GCA TECHNICAL REPORT NO. 66-18-N

NUTATION SENSOR

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GCA CORPORATION
Bedford, Massachusetts

COMBINED MONTHLY, QUARTERLY AND FINAL REPORT

CONTRACT NAS5-9592

PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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NUTATION SENSOR

Donald H. Fryklund

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December 1966

For Period Covering January through August 1966

GCA CORPORATION
GCA TECHNOLOGY DIVISION
Bedford, Massachusetts

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

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OBJECTIVE

Contract No. NAS5-9592 as ammended involves the provision of the necessary personnel, facilities, and services to design, fabricate, test, and deliver one prototype and four flight-qualified models of a nutation sensor in accordance with the GSFC document entitled "Specifications for a Nutation Sensor for ATS/SASSE (ATS-B) as revised, and GCA Corporation Proposal No. 4047-5-01 entitled "Nutation Sensor for ATS Program".

SUMMARY OF WORK PERFORMED DURING REPORTING PERIOD

Effort Expended during this reporting period consisted of four separate tasks.

(1) The construction and testing of a twelve-foot balanced pendulum used to calibrate the nutation sensors.

(2) Pre-testing, environmental testing, and post-testing four flight unit sensors.

(3) The calibration of four flight unit sensors to provide the following data:

(a) Logarythmic output versus deflection for four frequencies and three temperatures.

(b) Linear output versus deflection for four frequencies and three temperatures.

(c) Normalized frequency response for ten frequencies for both transducer and log amplifier outputs.

(d) Thermistor voltage versus temperature.

(e) Test point voltage versus output voltage.

(4) The reduction of recorder tape data to graphic data.

Four flight unit nutation sensors have been delivered to NASA, Hughes Aircraft Company, Space Systems Division, Los Angeles, California.

DETAILED DISCUSSION

The Measuring System

Sensor calibration was performed by the use of a twelve foot balanced pendulum which has the capability of variable frequency operation. The sensor under calibration was placed at the end of this pendulum in an environmental chamber to obtain response for different operating temperatures.

The Pendulum. - The extremely low frequencies encountered in the motion of nutation of the ATS, in the range 0.03 to 0.27 cps, required special test equipment for the nutation experiment. Two balanced pendulum systems were used in testing and calibration of the nutation sensors, one mounted into a space chamber for generating simple harmonic motion during thermal vacuum exposure, and the other, a much larger system, mounted on vibration isolators in ordinary sea-level environment, for sensor calibration.

The calibration pendulum is shown in Figure 1. This device consists of an aluminum alloy tube having a ballast weight on one end and an environmental (temperature) chamber on the other end. This assembly is mounted vertically to a rigid steel stand by means of knife edges at a point approximately 1/3 the distance down from the ballast weight. Unlike the simple pendulum the natural frequency of this system can be varied by the adjustment of the ballast weight. The lowest frequency is obtained when the system is just under neutral balance. The highest frequency, of course, is that of the pendulum configured as a simple pendulum, that is, with zero ballast weight. Ballast is varied, as shown in Figure 1, by forcing water in varying quantities into a tank gimbal-mounted onto the top end of the pendulum arm.

The sensor being calibrated is mounted into a temperature chamber located at the bottom end of the pendulum arm. At the same end is mounted a reference accelerometer. Below the chamber is a precision machinist's scale formed into an arc conforming to the path scribed by a pointed attached to the end of the pendulum. Visual readings are taken from this scale for each run to obtain an absolute calibration for the reference sensor.

The ratio of energy stored to energy dissipated per cycle of oscillation (or Q) varies, as with all oscillating systems, directly with the frequency. Hence, at low frequencies the free oscillation of this system damps rapidly and has a large decrement of decay. For this reason an electromegnet is used to forcibly drive the system at the low end of the frequency range. This drive system consists of a signal generator coupled to a push-pull power amplifier which, in turn, is coupled to the electromagnet which is configured into a push-pull variable reluctance actuator. When driving the pendulum with the electromagnet it is important to operate as near to resonance as possible. In this test system resonance was achieved by the use of small trim weights which were added to the bottom end of the pendulum. Off resonance operation results in a modulation of the oscillation in the familiar pattern of "beats".

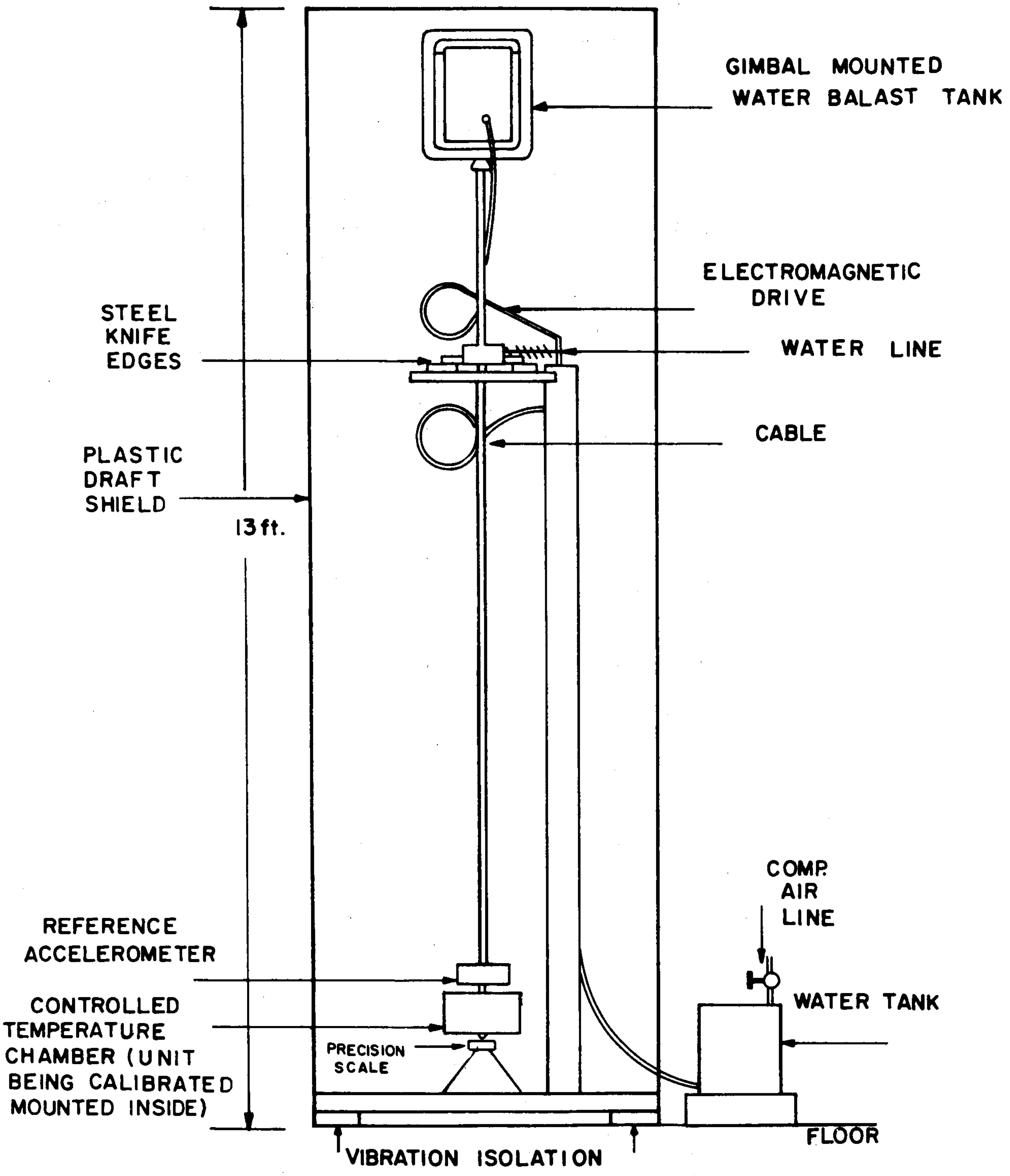


Figure 1. Balanced calibration pendulum.

Since the calibration pendulum must generate very low displacements to reach the low end of the nutation angle measurement scale, some difficulty has been encountered in achieving a good signal to noise ratio at low displacement amplitudes. The noise is strictly mechanical and is from two sources: the seismic vibration of the laboratory floor due to machinery and foot traffic, and air turbulence in the laboratory due to the air conditioning system, and again, foot traffic. The former was reduced by the use of vibration isolators placed under the steel stand, and by barring entrance to the work are during calibration. The latter was reduced by the use of a sealed plastic enclosure placed around the entire pendulum system. With reduced mechanical input the remaining noise was further reduced electrically by the use of a low pass ladder filter and a notch filter centered at the natural frequency of the reference sensor. By these techniques the signal to noise ratio at the threshold was increased to 20 dB or better. The noise calculation taken for the frequency of highese noise susceptability (high end) is shown in the notebook page reproduction, Figure 2.

The Reference. - The reference accelerometer used to calibrate the ATS nutation sensors is a beam-type PZT unit similar to the transducer used in the sensor itself. The transducer element was operated at room temperature by means of a heat sink plate whose temperature was monitored during each run. For each run the reference accelerometer was calibrated by taking direct displacement readings from the machinists scale described above. These readings were taken simultaneously with the calibration run and were taken once per oscillation until the displacement emplitude reduced to a level where reading accuracy deteriorated (fraction of an inch). The run was then completed relying on the linearity of the reference accelerometer. At the lower calibration frequencies; however, it was possible to use direct scale readings for the entire run since the threshold displacement here is large and is therefore readable with good accuracy.

The Measuring Circuit. - Four channels of data were taken simultaneously as shown in Figure 3. These channels are as follows: (1) Reference, (2) transducer output, (3) logarythmic amplifier output No. 1, and (4) logarythmic amplifier output No. 2.

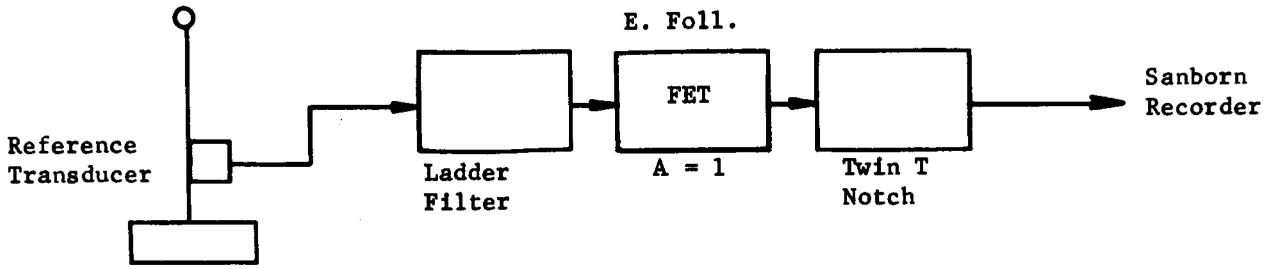
The last three channels are from the nutation sensor under calibration. Even though the sensor provides two outputs for the transducer (linear outputs), only one channel of data was needed since these outputs are always identical being tapping off from the same internal circuit point.

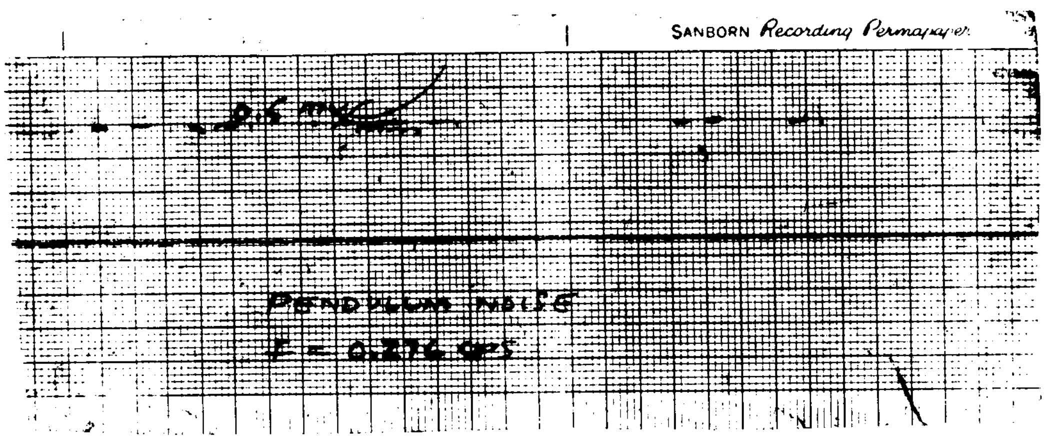
Notch filters were used in each channel to reduce the seismic noise. These notches were centered at the transducer natural frequency (7 cps). Filters were used only at the higher frequencies, 0.1 and 0.27 cps, where the threshold displacement for 0.001 degrees nutation is small.

FET followers were used in each channel. In Channel 1, the reference channel, the FET follower was used to simply isolate the two filters. In Channel 2, the transducer output, the FET follower is used to present a near infinite load resistance so that the measured output would be essentially the

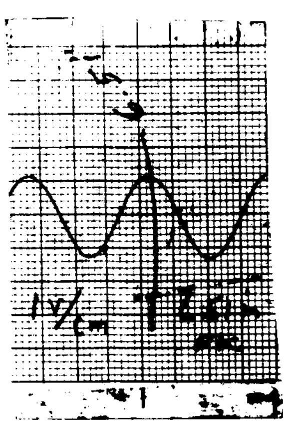
PENDULUM NOISE MEASUREMENT

Frequency 0.276 cps





Calibration of reference transducer



$$\frac{1.2 \times 1 \text{ v/cm}}{6.51} = \frac{x}{.016}$$

$$x = \frac{1.2 \times 0.016}{6.51} = \frac{1.2 \times 16}{6.51} \times 10^{-3}$$

$$= 2.95 \times 10^{-3} \text{ V. pk-pk}$$

$$V_{noise} = 0.25 \text{ mV pk-pk}$$

$$SN = 20 \log \frac{2.95}{0.25} = 20 \log 11.8$$

$$= 20 + \log 1.18 = 21.3 \text{ dB}$$

Figure 2.

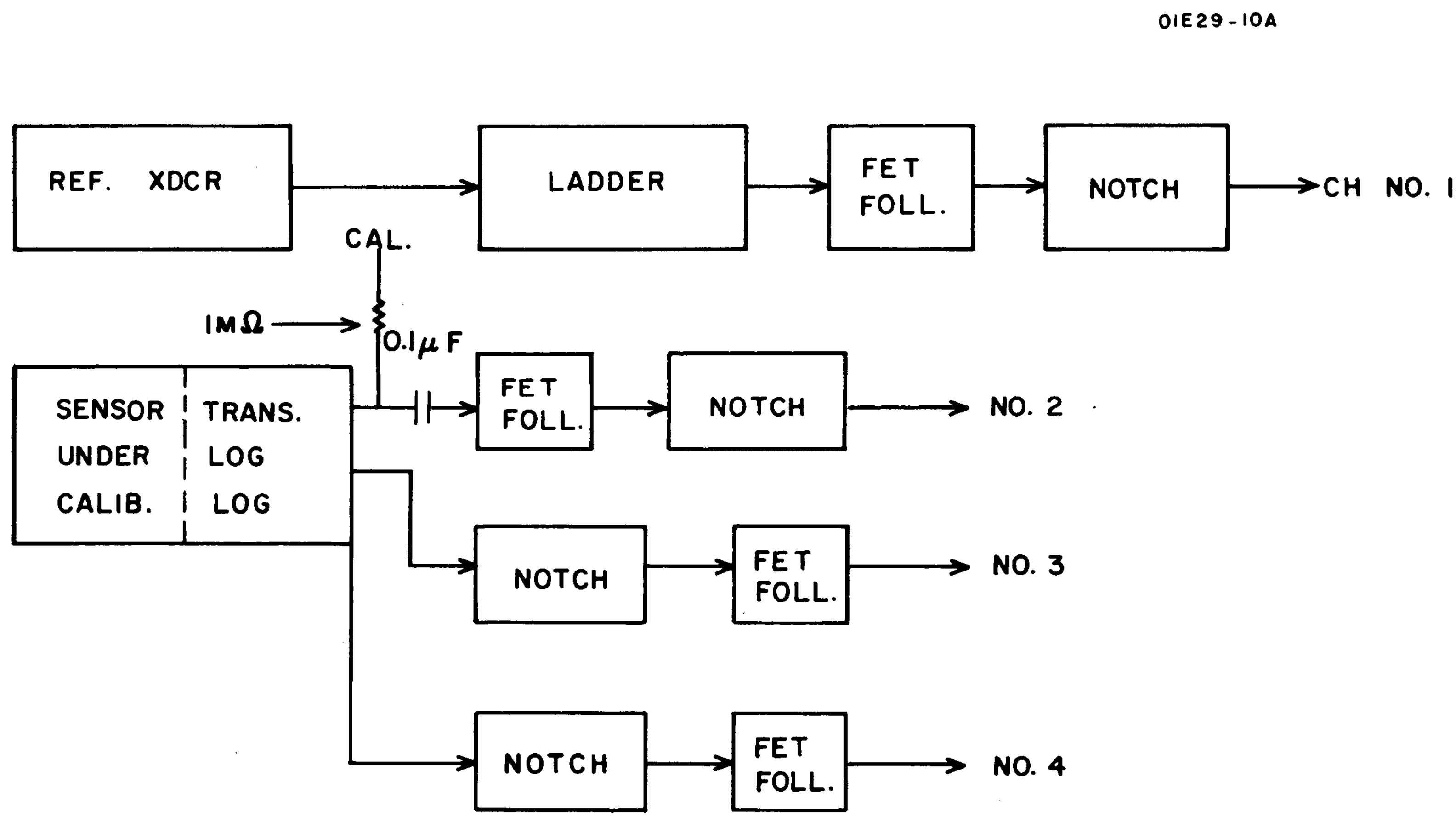


Figure 3. The measuring system.

open circuit voltage. In Channels 3 and 4, the log outputs, the FET followers were used to isolate the recorder impedance from the rest of the measuring circuit. This was necessary in these two channels because the recorder internal impedance changes with certain scale changes. This was not important in Channels 1 and 2 because the voltage levels here did not require a scale change which affected load impedance.

Each channel was calibrated before each run, first for DC with a precision voltage source, and then for AC with a function generator. Channel 2, the transducer output, was calibrated through a 1 megohm resistance as shown in Figure 3 to simulate the internal impedance of the nutation sensor.

In addition the following quantities were monitored and recorded in the test data book: (1) Thermistor voltages with a digital vm, (2) sensor temperature with a thermocouple, (3) oven temperature with a thermocouple, (4) sensor supply voltage with a VTVM, and (5) sensor total current with a simpson.

Sensor Frequency Response

Figure 4 is a plot of frequency response for three flight model nutation sensors. This curve is suggestive of a typical frequency response of an oscillating system whose natural frequency is centered at approximately 0.1 cps and whose damping is near critical. The sensor response was therefore examined closely to ascertain if indeed this was the case. The basic transducer design would rule this out since the natural frequency has been set at 7 cps, which is apparent from Figure 2A of Progress Report No. 2. However, it was thought that perhaps another unknown mode was being excited at 0.1 cps.

Resonances may be examined conveniently by observing the phase angle between the forcing function and the response of the driven system. For this type of system, independent of the amount of damping, the phase shift varies from zero angle at low frequencies, to 90 degrees at resonance, and to 180 degrees at high frequencies (infinity). If the output rise shown in Figure 4 around the frequency 0.1 cps is due to resonance, the phase shift between the pendulum input acceleration and the sensor output should be 90 degrees. The phase angle was checked at all frequencies, 0.03, 0.05, 0.1, and 0.27 cps and in all cases the output was in phase with the input acceleration. Since maximum acceleration occurs at the point of maximum deflection of the pendulum, the pendulum swing was simply observed at its peak and a mark was generated at this point. If the output is in phase with the input, this mark would appear at the peak of the output wave. The mark was generated by placing a block of expanded plastic of very small mass on the reference scale at a point just under the observed maximum deflection of the previous oscillation. The contact of the pendulum with the plastic block on the next swing caused a small deceleration with a corresponding change in output voltage.

Figure 5 shows this voltage change (encircled) for a 0.1 cps run. The indication is that the output wave is in phase with the input wave. Figure 6 shows the same phase measurement for 0.27 cps indicating again that input and

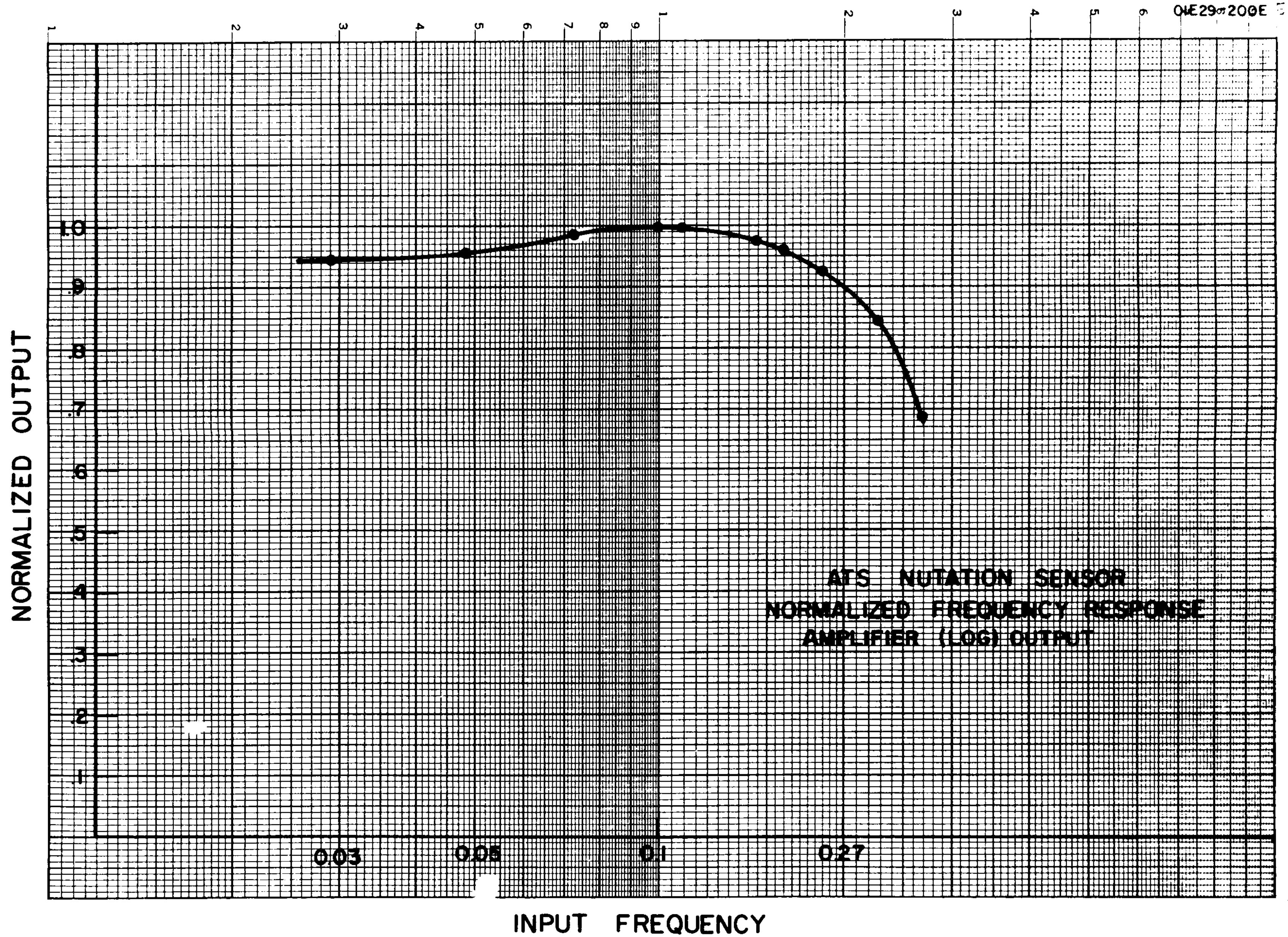

ATS NUTATION SENSOR
NORMALIZED FREQUENCY RESPONSE
AMPLIFIER (LOG) OUTPUT
NORMALIZED OUTPUT
INPUT FREQUENCY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.03
0.05
0.1
0.27

Figure 4.

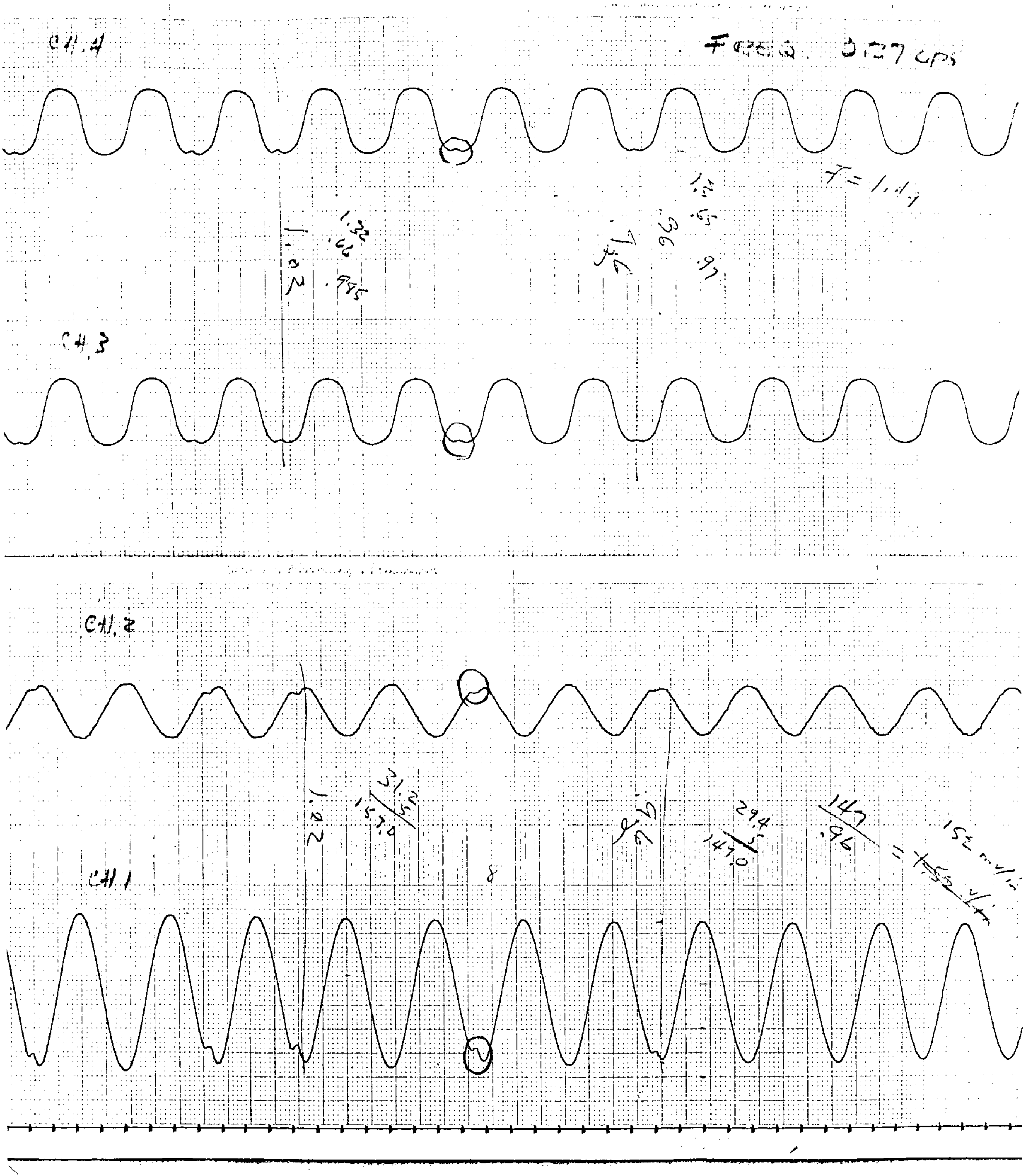


Figure 5.

Freq 0.1 cps

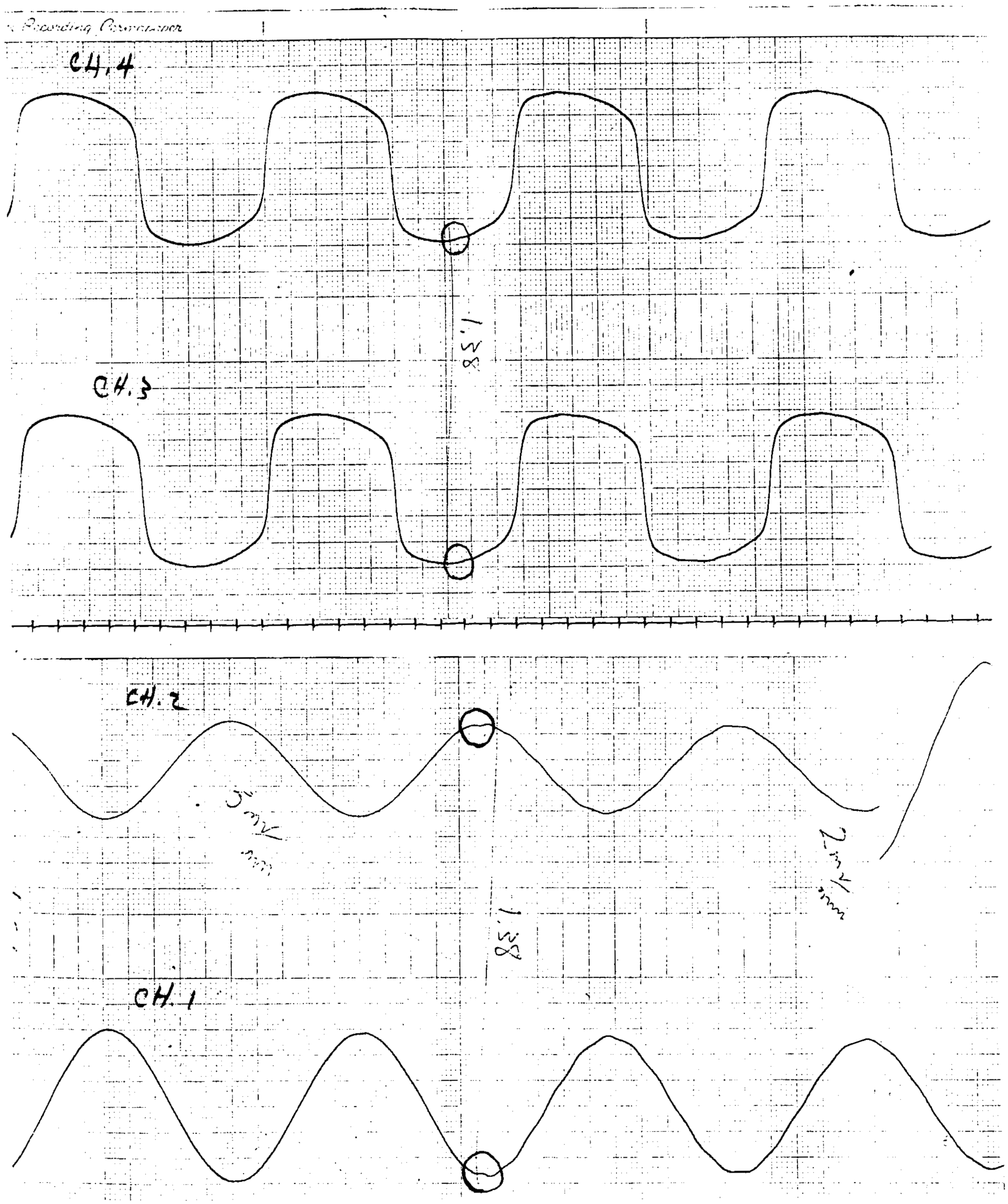


Figure 6.

output is in the required in-phase relationship. Similar measurements at 0.03 and 0.05 cps yield the same results. Therefore, the conclusion must be made that the output rise in Figure 4 is not due to resonance and that over the entire frequency range, the transducer is a true accelerometer.

The non-uniform response is then not due to reactive effects or energy storage in mass and compliance and must be caused by a frequency-dependent equivalent voltage generator. An explanation of how this could occur would assume that the bimorph beam bending is not uniform with deflection amplitude. Say at high deflection amplitudes such as one gets at low frequencies the beam bending occurs over the entire beam length and hence the entire piezoelectric element is strained. At low amplitudes, or at higher frequencies, the beam gives at some localized point (weaker point) limiting the straining of the element essentially to this region. A bimorph whose elements are cemented with epoxy resin such as are these units could very well have non-homogeneity in its bounding with length of the beam. Non-uniform straining of the piezelectric ceramic will result in a rather pronounced reduction in output voltage since those areas of ceramic that are not generating voltage acts as shunt capacitance which forms a voltage divider with the capacitance of the producing area which is always in series with the equivalent generator.

Table 1 is the data used to plot the curve in Figure 4. These data are shown to demonstrate the uniformity of the normalized sensor response from unit to unit. A thorough frequency response examination was made on flight unit 4 to obtain a more accurate curve, in particular between 0.1 and 0.27 cps.

The sensor transducer output normalized frequency response curve is shown in Figure 7 which further supports the non-reactive nature of the sensor frequency dependence. A resonance at a low frequency such as 0.1 cps would be expected to be mechanical in nature since if it was electrical the inductance and capacitance involved would be very large indeed and such large elements do not exist in the sensor electrical system. Assuming that it is mechanical the resonance should appear at the transducer output. This is not apparent in Figure 7.

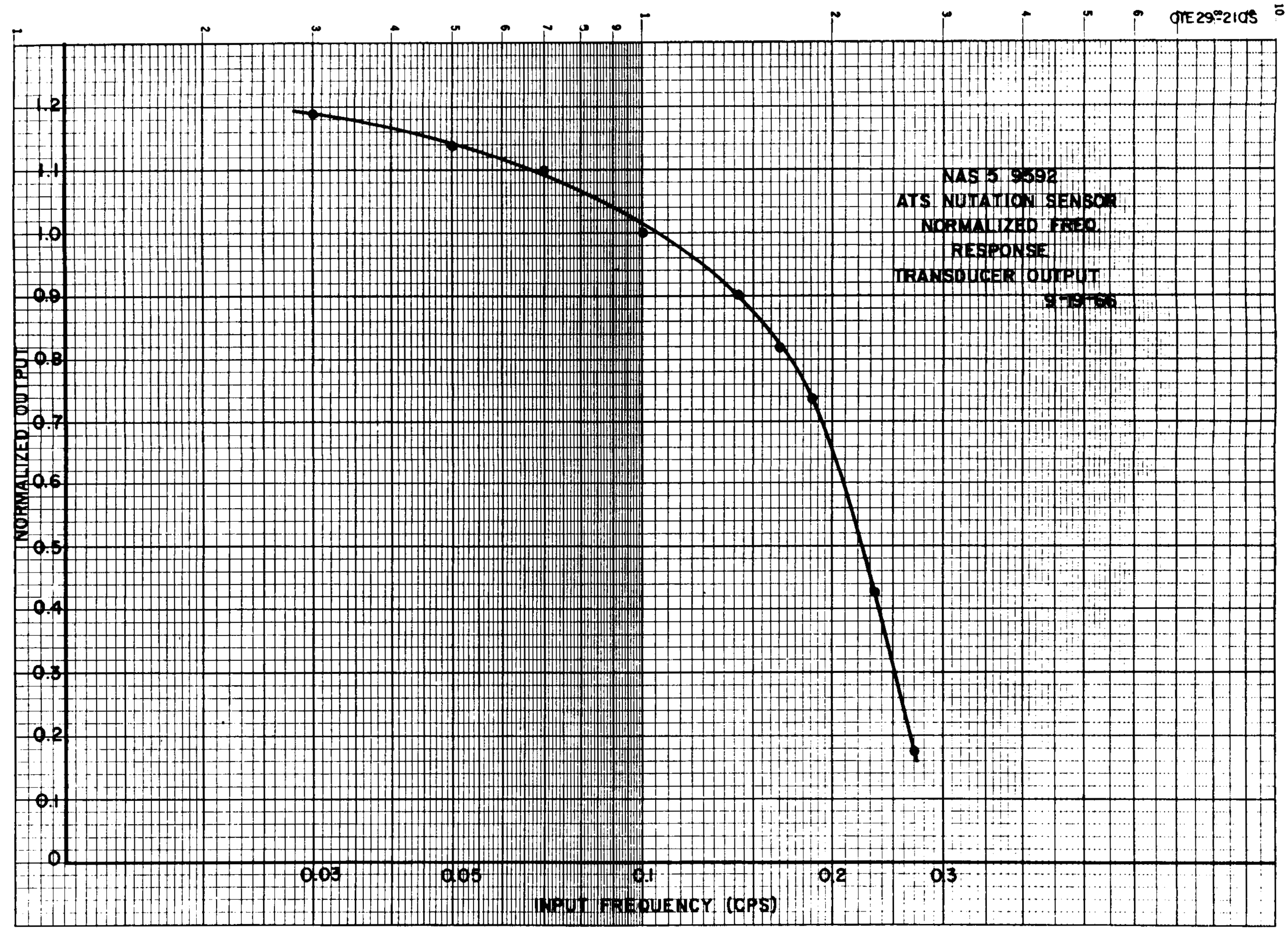


Figure 7. NAS5-9592 ATS nutation sensor normalized frequency response transducer output.

TABLE 1

NORMALIZED FREQUENCY RESPONSE

	Flight Unit No.				
Frequency	-1	-2	-4	-5	Spread
0.03 cps	0.925	0.95	0.91	0.94	±2.1 %
0.05	0.955	0.96	0.975	0.97	±1
0.1	1	1	1	1	0
0.27	0.65	0.64	0.69	0.66	±3.8
0.74			0.98		
1.08			1.0		
1.4			0.98		
1.65			0.95		
1.9			0.92		

APPENDIX I

TEST REPORT

NUTATION SENSOR FLIGHT ACCEPTANCE TESTS

1. Scope

This document reports the results of the flight acceptance tests for the flight models ATS NAS5-9592 Nutation Sensors, Serial Nos. AG-0282-1, -2, -4, and -5. Tests consisted of random and sine wave vibration and thermal vacuum.

2. Applicable Documents

"Environmental Test Plan, Contract No. NAS5-9592," dated 21 September 1965, Part 5, Amended as follows: Paragraph 5.3.1: The temperature is changed to $40 \pm 2^{o}F$. Paragraph 5.3.2: The temperature is changed to $100 \pm 2^{o}F$.

3. Pre-tests

The nutation sensors were subjected to functional tests prior to environmental exposure to provide reference performance data. In these tests the sensors were excited at 0.27 cps on the balanced pendulum and a plot of output voltage versus input deflection was obtained for all output channels. This data is shown in Figures 1, 2, 3, and 4. All monitor outputs were checked and two sets of squibs were fired in each unit. Performance was satisfactory for all tests.

4. Thermal Vacuum Tests

The sensors were placed in the space chamber on a balanced pendulum exciter (described in NAS5-9592 Progress Report No. 3). The pressure was reduced to below 10^{-5} torr and ambient temperatures of $40 \pm 2^{o}F$ and $100 \pm 2^{o}F$ were established. For each temperature the exposure time was 12 hours. During the entire test period including the transient time of temperature adjustment, the sensors were checked for operational performance by energizing the balanced pendulum to a known displacement.

4.1 High Temperature Thermal Vacuum Tests

Table 1 and 3 shows the results of the $100^{o}F$ ambient thermal vacuum tests.

4.2 Low Temperature Thermal Vacuum Tests

Table 2 and 4 shows the results of the $40^{o}F$ ambient thermal vacuum tests.

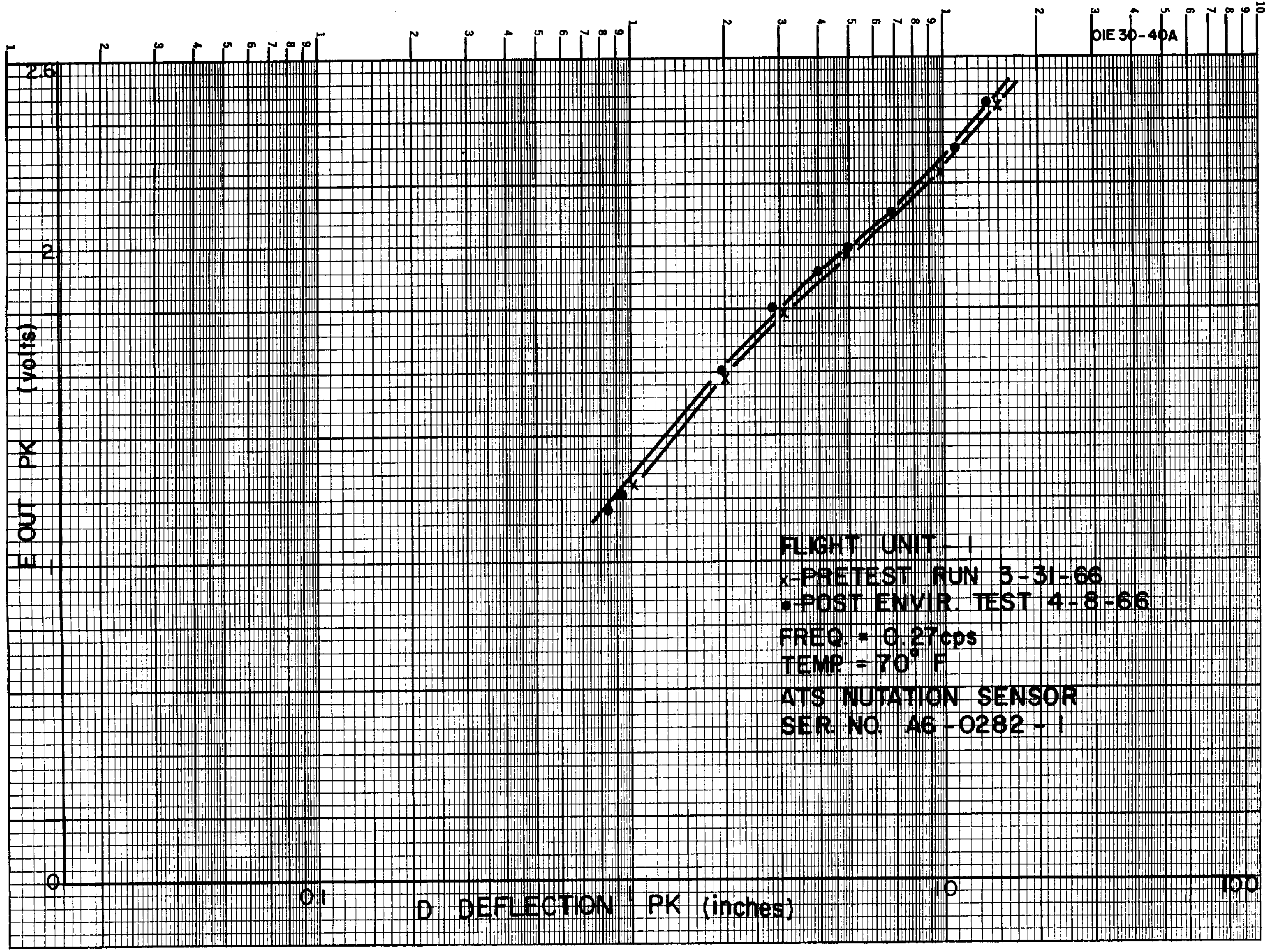
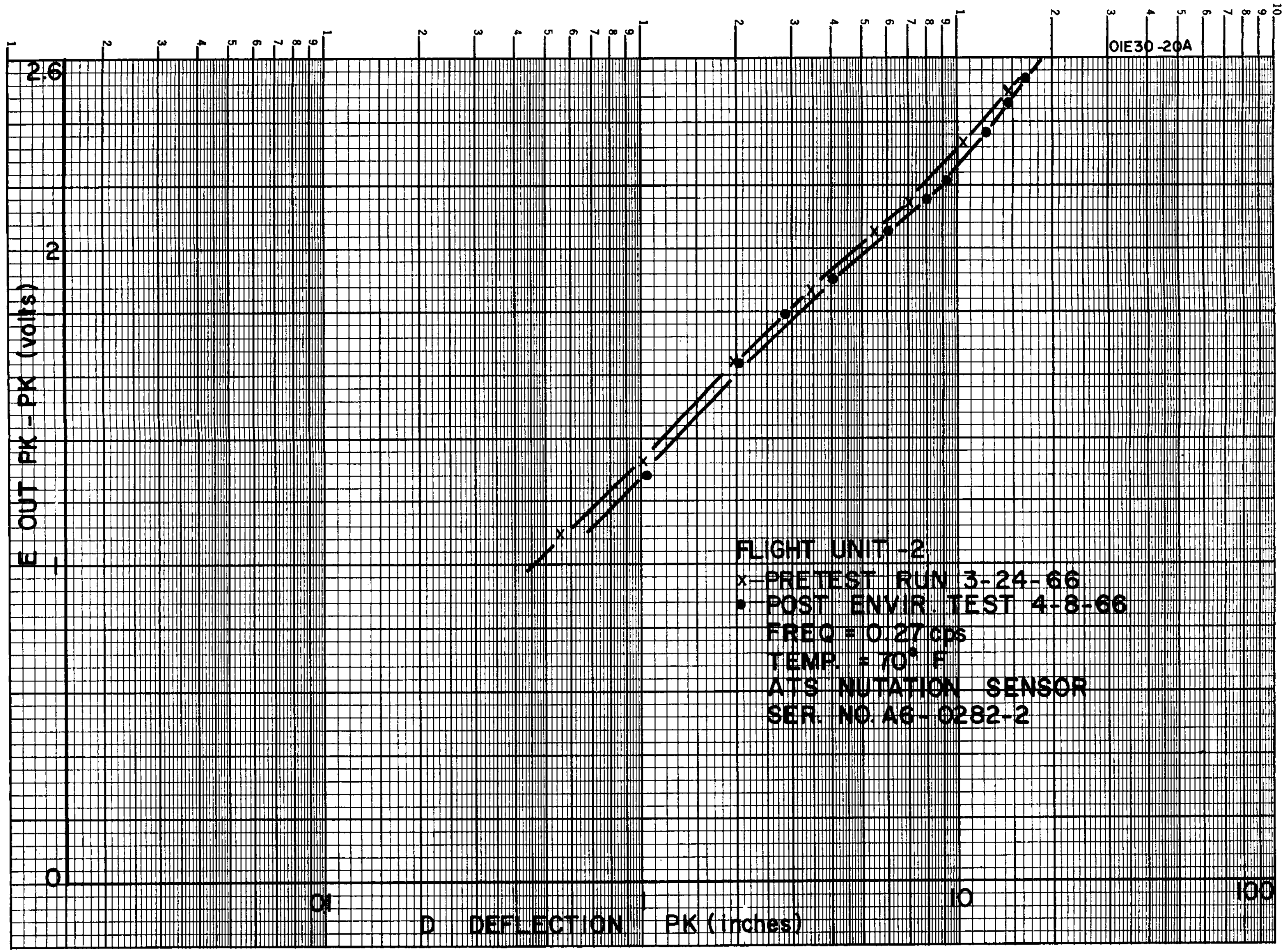
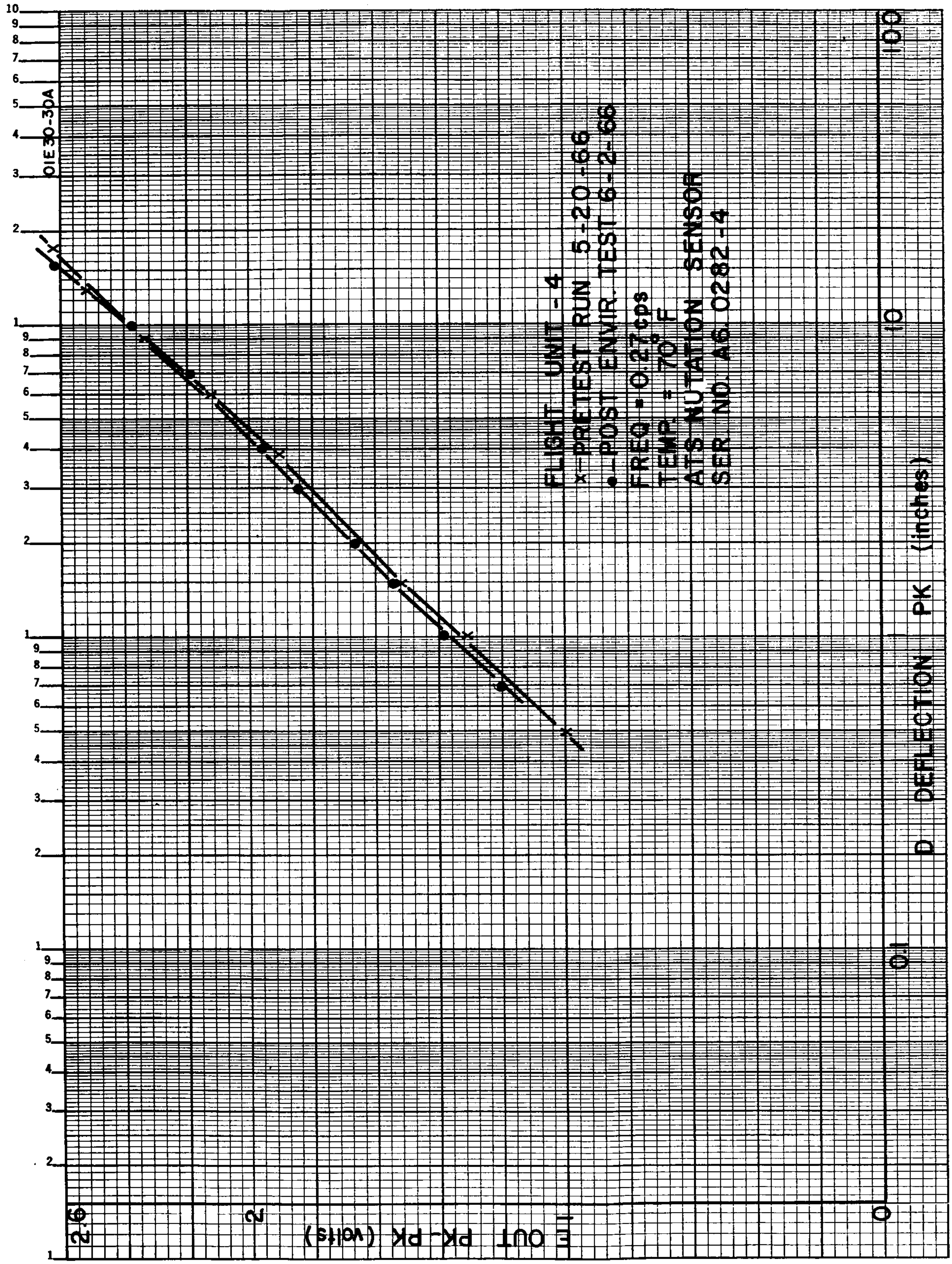

FLIGHT UNIT - I
x-PRETEST RUN 3-31-66
•-POST ENVIR. TEST 4-8-66
FREQ. = 0.27cps
TEMP. = 70° F
ATS NUTATION SENSOR
SER. NO. A6-0282 - I
E OUT PK (volts)
D DEFLECTION PK (inches)
DIE 30-40A

Figure I-1.



OIE30-20A
E OUT PK-PK (volts)
2.6
2
1
0
.01
.1
1
10
100
D DEFLECTION PK (inches)
FLIGHT UNIT -2
x-PRETEST RUN 3-24-66
•-POST ENVIR TEST 4-8-66
FREQ = 0.27 cps
TEMP. = 70° F
ATS NUTATION SENSOR
SER. NO. A6-0282-2

Figure I-2.



FLIGHT UNIT -4
x-PRETEST RUN 5-20-66
●-POST ENVIR. TEST 6-2-66
FREQ = 0.27 cps
TEMP. = 70° F
ATS NUTATION SENSOR
SER. NO. A6. 0282-4
D DEFLECTION PK (inches)
E OUT PK-PK (volts)
0.1
10
100
2.6
2
1
0
OIE 30-30A

Figure I-3.

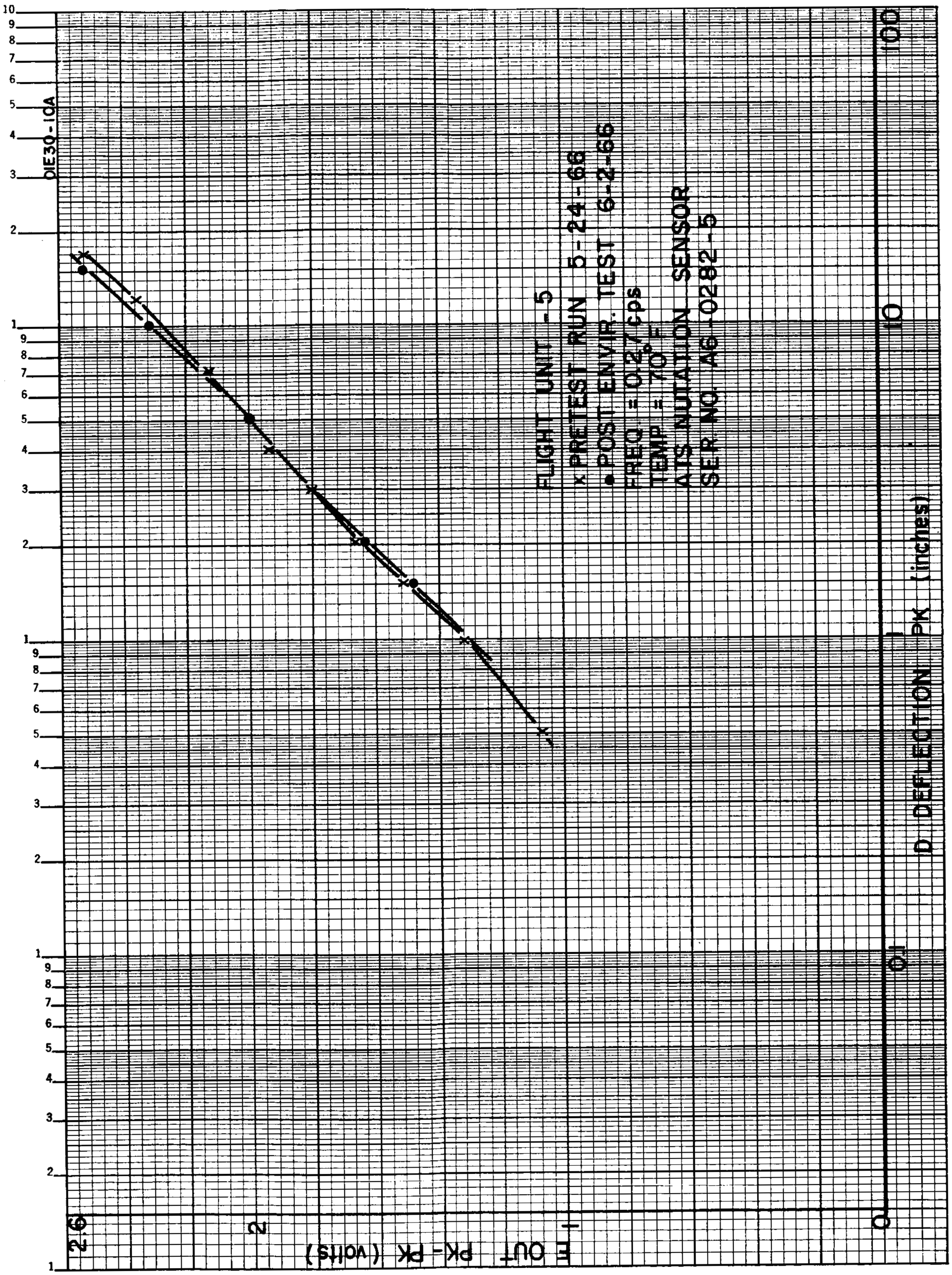

FLIGHT UNIT -5
x PRETEST RUN 5-24-66
• POST ENVIR. TEST 6-2-66
FREQ = 0.27 cps
TEMP = 70°F
ATS NUTATION SENSOR
SER NO. A6-0282-5
D DEFLECTION PK (inches)
E OUT PK-PK (volts)

Figure I-4.

5. Vibration Tests

The flight model nutation sensors were exposed to sine wave and random vibration per Tables 3 and 4, Page 7, of the NAS5-9592 Environmental Test Plan. These tables are identical with ATS specification entitled "Environmental Qualification and Acceptance Test Specification - Component Testing" dated 9 September 1964. Vibration testing is covered in detail in Appendices II and III.

6. Functional Tests, Post Environmental

After environmental exposure, the nutation sensors were placed on the balanced pendulum and at room temperature their performance was checked at 0.27 cps to ascertain satisfactory survival. The results of this check is shown in Figures 1 and 2. All monitor outputs were checked and one set of squibs were blown in each unit. Satisfactory results were obtained for all tests.

TABLE 1

OPERATIONAL HIGH TEMPERATURE THERMAL-VACUUM TEST DATA

Flight Unit Serial No. A6-0282-1

Pressure: 2×10^{-6} mm Hg

Ambient Temp: 37.6°C (99.2°F)

Sensor Temp: 50°C (122°F)

I_{total}: 24 ma

Pendulum Deflection: 0.25 in pk-pk

Frequency: 0.513 cps

Logarythmic Amplifier Output: 2.14 ± 0.04V pk-pk – for 3 checks over 12 hours

Transducer Output: 159 ± 1 mv pk-pk – for 3 checks over 12 hours

Flight Unit Serial No. A6-0282-2

Pressure: 7×10^{-6} mm Hg

Ambient Temp: 40°C (104°F)

Sensor Temp: 53.5°C (128.3°F)

I_{total}: 27 ma

Pendulum Deflection: 0.25 in pk-pk

Frequency: 0.52 cps

Logarythmic Amplifier Output: 2.155 ± 0.025V pk-pk – for 3 checks over 12 hours

Transducer Output: 150.5 ± 0.5 mv pk-pk – for 3 checks over 12 hours

TABLE 2

OPERATIONAL LOW TEMPERATURE THERMAL-VACUUM TEST DATA

Flight Unit Serial No. A6-0282-1

Pressure: 8×10^{-8} mm Hg

Ambient Temp: 4°C (39.2°F)

Sensor Temp: 42.3°C (109°F)

I_{total}: 55.1 ma

Pendulum Deflection: 0.25 in pk-pk

Frequency: 0.513 cps

Logarythmic Amp. Output: 2.1 ± 0.0V pk-pk — for 3 checks over 12 hours

Transducer Output: 157.5 ± 2.5 mv pk-pk — for 3 checks over 12 hours

Flight Unit Serial No. A6-0282-2

Pressure: 6×10^{-6} mm Hg

Ambient Temp: 3.5°C (38.3°F)

Sensor Temp: 34°C (93.2°F)

I_{total}: 47.5 ma

Pendulum Deflection: 0.25 in pk-pk

Frequency: 0.52 cps

Logarythmic Amp. Output: 2.175 ± 0.005V — for 3 checks over 12 hours

Transducer Output: 151 ± 0.00 mv — for 3 checks over 12 hours

TABLE 3

OPERATIONAL HIGH TEMPERATURE THERMAL-VACUUM TEST DATA

Flight Unit Serial No. A6-0282-4

Pressure: 2×10^{-7} mm Hg

Ambient Temp: 38.5°C (100°F)

Sensor Temp: 49°C (120°F)

I_{total}: 25 ma

Pendulum Deflection: 0.245 in pk-pk

Frequency: 0.52 cps

Logarythmic Output: 2.175 ± 0.005V pk-pk — For 2 checks over 12 hours

Transducer Output: 237 ± 3 mv pk-pk — For 2 checks over 12 hours

Flight Unit Serial No. A6-0282-5

Pressure: 2×10^{-6} mm Hg

Ambient Temp: 38.5°C (100°F)

Sensor Temp: 50°C (122°F)

I_{total}: 24 ma

Pendulum Deflection: 0.25 in pk-pk

Frequency: 0.52 cps

Logarythmic Output: 1.97 ± 0.03V pk-pk — For 4 checks over 12 hours

Transducer Output: 147 ± 2 mv pk-pk — For 4 checks over 12 hours

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TABLE 4

OPERATIONAL LOW TEMPERATURE THERMAL VACUUM TEST DATA

Flight Unit Serial No. A6-0282-4

Pressure: 2×10^{-6} mm Hg

Ambient Temp: $4^{o}C$ ($39.2^{o}F$)

Sensor Temp: $36^{o}C$ ($96.8^{o}F$)

I_{total}: 54.5 ma

Pendulum Deflection: 0.25 in pk-pk

Frequency: 0.52 cps

Logarythmic Output: 2.21 ± 0.02V pk-pk — For 4 checks over 12 hours

Transducer Output: 237 ± 5 mv pk-pk — For 4 checks over 12 hours

Flight Unit Serial No. A6-0282-5

Pressure: 2×10^{-7} mm Hg

Ambient Temp: $4.5^{o}C$ ($40.1^{o}F$)

Sensor Temp: $36^{o}C$ (96.8^{o})

I_{total}: 50 ma

Pendulum Deflection: 0.245 in pk-pk

Frequency: 0.52 cps

Logarythmic Output: 1.99 ± 0.025V pk-pk — For 2 checks over 12 hours

Transducer Output: 150 ± 0.5 mv pk-pk — For 2 checks over 12 hours

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Test Report No. NT-2968-11 No. of Pages 7

APPENDIX II

Report of Test on

NUTATION SENSORS

Sinusoidal and Random Frequency Vibration Tests

for

GCA Technology Division

Associated Testing Laboratories, Inc.

Burlington, Massachusetts

Date April 14, 1966

	Prepared	Checked	Approved
By	T. Jarek	R. Montvitt	D. C. Jensen
Signed	T. Jarek	R. Montvitt	D. C. Jensen
Date	4/14/66	4/14/66	4/14/66

Administrative Data

1.0 Purpose of Test:

To determine the effects on the submitted Nutation Sensors when they are subjected to a Sinusoidal and Random Frequency Vibration Tests when performed in accordance with the referenced Specification and the Test Procedures of this Report.

2.0 Manufacturer:
GCA Technology Division
A Division of GCA Corporation
Bedford, Massachusetts

3.0 Manufacturer's Type or Model No.:
Flight Units I and II.

4.0 Drawing, Specification or Exhibit:
GCA Technology Division Environmental Test Plan dated September 21, 1965.

5.0 Quantity of Items Tested:
Two (2) (Serial Nos. A6-0282-1 and A6-0282-2.)

6.0 Security Classification of Items:
Unclassified

7.0 Date Test Completed:
April 8, 1966

8.0 Test Conducted By:
Associated Testing Laboratories, Inc.
NEW ENGLAND DIVISION

9.0 Disposition of Specimens:
Returned to GCA Technology Division.

10.0 Abstract:

The submitted Nutation Sensors were subjected to Random Frequency Vibration over the frequency range of 20 to 2000 cps at an overall acceleration level of 7.3g's rms. Upon completion of each axis of vibration, the test specimens were visually examined for evidence of physical damage and none was noted.

The Nutation Sensors were then subjected to Sinusoidal Vibration over

10.0 Abstract (continued)

the frequency range of 10 to 2000 cps at various levels of applied acceleration up to a maximum of ±12.3g's. Following completion of each axis of vibration, the test specimens were visually examined for evidence of physical damage and none was noted.

LIST OF APPARATUS

Item	Manufacturer	Model No.	Accuracy	Calibration Date	Calibration Date Due
Vibration System consisting of:	MB Electronics		Freq.±2% Ampl.±5%	2-17-66	5-17-66
Vibration Exciter		C-50			
Power Amplifier		4150MB			
Control Console		T130MC			
Accelerometer	Endevco Corporation	2215-C		1-21-66	4-21-66
Vibration System consisting of:	Calidyne Company		Freq.±2% Ampl.±5%	4-5-66	5-5-66
Vibration Exciter		B44			
Signal Generator		DY2200			
Signal Monitor		54			
Power Supply (2 units)		68			
Field Supply		102			
Random Analyzing System	Ling Electronics				
Electronic Counter	Hewlett-Packard	521A	±1 count	2-9-66	5-9-66
Timer	Dimco-Gray Co.	165	±1 second	12-7-65	6-7-66
Multimeter	AVO, Ltd.,	8-Mark II		3-21-66	6-21-66

RANDOM FREQUENCY VIBRATION TEST

TEST PROCEDURE

The submitted Nutation Sensors were subjected to a Random Frequency Vibration Test in accordance with Paragraph 5.2 of the submitted Environmental Test Plan dated September 21, 1965. The following is a description of the Test Procedure as it was performed.

The Nutation Sensors were securely fastened to a Vibration Test fixture which, in turn, was securely fastened to the Vibration Exciter. A Crystal Accelerometer was then mounted to the test fixture and electrically connected to the Vibration Test equipment. However, prior to mounting the test specimen to the fixture, the Vibration System and fixture were equalized at the actual test levels shown in Table I. The System used for equalization contained 44 parallel band-pass filters with individual attenuators for spectrum shaping. Each filter had a maximum bandwidth of 50 cps. The Random Frequency System was equalized at the power spectral density levels shown below:

Table I

Frequency (cps)	Power Spectral Density Level (g^2/cps)
20 - 150	0.01
150 - 300	+3 db/octave
300 - 2000	0.02

Tolerance ±3 db.

Upon completion of equalization, an analysis of the Random signal was performed by plotting the power spectral density level an an X-Y Recorder. This was performed using a 50 cps bandwidth tracking filter from 100 to 2000 cps and a 10 cps bandwidth tracking filter from 20 to 100 cps. The X-Y Plot was then used to verify that the Random Signal levels were within the Specification limits (see Figure 1).

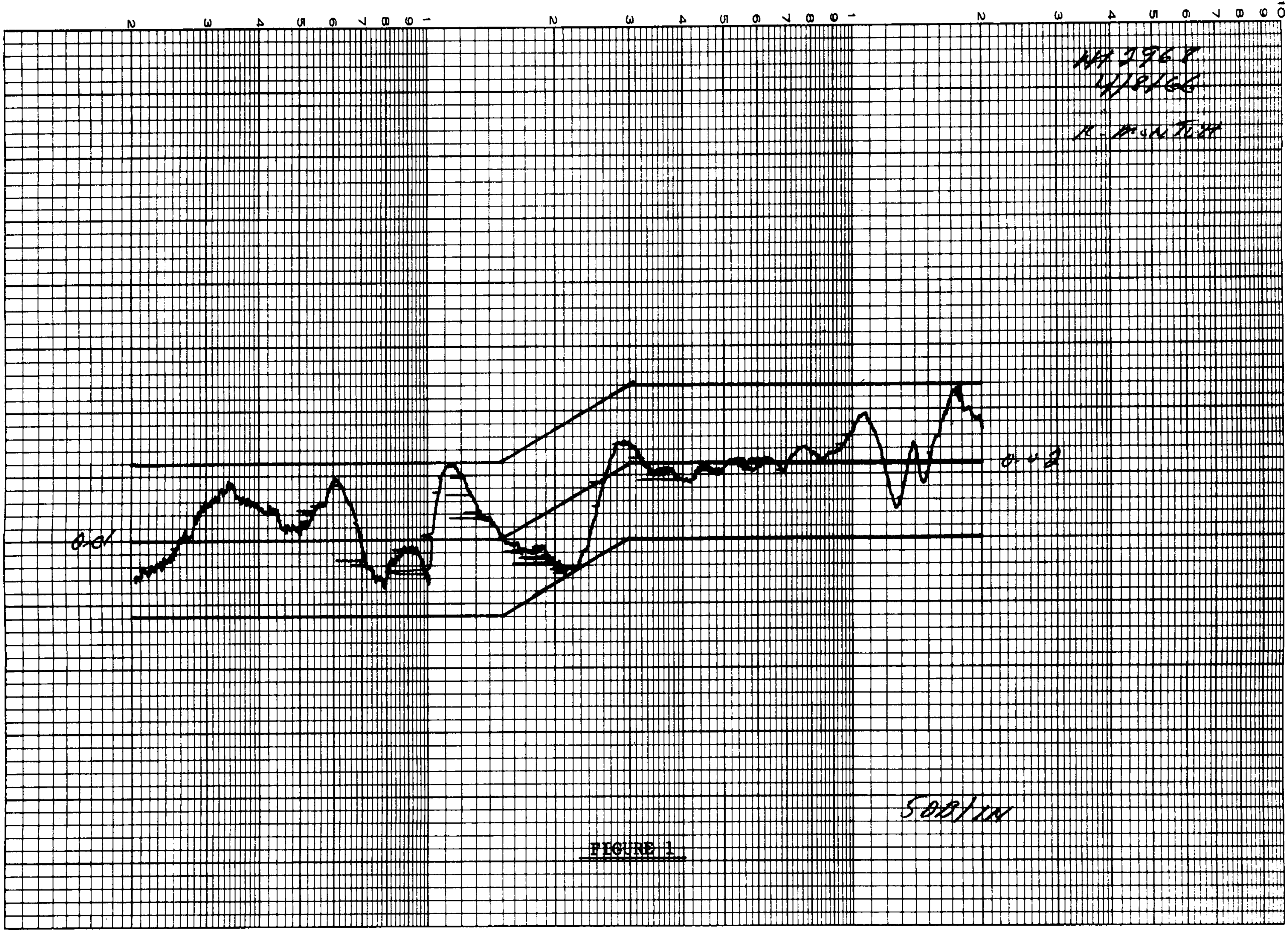


FIGURE 1

RANDOM FREQUENCY VIBRATION TEST

TEST PROCEDURE (continued)

After equalization, the test specimen was securely mounted to the test fixture and subjected to the Random Frequency Vibration at the desired test level for a period of two minutes. This Procedure was performed with the applied Vibration acting along each of the three mutually perpendicular axes. The axes are defined as follows:

Axis X - Parallel to the minor axis and the mounting base of each unit.

Axis Y - Parallel to the major axis and the mounting base of each unit.

Axis Z - Perpendicular to the mounting base of each unit.

During vibration, the Nutation Sensors were monitored by an Engineering Representative of GCA Technology Division. Upon completion of each axis of vibration, the test specimens were visually examined for evidence of physical damage.

TEST RESULTS

There was no visible evidence of physical damage noted as a result of the Random Frequency Vibration Test.

SINUSOIDAL VIBRATION TEST

TEST PROCEDURE

The submitted Nutation Sensors were subjected to a Sinusoidal Vibration Test in accordance with Paragraph 5.2 of the submitted GCA Technology Environmental Test Plan dated September 21, 1965. The following is a description of the Test Procedure as it was performed.

The Nutation Sensors were securely mounted to the Vibration Test fixture which , in turn, was securely fastened to the Vibration Exciter. A Crystal Accelerometer was then mounted as closely as practicable to one of the mounting points of the specimen and was used to control the input to the units. The Nutation Sensors were then subjected to Sinusoidal Vibration over the frequency range of 10 to 2000 cps at various levels of applied acceleration as shown in Table II.

Table II

Frequency (cps)	Axis	Level (0-peak G)
10 - 25	Thrust	± 1.5g
25 - 250	Z-Z	± 7.7g
250 - 400		±12.3g
400 - 2000		± 5.0g
10 - 17	Lateral	.33 in. d.a.
17 - 250	X-X	± 5.0g
250 - 400	and	±10.0g
400 - 2000	Y-Y	± 5.0g

The frequency range of 10 to 2000 cps was traversed logarithmically at a rate of 4 octaves/minute. This Procedure was performed once with the applied vibration acting along each of the three mutually perpendicular axes. The axes are defined in the Test Procedure for the Random Frequency Vibration Test.

SINUSOIDAL VIBRATION TEST

TEST PROCEDURE (continued)

The Nutation Sensors were electrically monitored during Vibration by an Engineering Representative of GCA Technology Division. Upon completion of the entire Vibration Test, the units were visually examined for evidence of physical damage.

TEST RESULTS

There was no visible evidence of physical damage noted as a result of the Sinusoidal Frequency Vibration Test. All Electrical Test Data was retained by the Engineering Representative of GCA Technology Division.

Test Report No. NT-3097-11 No. of Pages 8

APPENDIX III

Report of Test on

NUTATION SENSORS

Sinusoidal and Random Frequency Vibration Tests

for

GCA Technology Division

Associated Testing Laboratories, Inc.

Burlington, Massachusetts

Date June 1, 1966

	Prepared	Checked	Approved
By	T. Jarek	C. Bryan	D. C. Jensen
Signed	T. Jarek	C. Bryan	D. C. Jensen
Date	6/1/66	6/1/66	6/1/66

Administrative Data

1.0 Purpose of Test:

To determine the effects on the submitted Nutation Sensors when they are subjected to Sinusoidal and Random Frequency Vibration Tests when performed in accordance with the referenced Specification and the Test Procedures of this Report.

2.0 Manufacturer: GCA Technology Division
A Division of GCA Corporation
Bedford, Massachusetts

3.0 Manufacturer's Type or Model No.: Flight Units

4.0 Drawing, Specification or Exhibit: GCA Technology Division Environmental Test Plan dated September 21, 1965.

5.0 Quantity of Items Tested: Two (2) (Serial Nos. A6-0282-4 and A6-0282-5.)

6.0 Security Classification of Items: Unclassified

7.0 Date Test Completed: May 25, 1966

8.0 Test Conducted By: **Associated Testing Laboratories, Inc.**
NEW ENGLAND DIVISION

9.0 Disposition of Specimens: Returned to GCA Technology Division.

10.0 Abstract:

The submitted Nutation Sensors were subjected to Random Frequency Vibration over the frequency range of 20 to 2000 cps at an overall acceleration level of 7.3g's rms. Upon completion of each axis of vibration, the test specimens were visually examined for evidence of physical damage and none was noted.

The Nutation Sensors were then subjected to Sinusoidal Vibration

10.0 Abstract (continued)

over the frequency range of 10 to 2000 cps at various levels of applied acceleration up to a maximum of ±12.3g's. Following completion of each axis of vibration, the test specimens were visually examined for evidence of physical damage and none was noted.

LIST OF APPARATUS

Item	Manufacturer	Model No.	Accuracy	Calibration Date	Calibration Date Due
Vibration System consisting of:	MB Electronics		Freq.±2% Ampl.±5%	5-17-66	8-17-66
Vibration Exciter		C-50			
Power Amplifier		4150MB			
Control Console		T130MC			
Accelerometer	Endevco Corporation	2215-C		4-25-66	7-25-66
Random Console	Ling Electronics		±5%	5-12-66	6-12-66
Random Analyzing System	Ling Electronics			5-23-66	6-23-66
Electronic Counter	Hewlett-Packard	521A	±1 count	5-9-66	8-9-66
Timer	Dimco-Gray Company	165	±1 sec.	12-7-65	6-7-66
Multimeter	AVO, Ltd.	8-Mark II		3-21-66	6-21-66

RANDOM FREQUENCY VIBRATION TEST

TEST PROCEDURE

The submitted Nutation Sensors were subjected to a Random Frequency Vibration Test in accordance with Paragraph 5.2 of GCA Technology Division Environmental Test Plan dated September 21, 1965. The following is a description of the Test Procedure as it was performed.

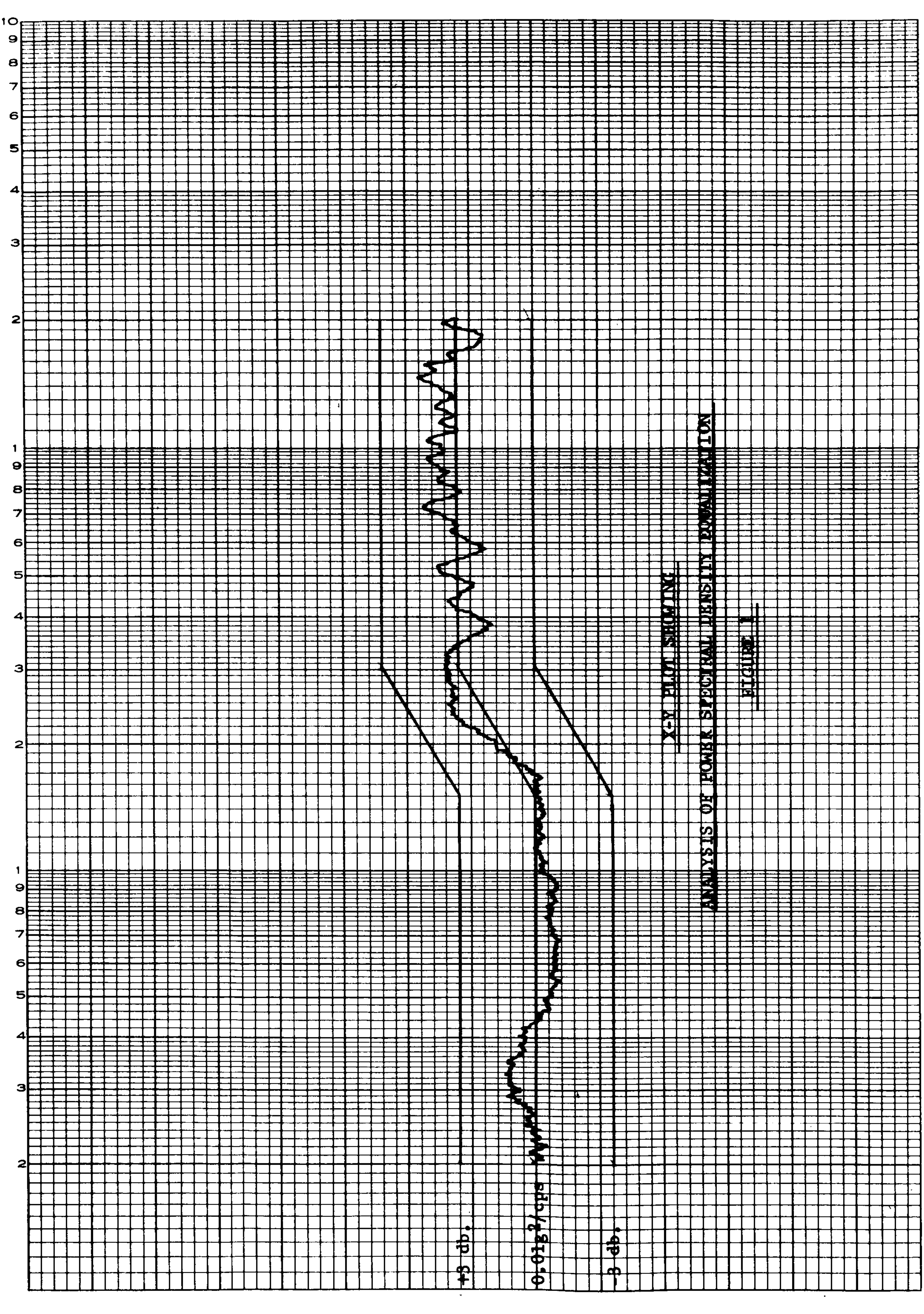
The Nutation Sensors were securely fastened to a Vibration Test fixture which, in turn, was securely fastened to the Vibration Exciter. A Crystal Accelerometer was then mounted to the test fixture and electrically connected to the Vibration Test equipment. However, prior to mounting the test specimen to the fixture, the Vibration System and fixture were equalized at the actual test levels shown in Table I. The System used for equalization contained 44 parallel band-pass filters with individual attenuators for spectrum shaping. Each filter had a maximum bandwidth of 50 cps. The Random Frequency System was equalized at the power spectral density levels shown below:

Table I

Frequency (cps)	PSD Level (g^2/cps)
20 - 150	0.01
150 - 300	+3 db/octave
300 - 2000	0.02

Tolerance ±3 db.

Upon completion of equalization, an analysis of the Random signal was performed by plotting the power spectral density level on an X-Y Recorder. This was performed using a 50 cps bandwidth tracking filter from 100 to 2000 cps and a 10 cps bandwidth tracking filter from 20 to 100 cps. The X-Y Plot was then used to verify that the Random signal levels were within the Specification limits (see Figure 1).



X-Y PLOT SHOWING

ANALYSIS OF POWER SPECTRAL DENSITY EQUALIZATION

FIGURE 1

RANDOM FREQUENCY VIBRATION TEST

TEST PROCEDURE

After equalization, the test specimen was securely mounted to the test fixture and subjected to the Random Frequency Vibration at the desired test level for a period of two minutes. This Procedure was performed with the applied vibration acting along each of the three mutually perpendicular axes. The axes are defined as follows:

Axis X - Parallel to the minor axis and the mounting base of each unit.

Axis Y - Parallel to the major axis and the mounting base of each unit.

Axis Z - Perpendicular to the mounting base of each unit.

During vibration, the Nutation Sensors were monitored by an Engineering Representative of GCA Technology Division. Upon completion of each axis of vibration, the test specimens were visually examined for evidence of physical damage.

TEST RESULTS

There was no visible evidence of physical damage noted as a result of the Random Frequency Vibration Test.

SINUSOIDAL VIBRATION TEST

TEST PROCEDURE

The submitted Nutation Sensors were subjected to a Sinusoidal Vibration Test in accordance with Paragraph 5.2 of the submitted GCA Technology Environmental Test Plan dated September 21, 1965. The following is a description of the Procedure as it was performed.

The Nutation Sensors were securely mounted to the Vibration Test fixture which, in turn, was securely fastened to the Vibration Exciter. A Crystal Accelerometer was then mounted as closely as practicable to one of the mounting points of the specimen and was used to control the input to the unit. The Nutation Sensors were then subjected to Sinusoidal Vibration over the frequency range from 10 to 2000 cps at various levels of applied acceleration as shown in Table II.

Table II

Frequency (cps)	Axis	Level (0-peak G)
10 - 25	Thrust	± 1.5g
25 - 250	Z-Z	± 7.7g
250 - 400		±12.3g
400 - 2000		± 5.0g
10 - 17	Lateral	.33 inch d.a.
17 - 250	X-X	± 5.0g
250 - 400	and	±10.0g
400 - 2000	Y-Y	± 5.0g

The frequency range of 10 to 2000 cps was traversed logarithmically at a rate of 4 octaves/minute. This Procedure was performed once with the applied vibration acting along each of the three mutually perpendicular axes. The axes are defined in the Test Procedure for the Random Frequency Vibration Test.

SINUSOIDAL VIBRATION TEST

TEST PROCEDURE (continued)

The Nutation Sensors were electrically monitored during Vibration by an Engineering Representative of GCA Technology Division. Upon completion of the entire Vibration Test, the units were visually examined for evidence of physical damage.

TEST RESULTS

There was no visible evidence of physical damage noted as a result of the Sinusoidal Vibration Test. All Electrical Data was retained by the Engineering Representative of GCA Technology Division.