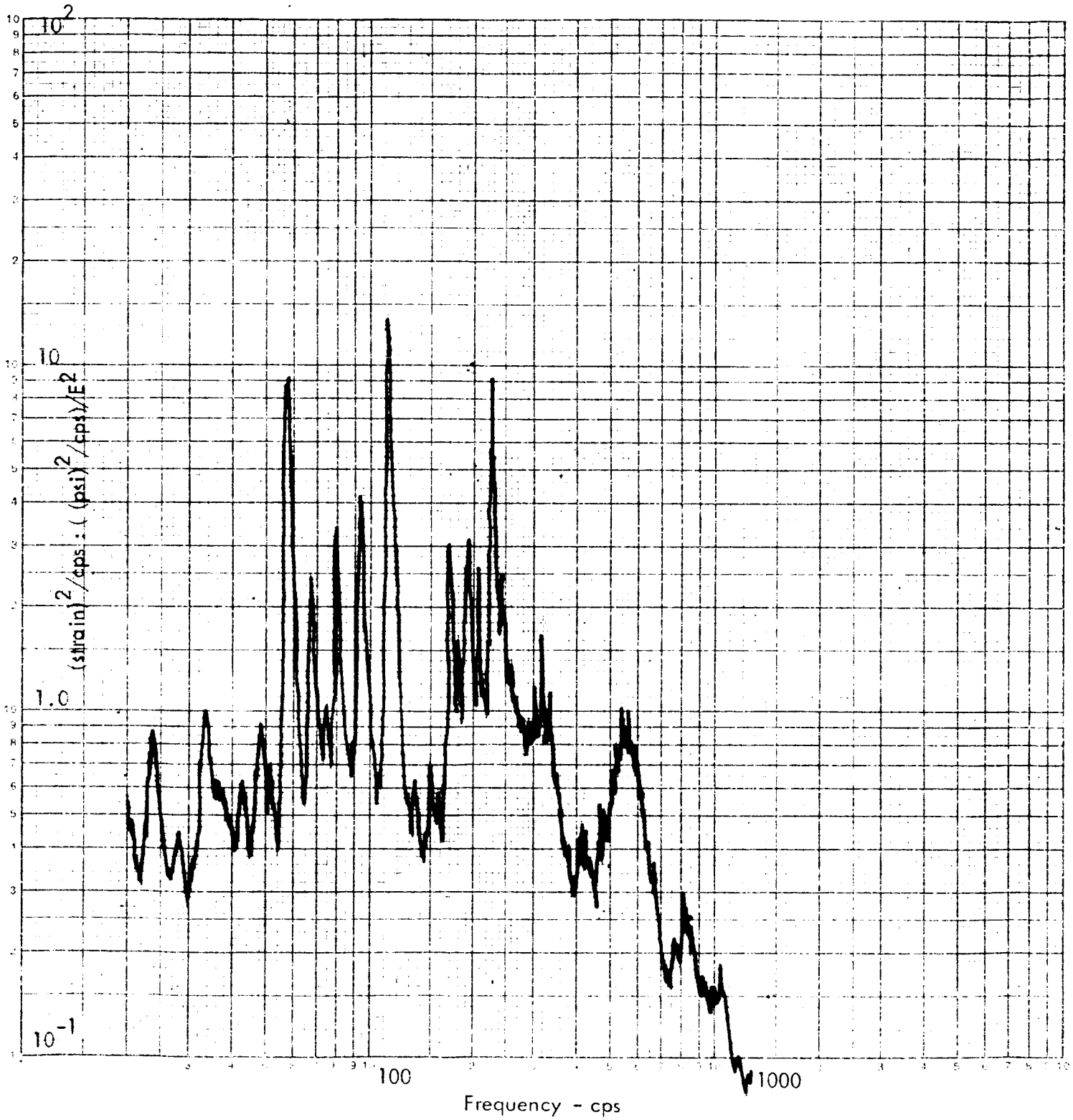


Figure 147 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 13

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 5

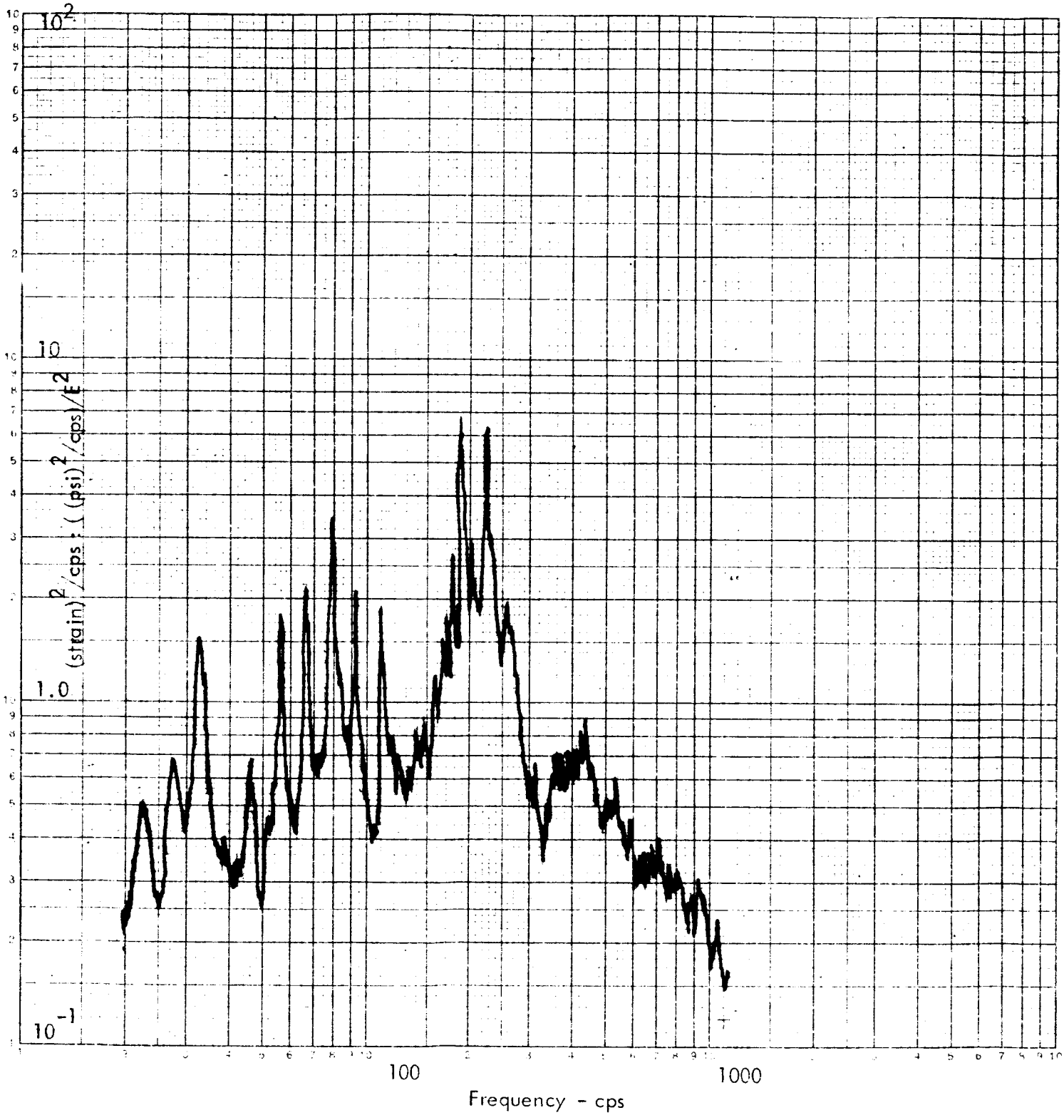


Figure 148 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 14

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 6

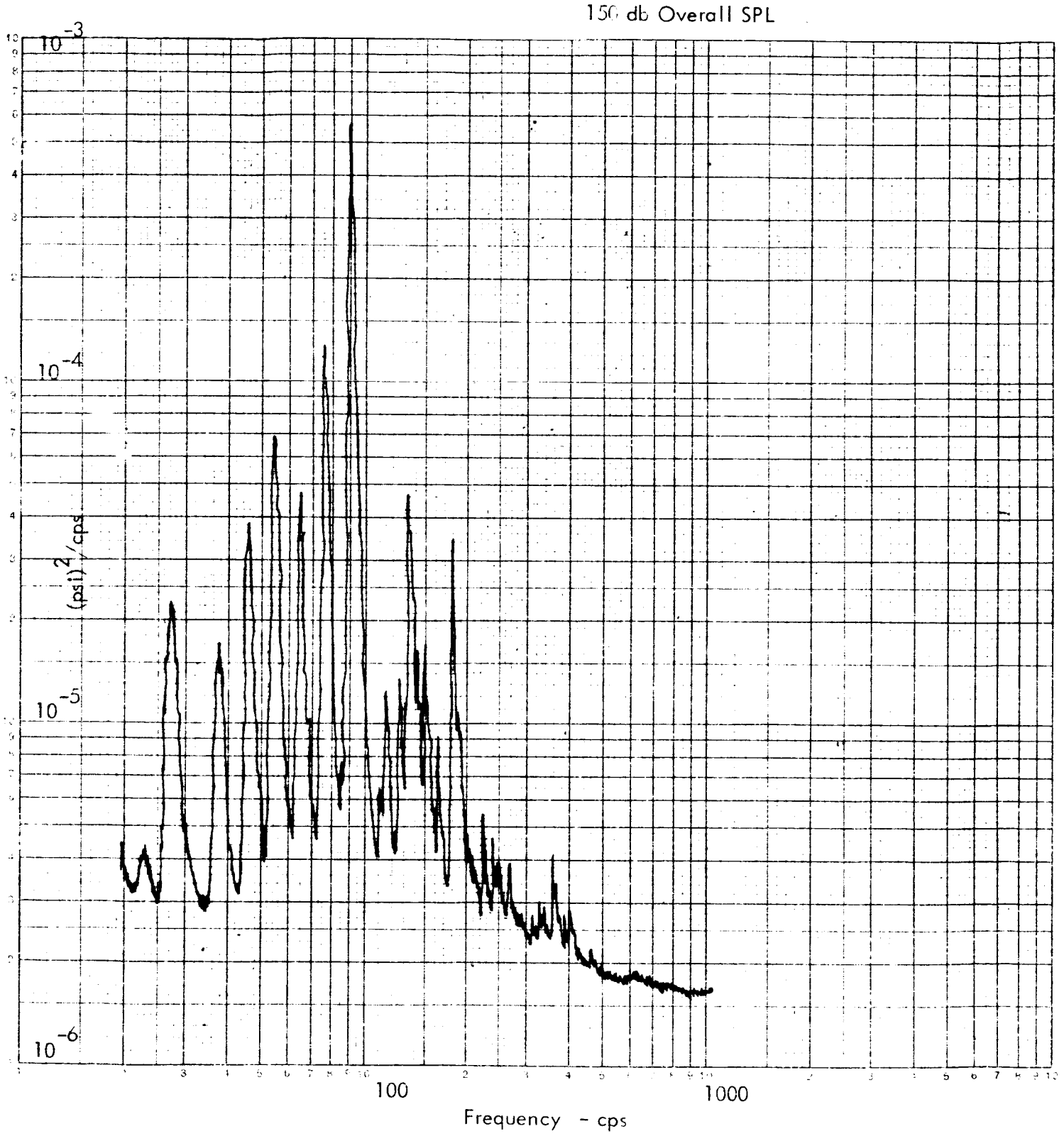


Figure 149 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 1

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 6

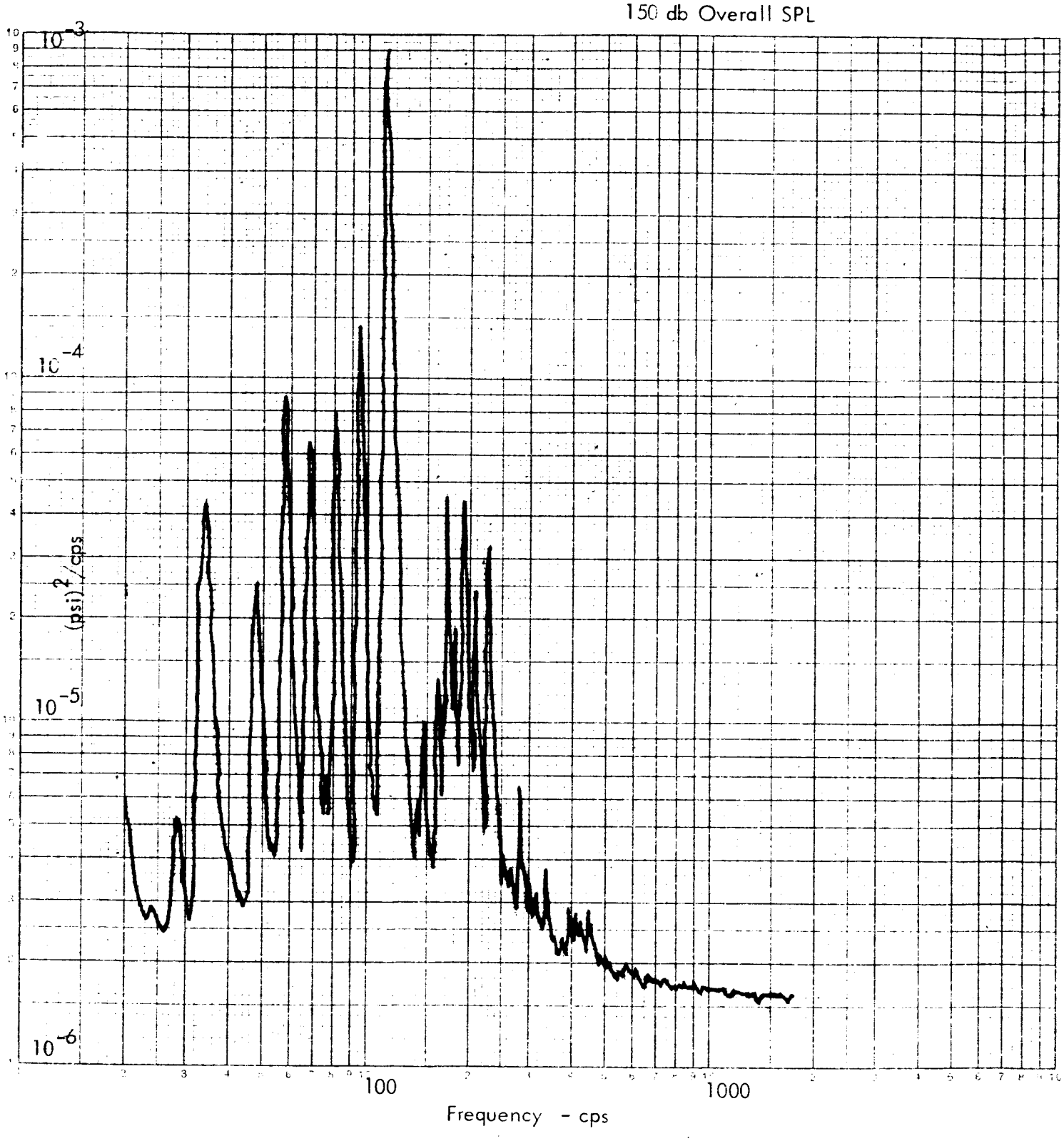


Figure 150 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 2

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 6

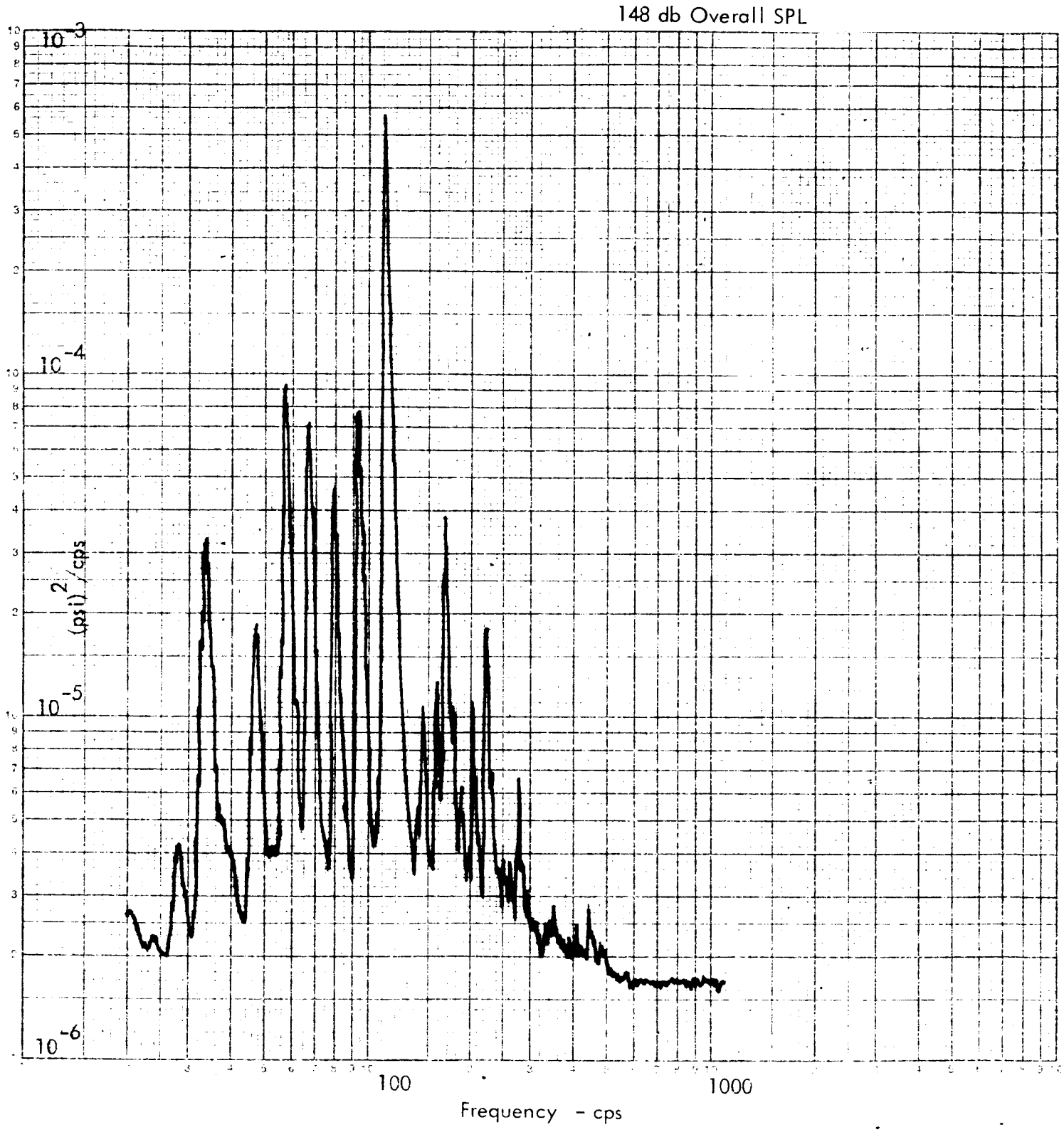


Figure 151 Shroud Panel No. 3 -Power Spectral Density- Microphone No. 3

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 6

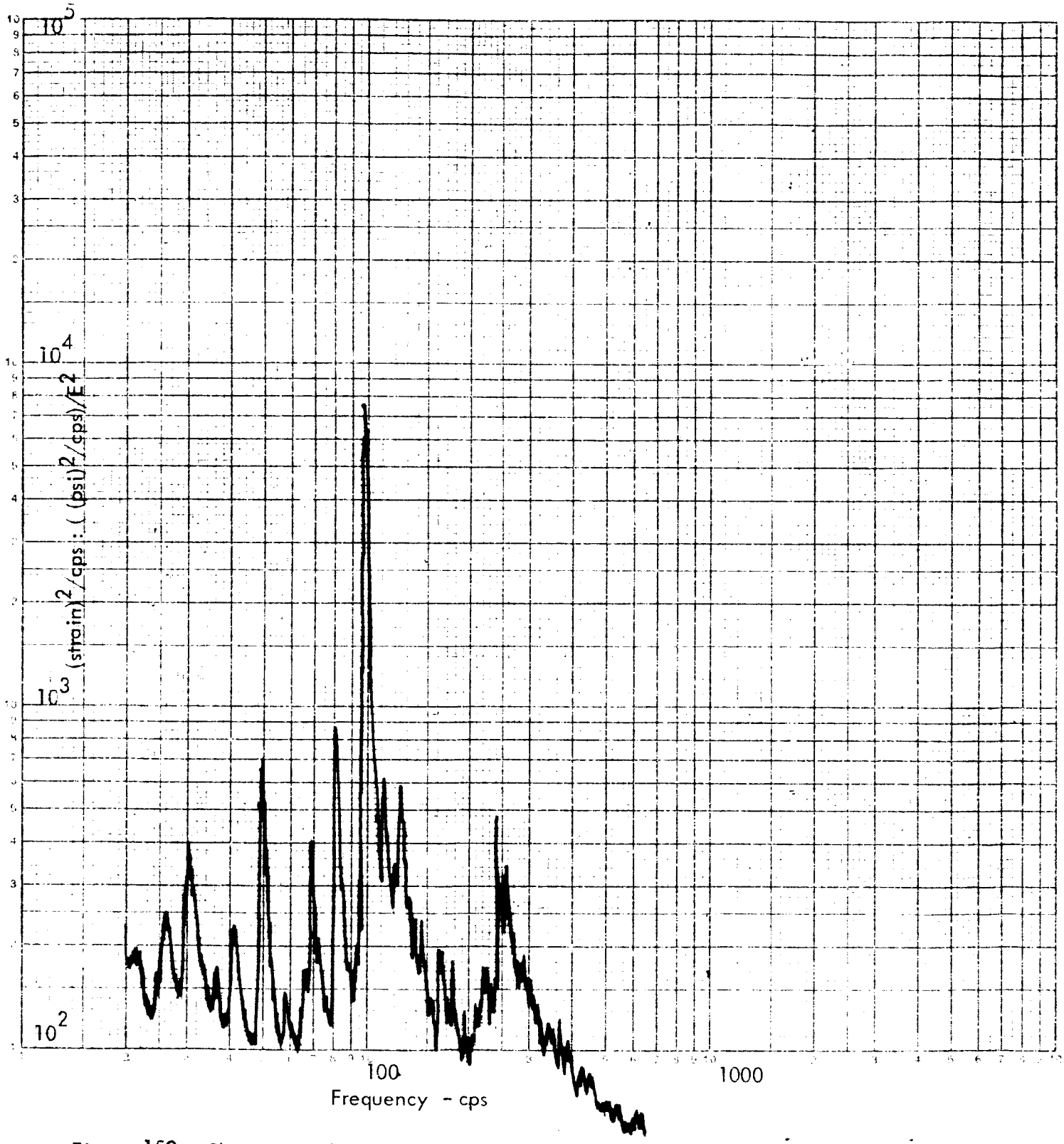


Figure 152 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 2

Date : 28 May 1963

Filter Bandwidth : 2 cps
Run No. 6

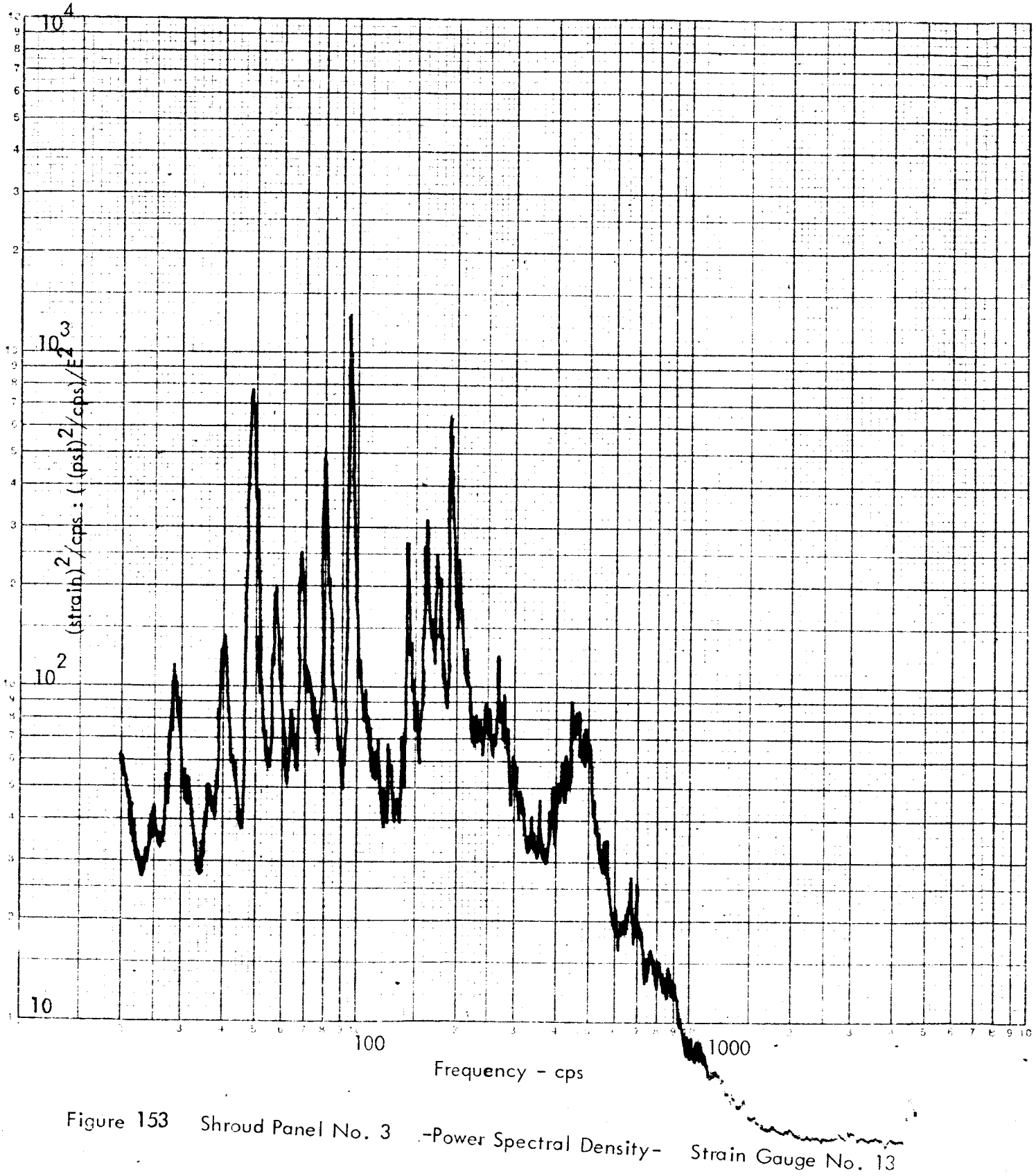


Figure 153 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 13

Date : 23 May 1963

Filter Bandwidth : 2 cps
Run No. 6

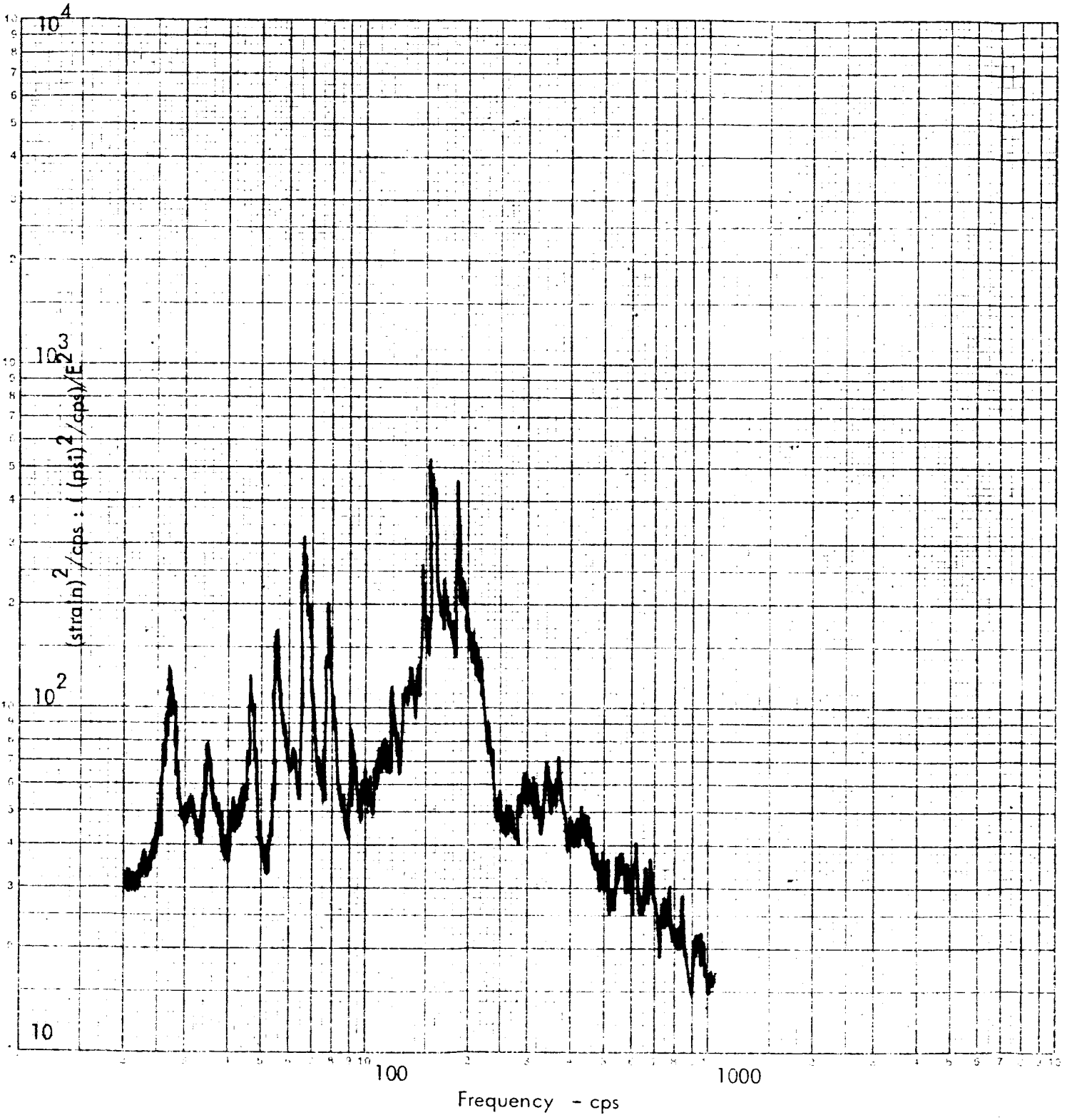


Figure 154 Shroud Panel No. 3 -Power Spectral Density- Strain Gauge No. 14

MI-LOGARITHMIC 3 CYCLES X 10 DIVISIONS

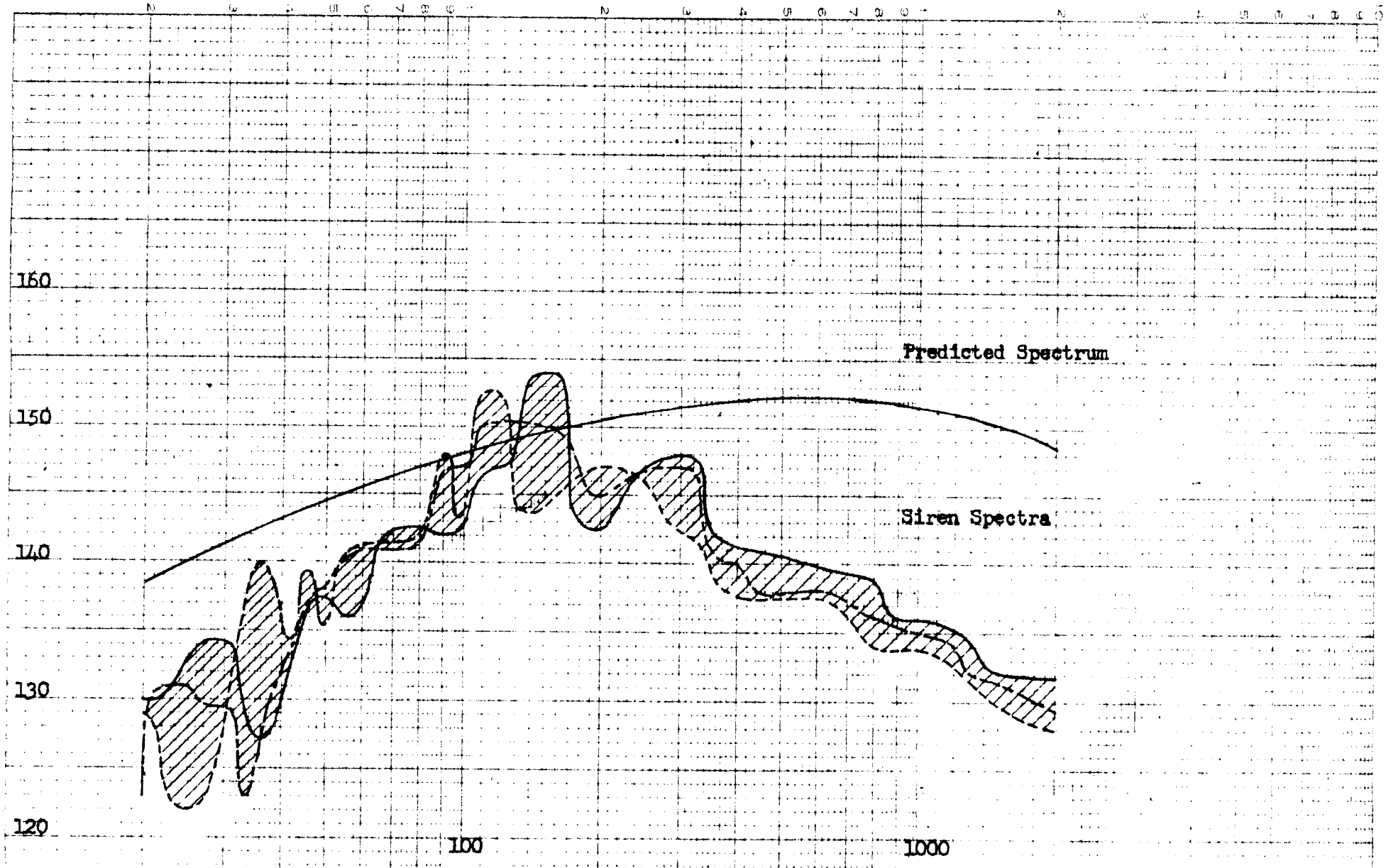


Figure 155A Comparison of Siren and Predicted Spectra
-One Third Octave Band Levels Panel No. 1

KEUFFEL & ESSER CO.

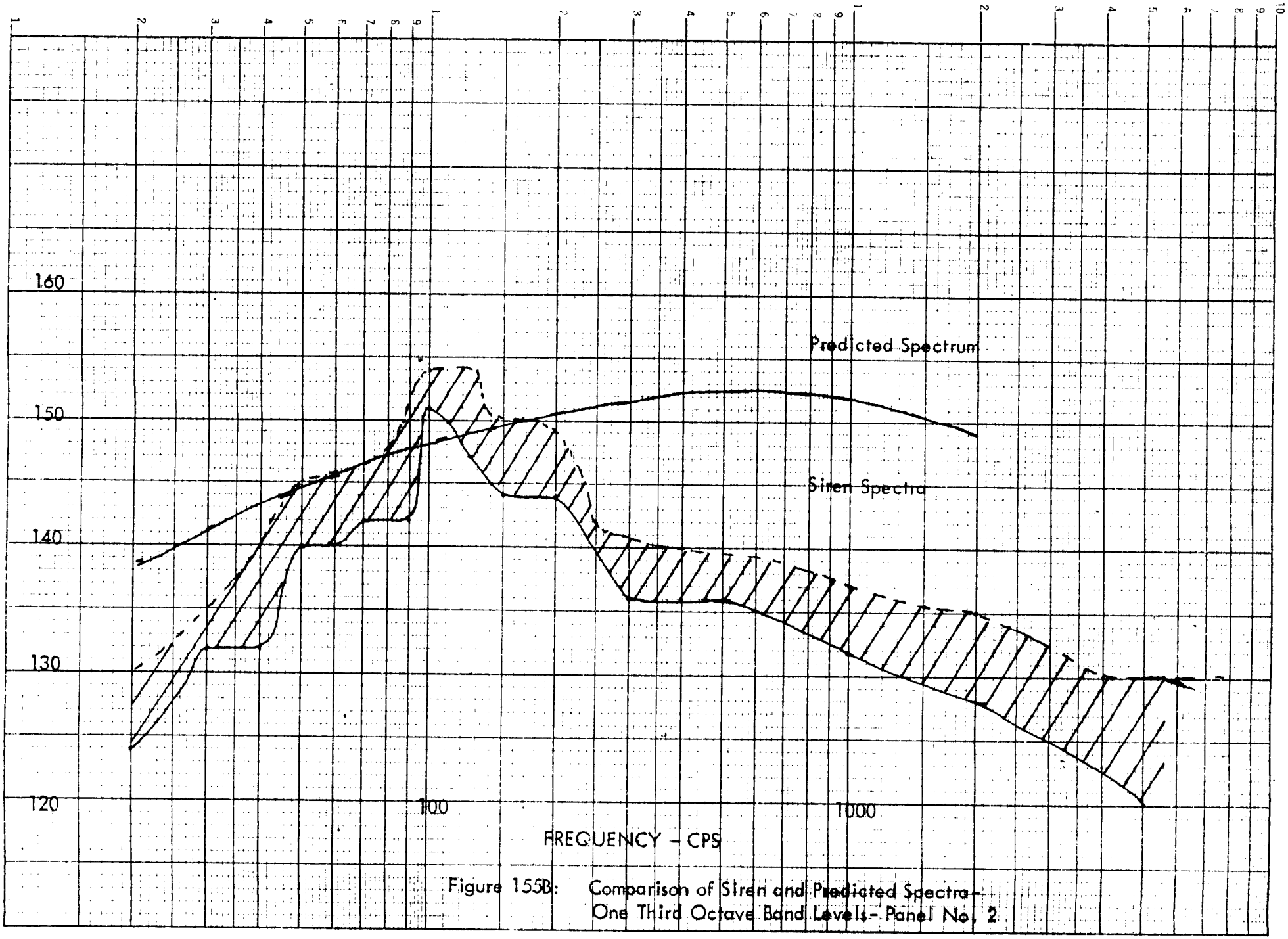


Figure 155B: Comparison of Siren and Predicted Spectra-
One Third Octave Band Levels- Panel No. 2

K&E [redacted] I-LO [redacted] HMIC [redacted] 359 [redacted]
KEUFFEL & ESSER CO.
4 CYCLES X 10 CYCLES

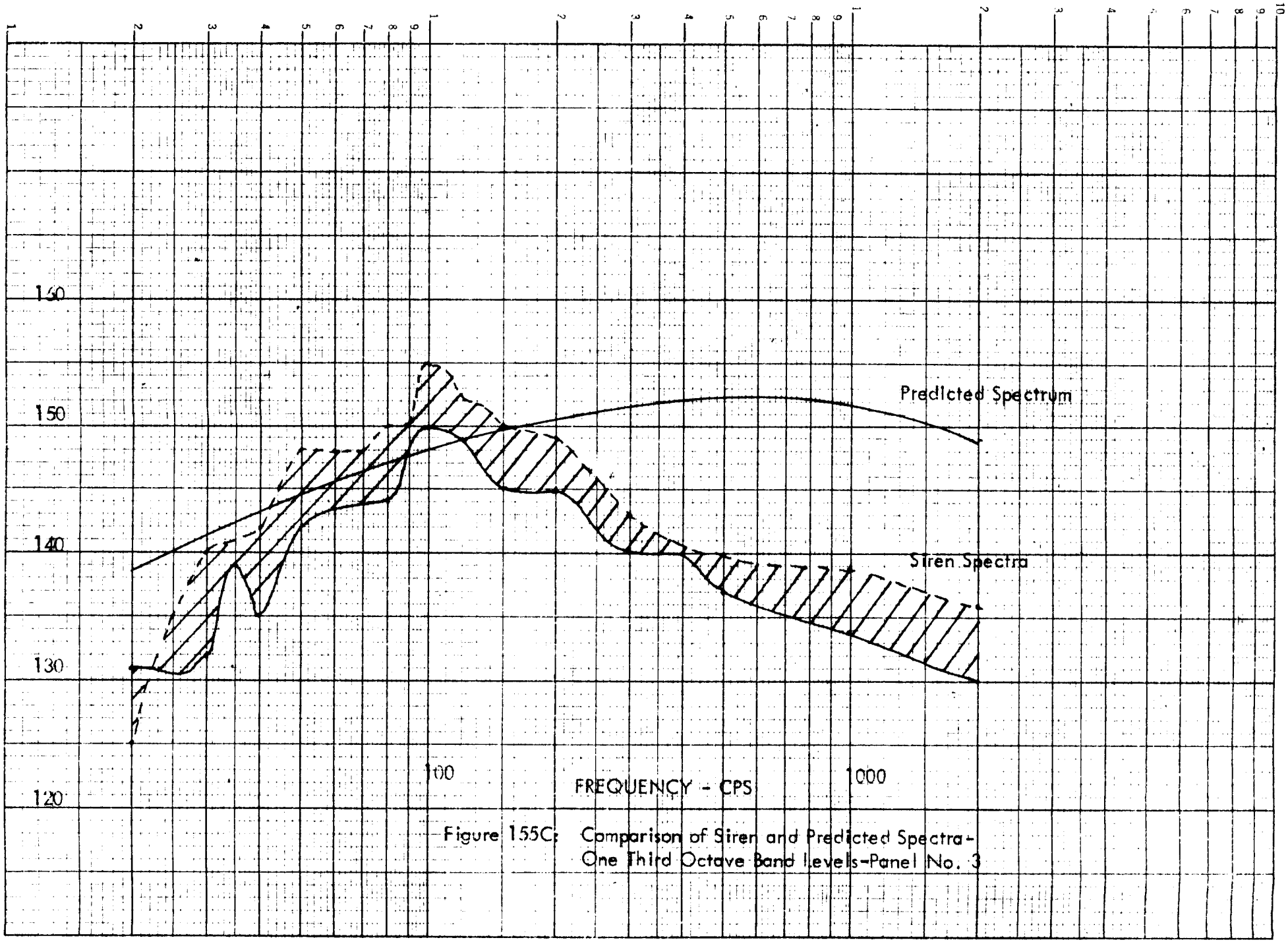


Figure 155C: Comparison of Siren and Predicted Spectra - One Third Octave Band Levels - Panel No. 3

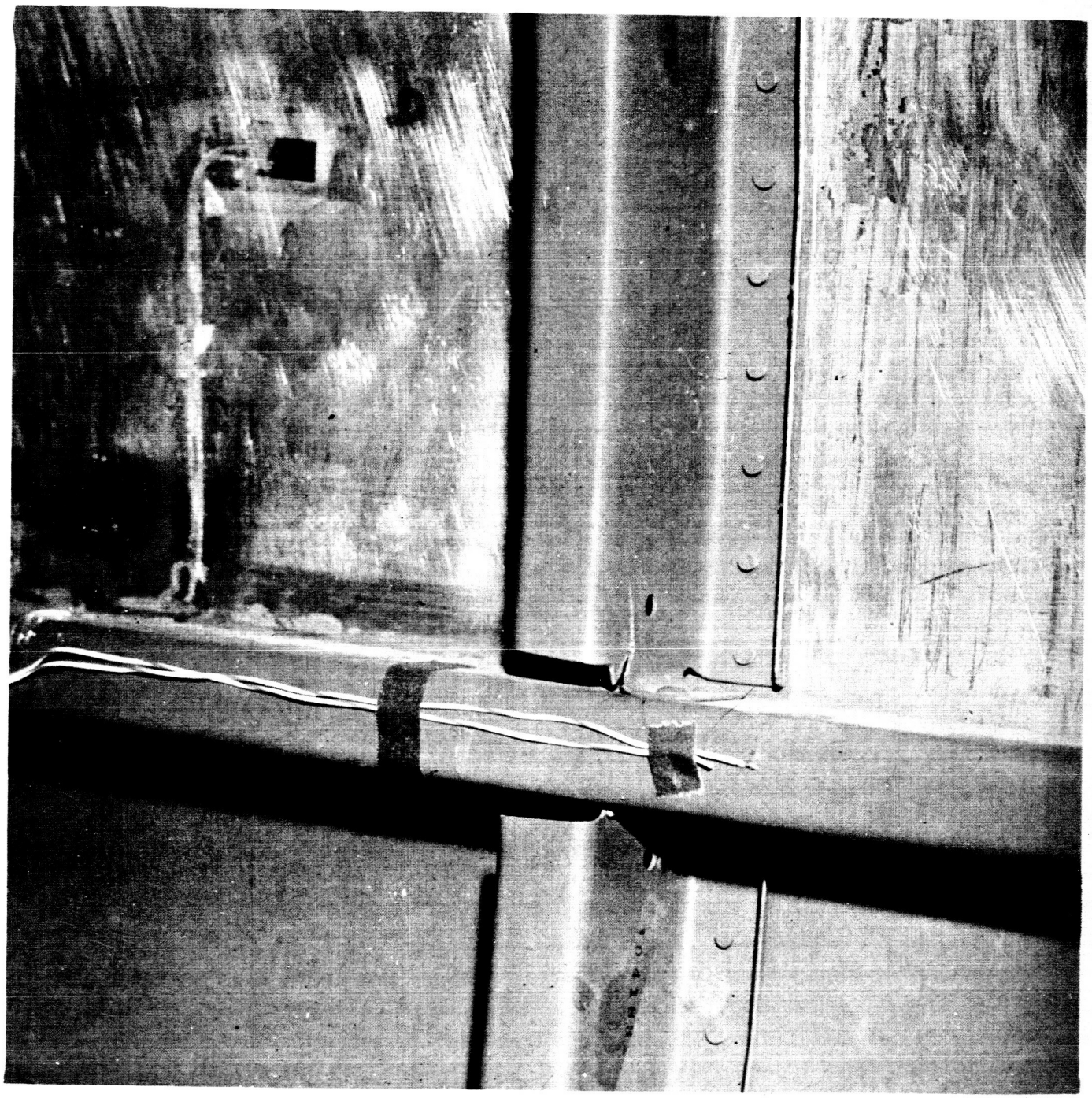


Figure 156: Example of Intercoastal Fatigue Crack-Panel Number 1

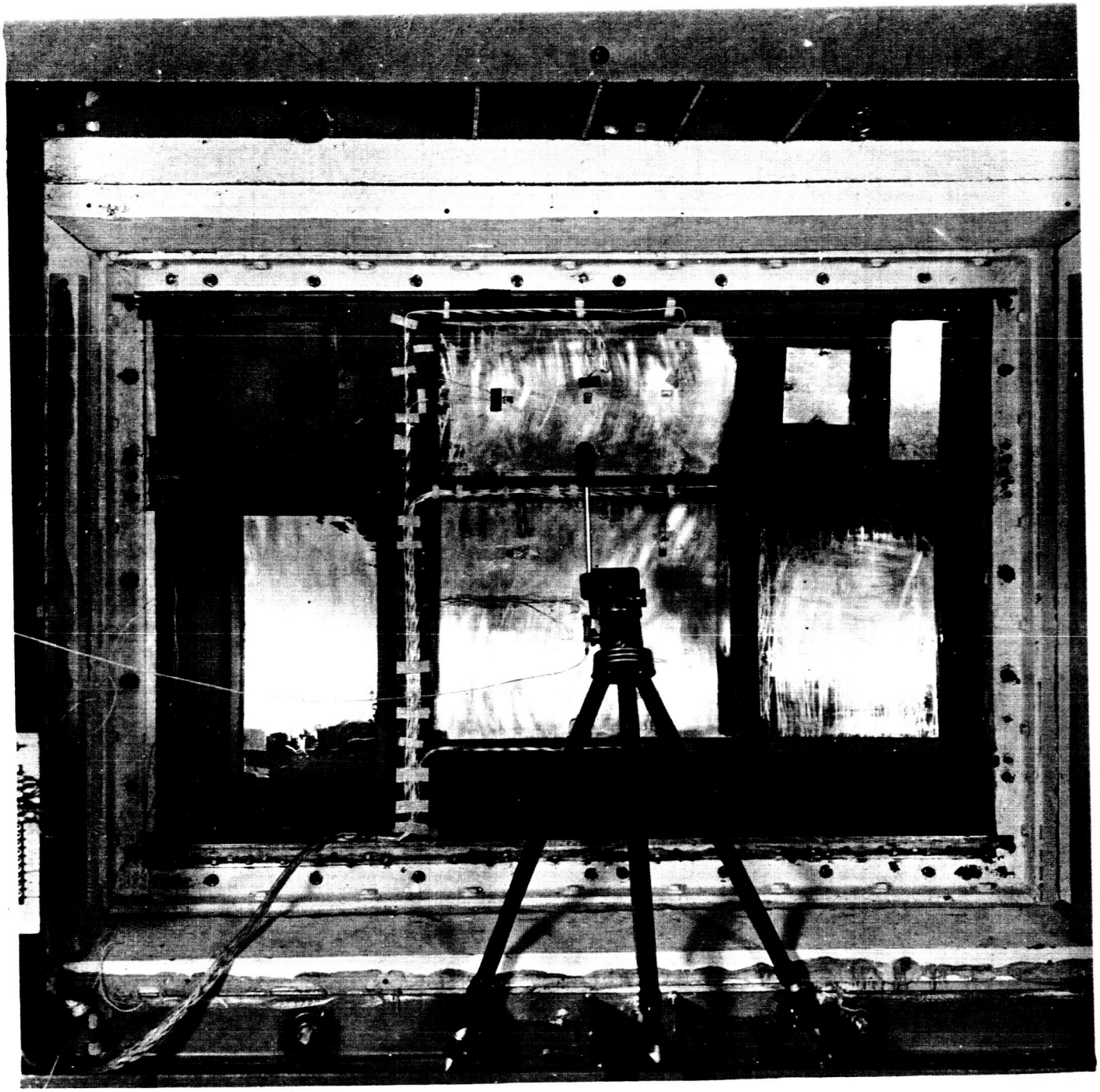


Figure 157: Rear View of Panel Number 1 After Failure.

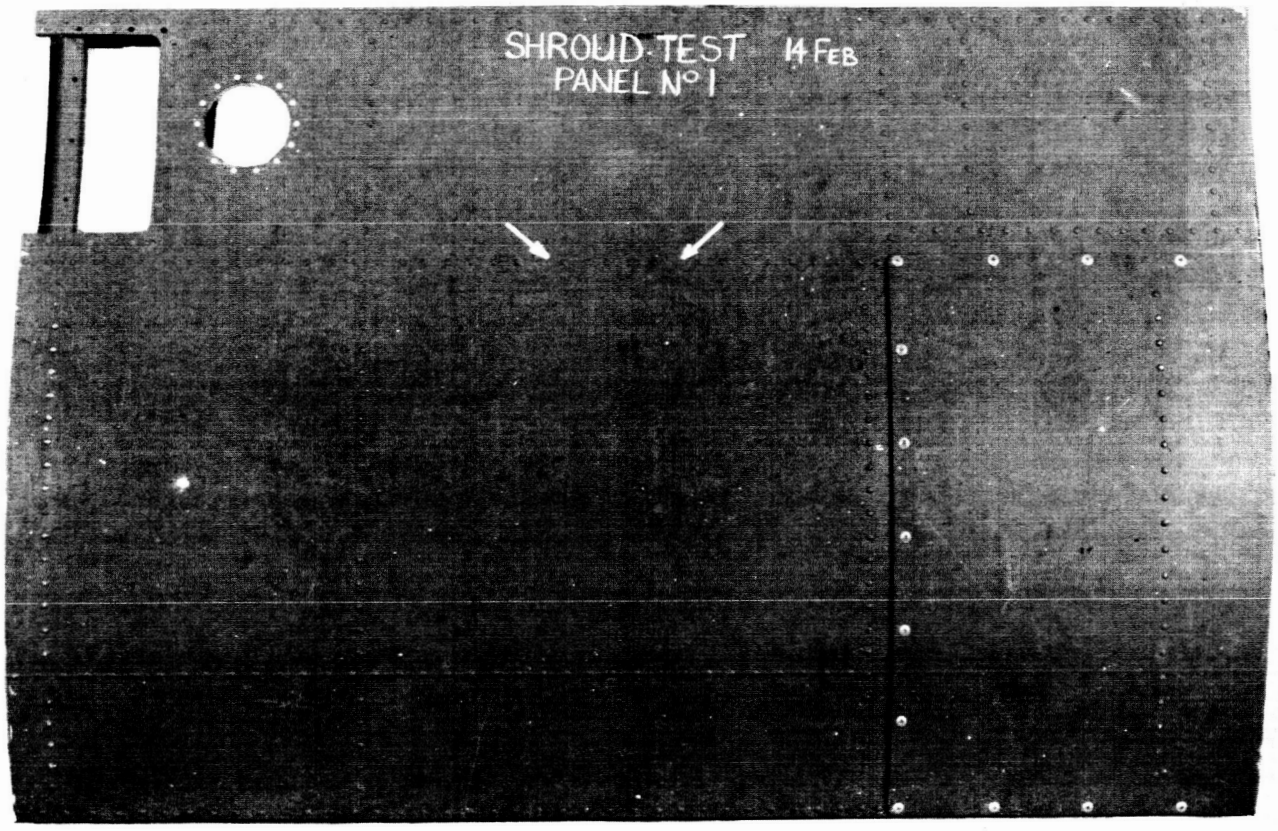


Figure 158: Front View of Panel Number 1 Showing Fatigue Crack.

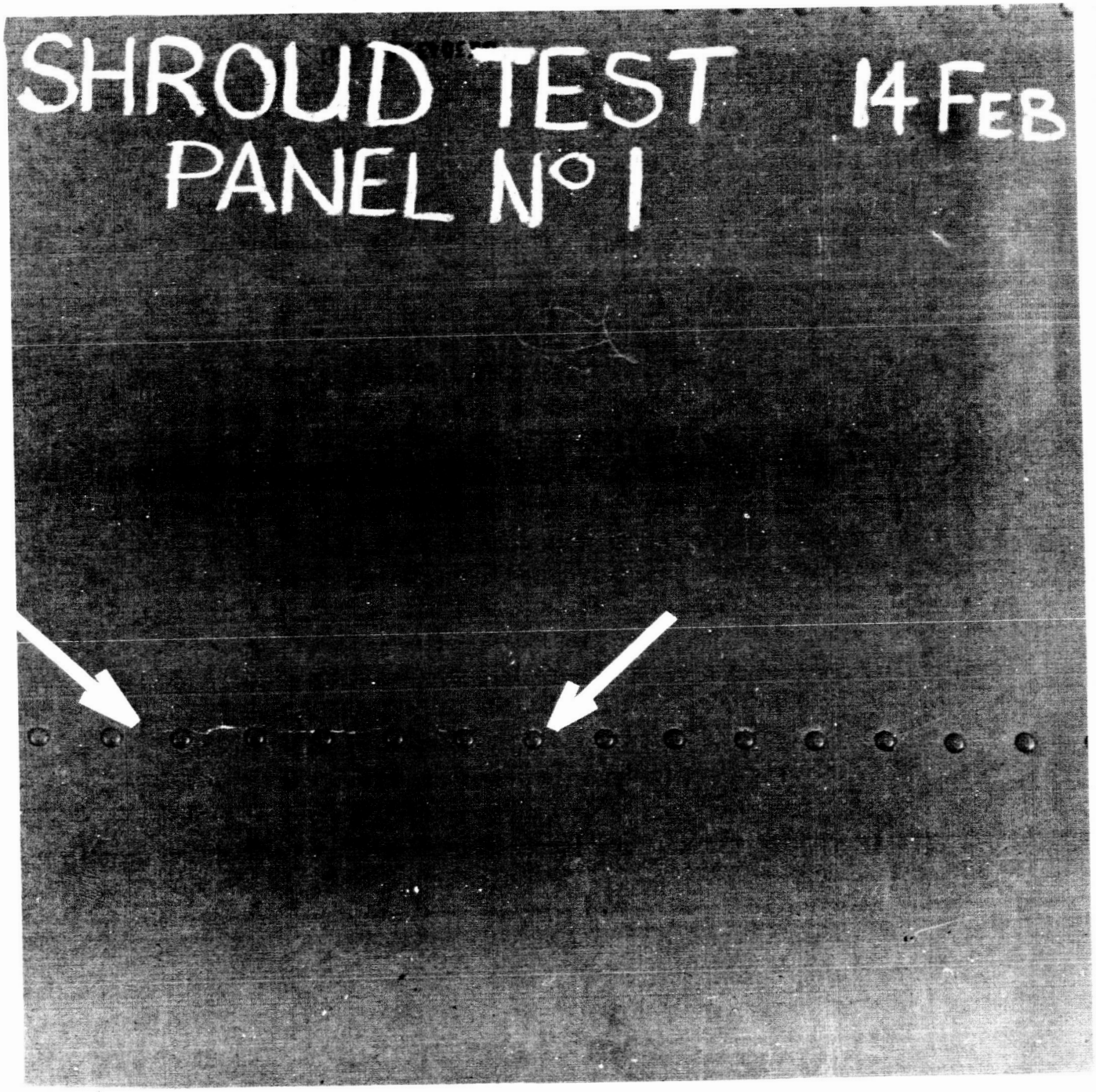


Figure 159: Close-Up of Fatigue Crack-Panel Number 1.

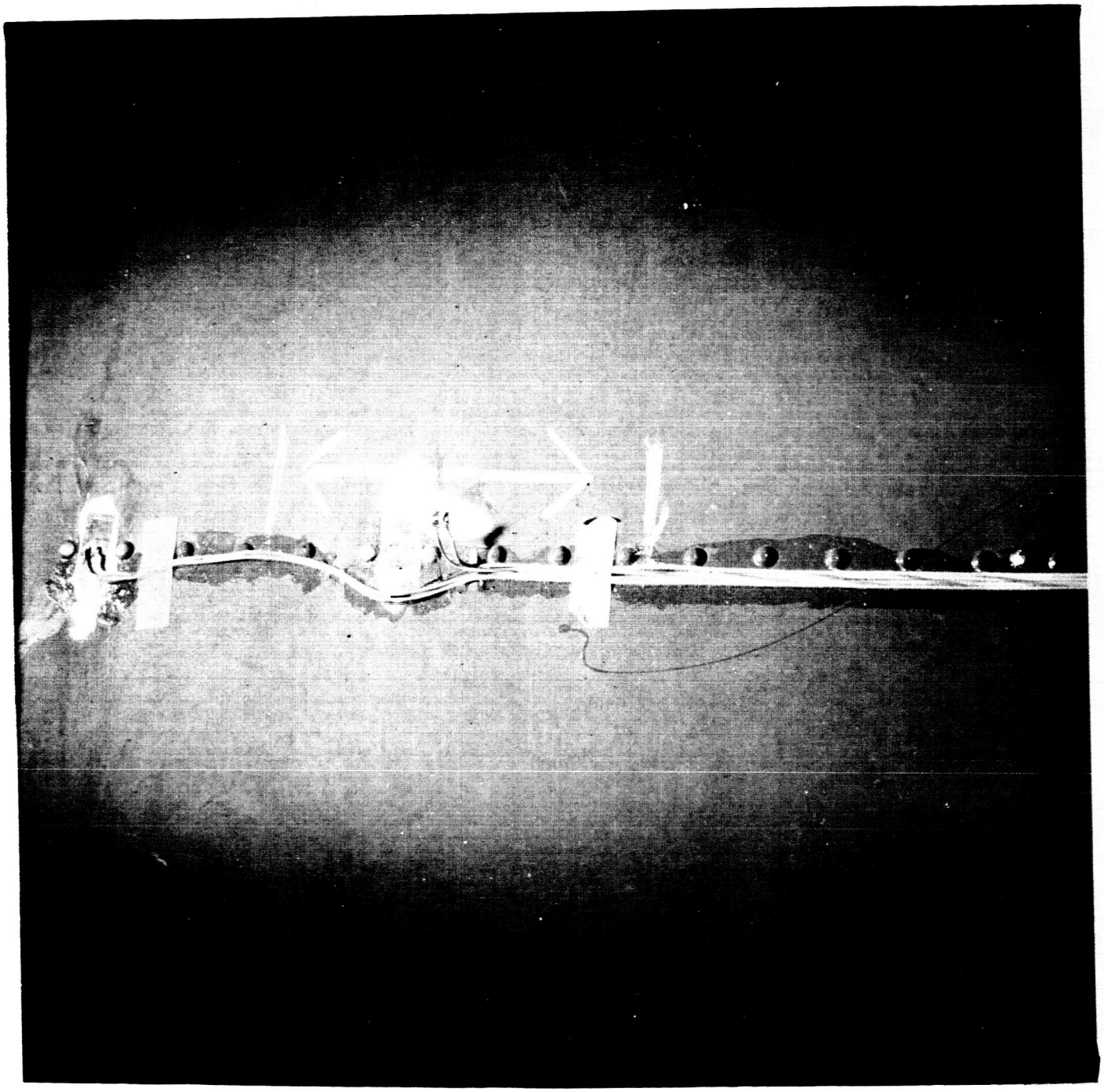


Figure 160: First Indication of Fatigue Crack-Panel Number 2.

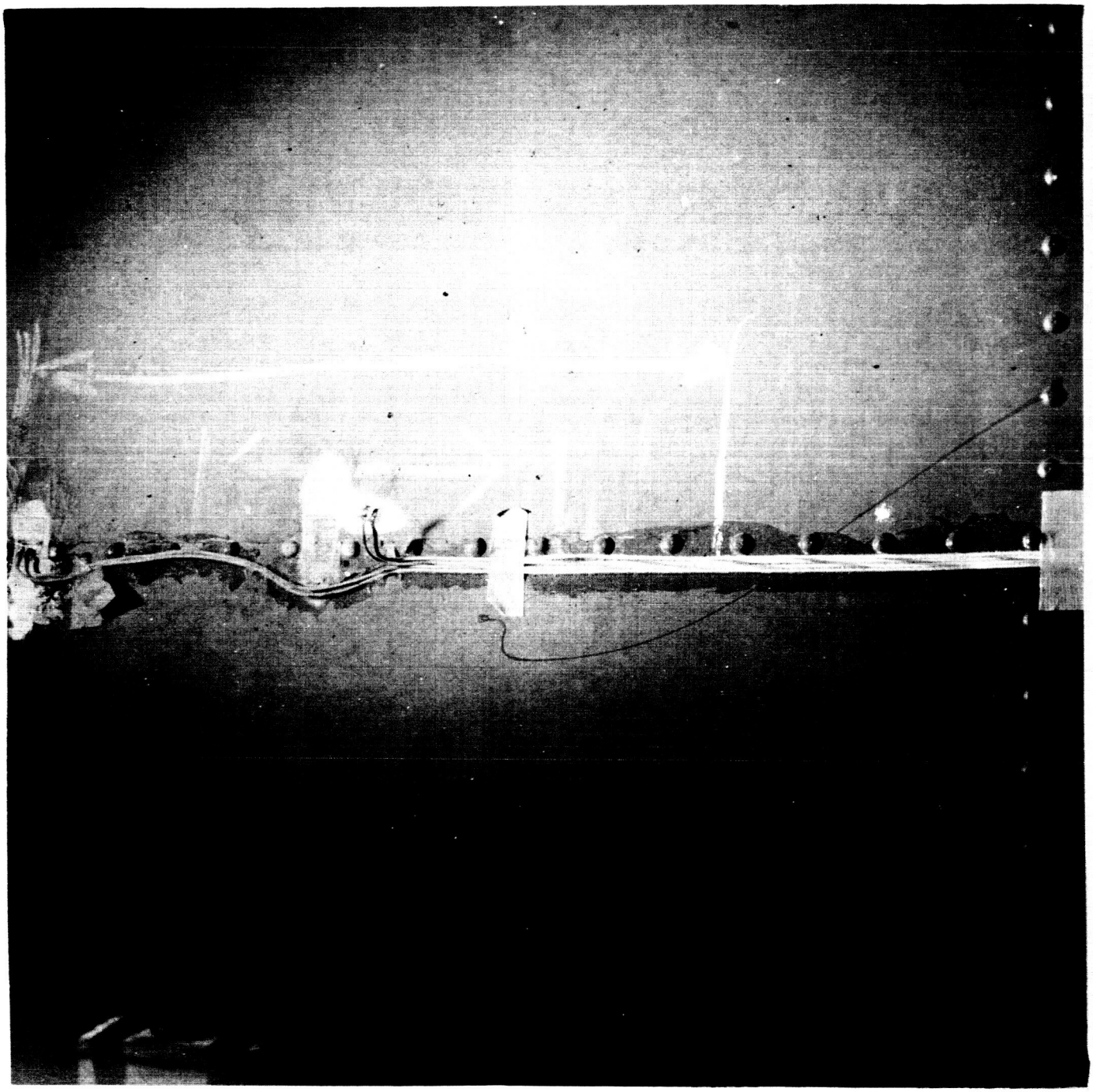


Figure 101: Growth of Fatigue Crack-Panel Number 2.

Figure 162: Panel Number 2 After Failure-Rear View.

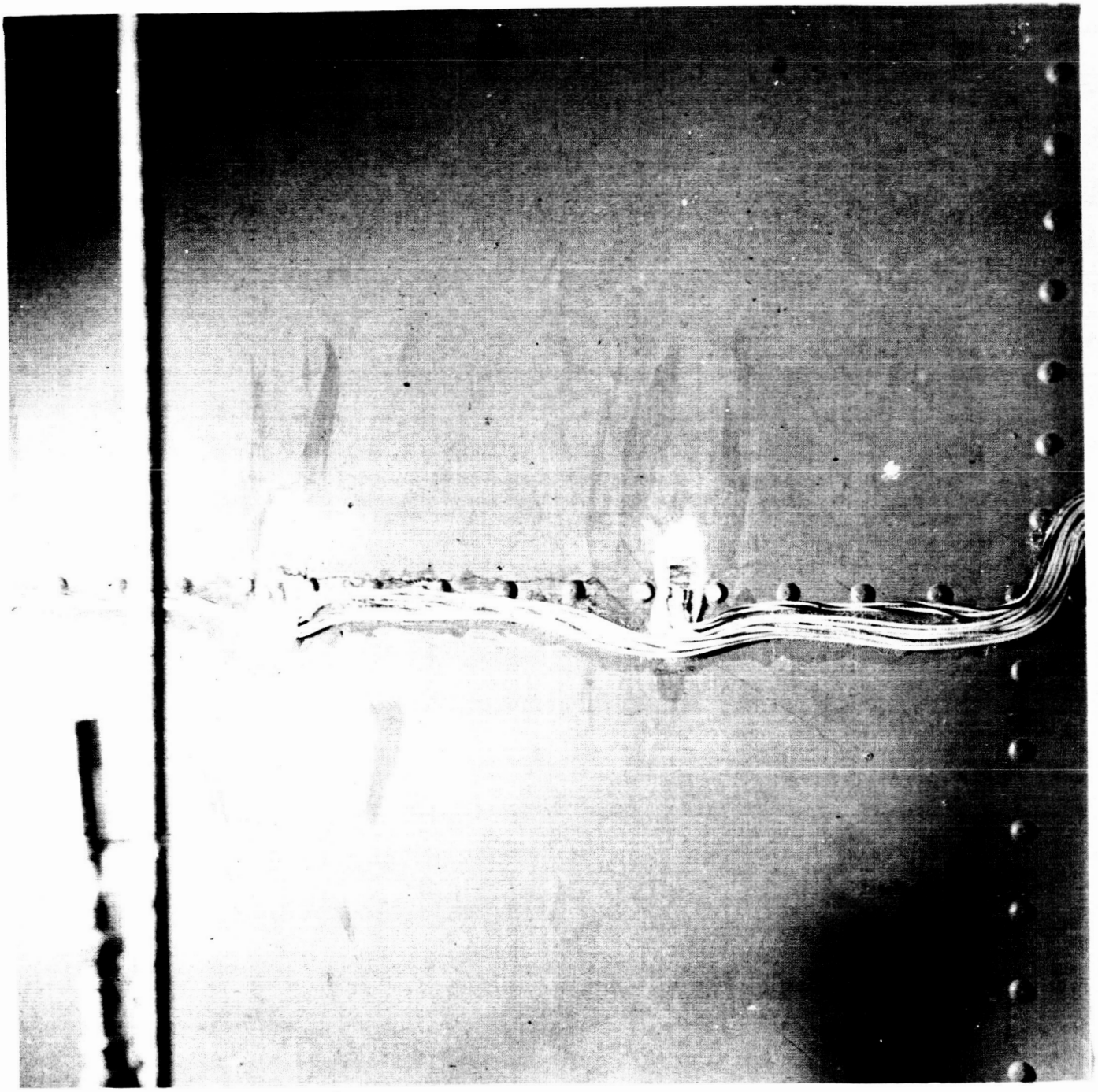


Figure 163: Fatigue Crack-Panel Number 3.

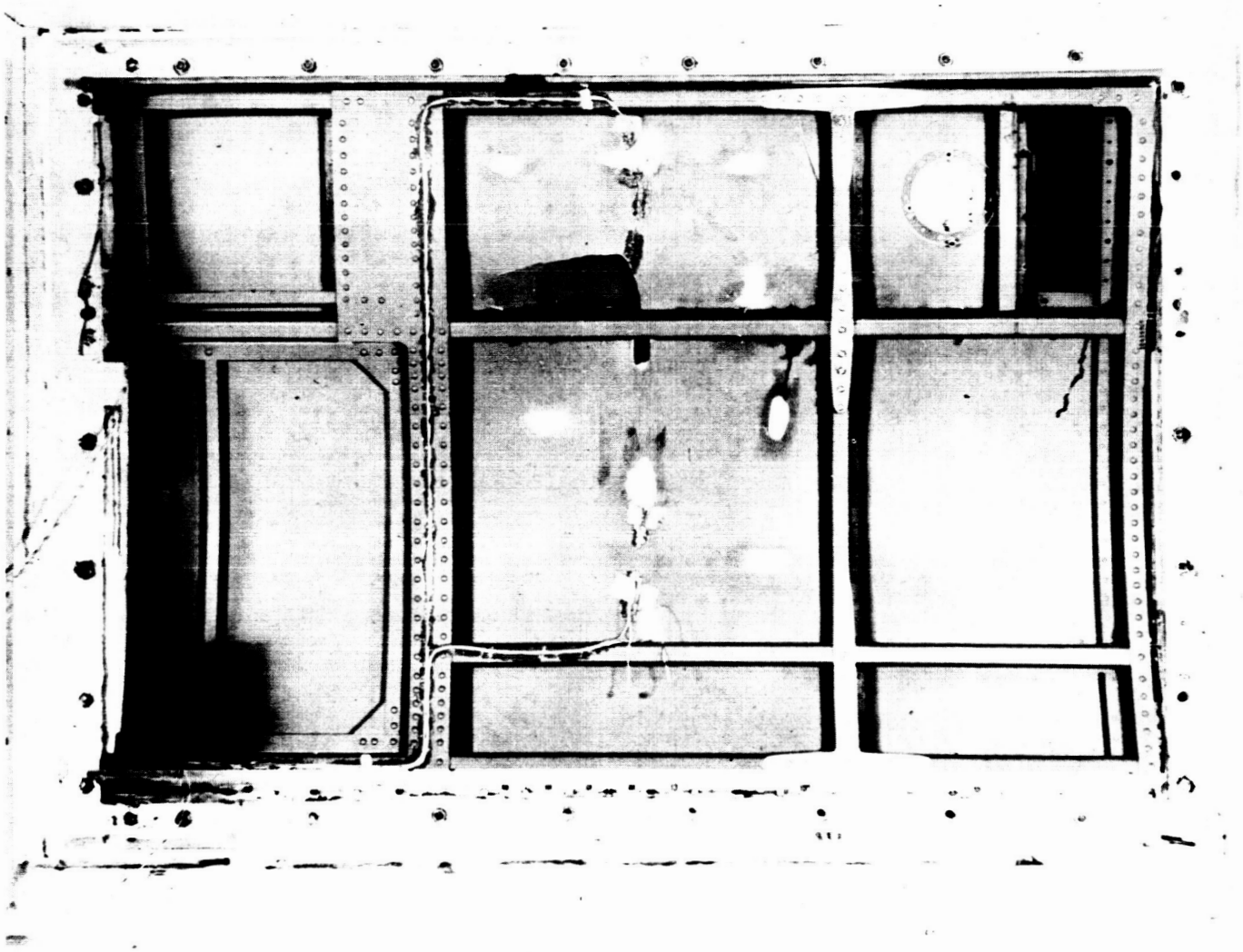


Figure 164: Panel Number 3 After Failure- Rear View.

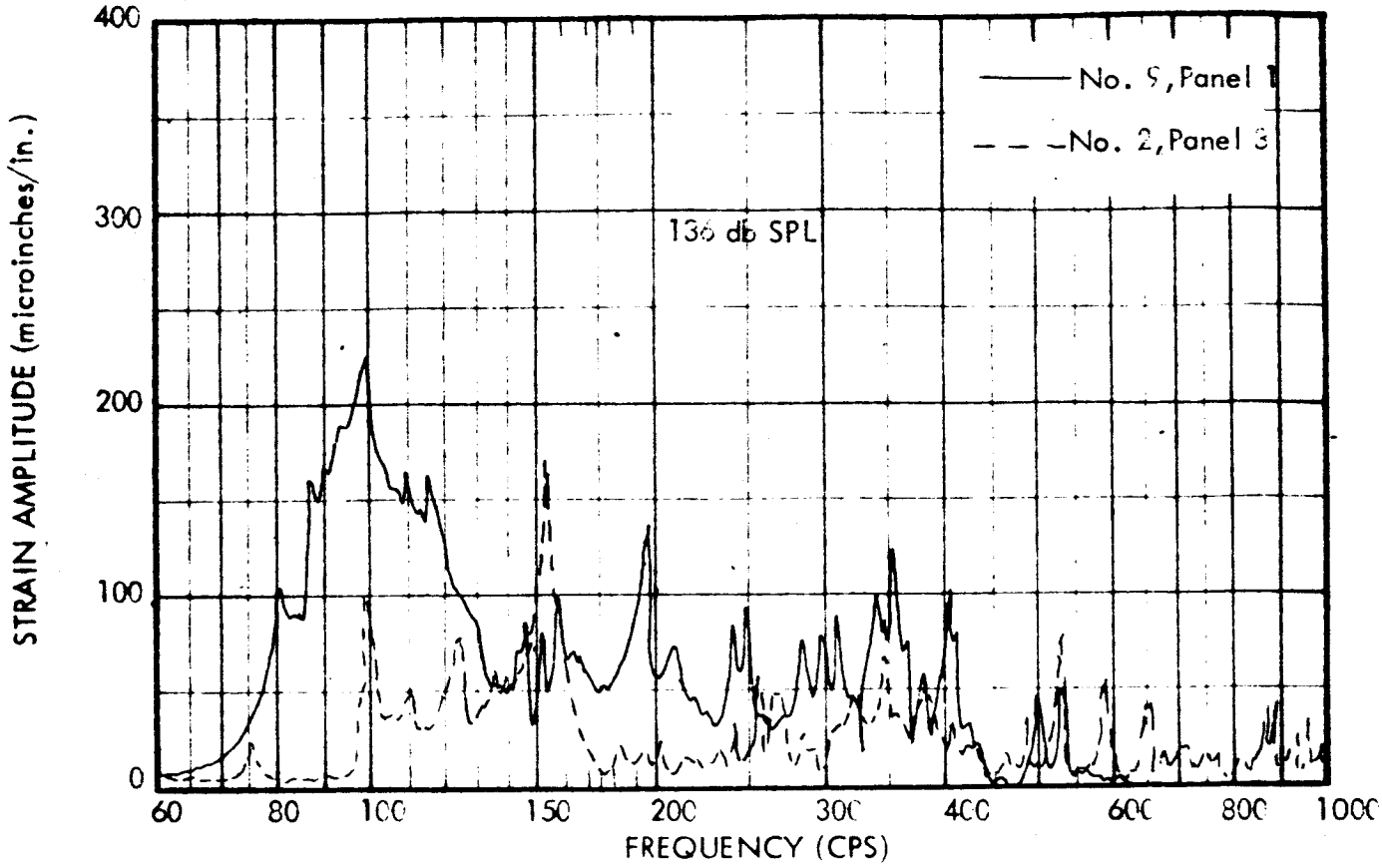


Figure 165: Panel No. 1 and 3--- Discrete Frequency Sweeps----Strain Gauges 9 and 2

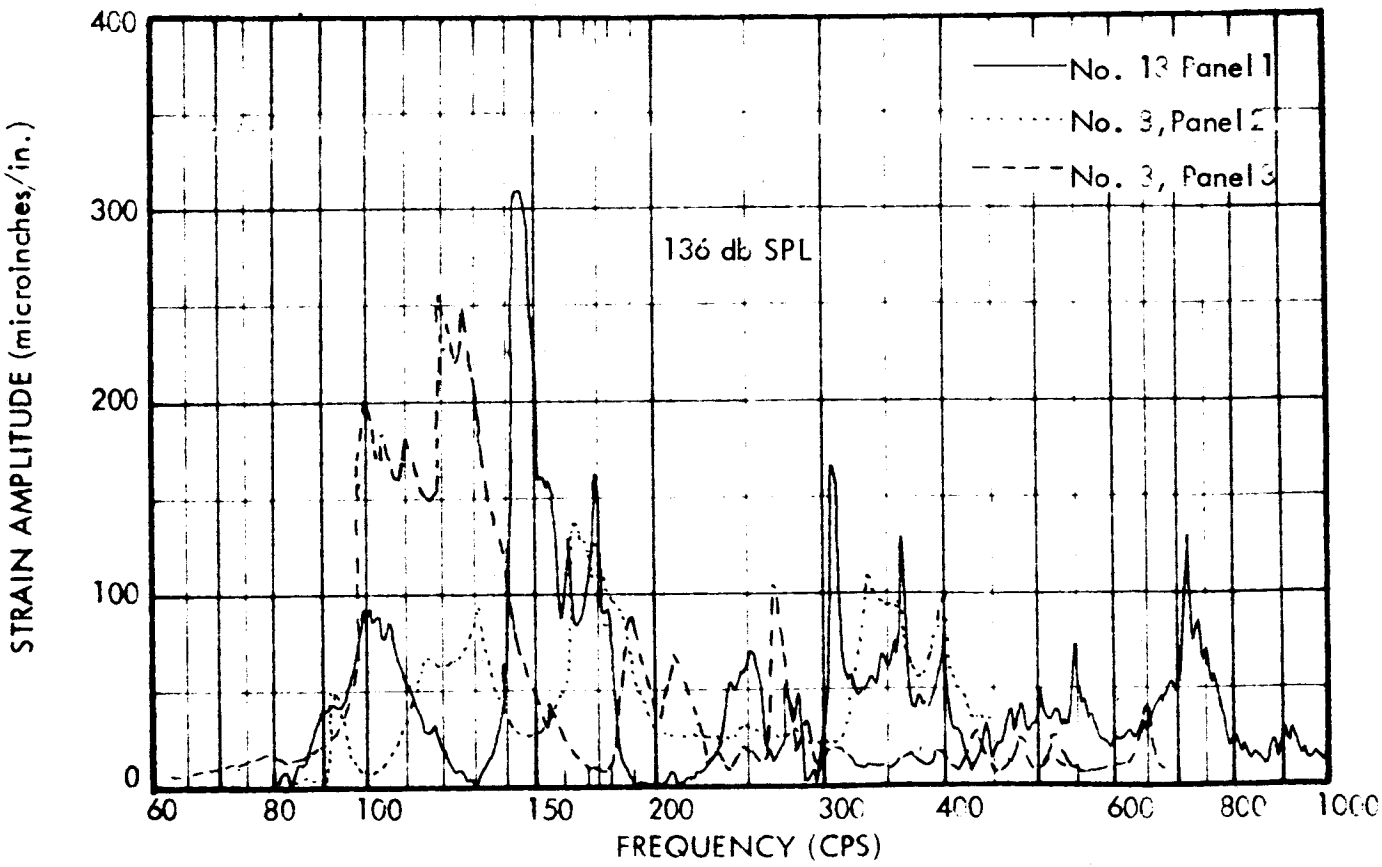


Figure 166 Panel No.1, 2, 3---Discrete Frequency Sweeps-- Strain Gauges 13, 3 and 3

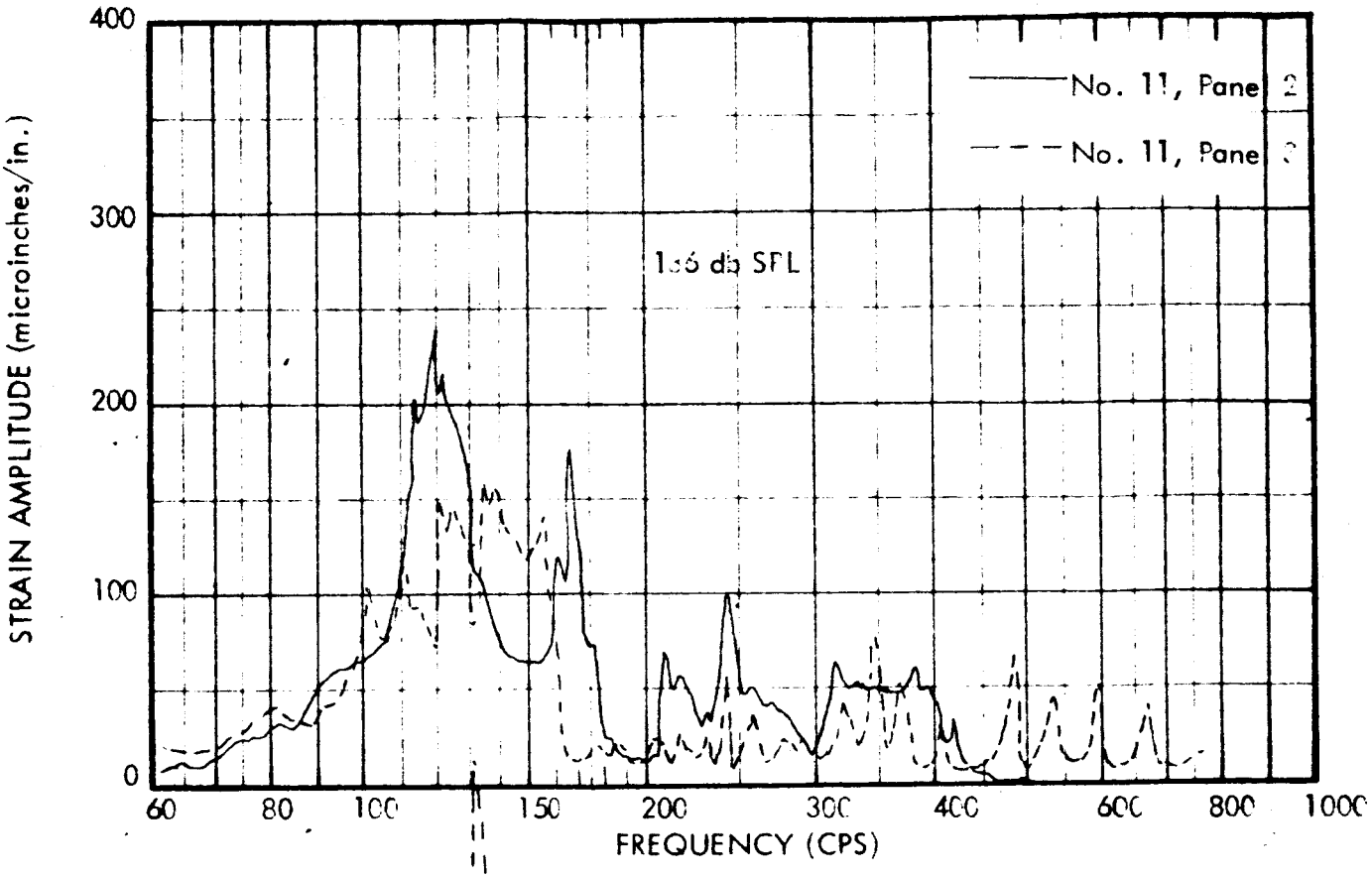


Figure 167 Panel No. 2 and 3 --- Discrete Frequency Sweeps----Strain Gauge 11

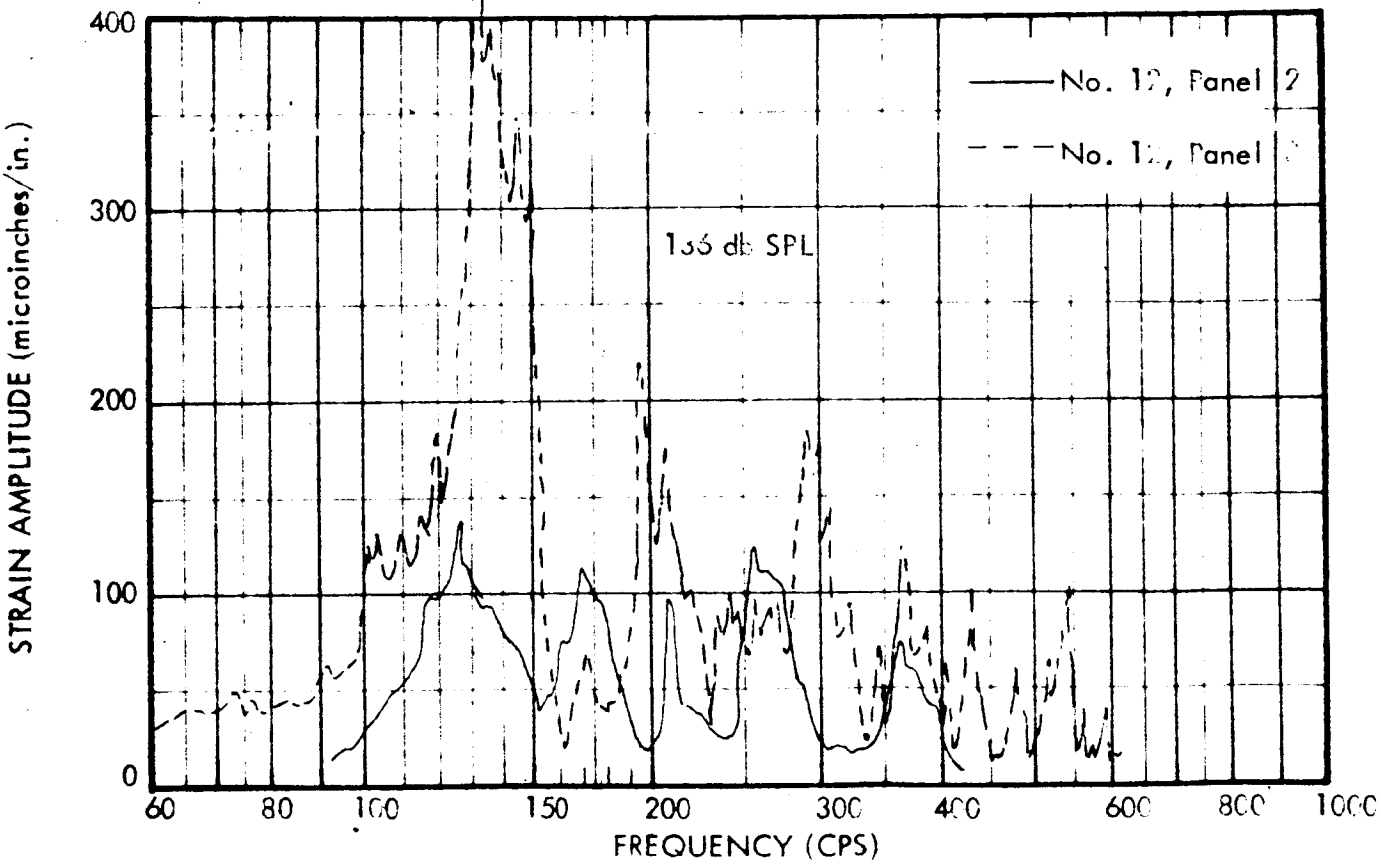


Figure 168 Panel No. 2 and 3---Discrete Frequency Sweeps-- Strain Gauge 12