AD-A134 882 A DETAILED EVALUATION OF THE ENDEVCO MODEL 7302 (TRADE NAME) ANGULAR ACCELEROMETER(U) NAVAL BIODYNAMICS LAB NEW ORLEANS LA G C WILLEMS AUG 83 NBDL-83R009 1/1

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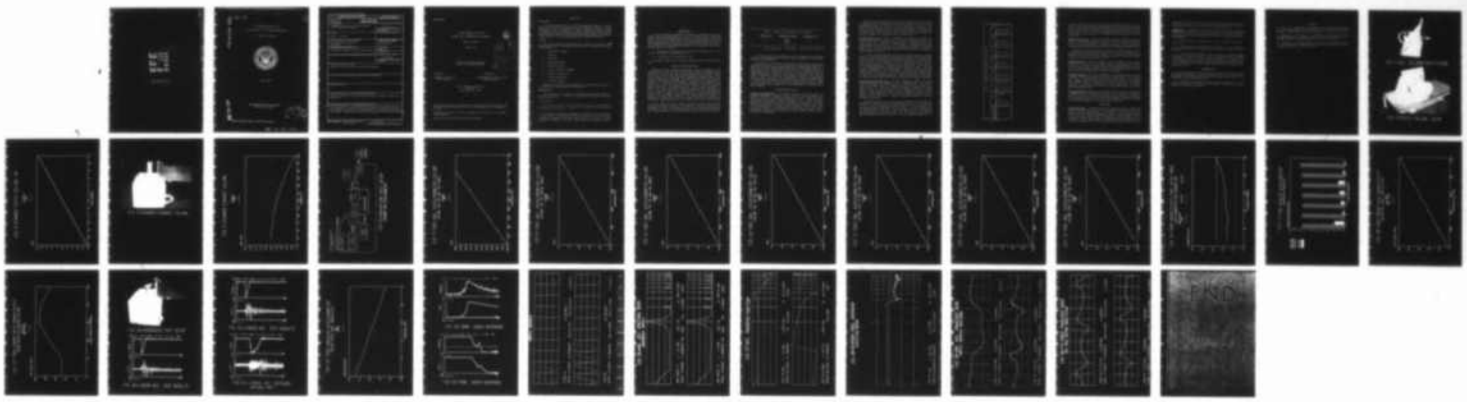

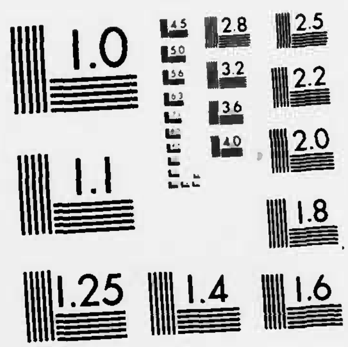

MICROCOPY RESOLUTION TEST CHART
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AD-A134 882

NBDL - 83R009

A DETAILED EVALUATION OF THE ENDEVCO MODEL 7302(R) ANGULAR ACCELEROMETER

Gilbert C. Willems

August 1983

NAVAL BIODYNAMICS LABORATORY
New Orleans, Louisiana

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER NBDL-83R009	2. GOVT ACCESSION NO. AD-A134 882
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) A Detailed Evaluation of the Endevco Model 7302(R) Angular Accelerometer	5. TYPE OF REPORT & PERIOD COVERED Research Report
	6. PERFORMING ORG. REPORT NUMBER NBDL-83R009
7. AUTHOR(s) Gilbert C. Willems	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Biodynamics Laboratory Box 29407 New Orleans, LA 70189	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS M0097PN001-5001
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Medical Research and Development Command	12. REPORT DATE August 1983
	13. NUMBER OF PAGES 35
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Angular Accelerometer, Calibration Techniques, Accelerometer, Acceleration Measurement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study docuemnts a calibration technique for angular accelerometers and the performance of the Endevco 7302(R) accelerometer. Parameters evaluated are: Linearity, sensitivity, crossaxis response, temperature effects, transient and frequency response, spectral fidelity and linear acceleration sensitivity.

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A DETAILED EVALUATION OF THE ENDEVCO MODEL 7302® ANGULAR ACCELEROMETER

Gilbert C. Willems

August 1983

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SUMMARY PAGE

THE PROBLEM

An important parameter in the study of biomechanical response to various stimuli is the angular acceleration of certain anatomical segments. Current preferred practice is to compute these values indirectly, using data acquired via arrays of linear accelerometers. A small, lightweight transducer capable of performing angular acceleration measurements directly has the potential of reducing both the number of required data acquisition channels, and computational complexity. This report evaluates such a candidate transducer.

FINDINGS

This study documents the performance of a sample of the Endevco 7302® angular accelerometer. Experimentally derived data are presented concerning the following:

a. Calibration technique

b. Linearity

c. Sensitivity

d. Temperature effects

e. Crossaxis response

f. Linear acceleration response

g. Spectral characteristics

h. Frequency dependency

i. Transient response

Subject to the limitations discussed in the text, the device seems to be a viable means of measuring angular accelerations.

RECOMMENDATIONS

User needs should be compared with performance capabilities and limitations of the transducer. If there is a suitable match, the device should perform effectively.

ACKNOWLEDGEMENTS

The author is indebted to Mr. D. Knouse for assistance in data acquisition and reduction; to Ms. G. Bourgeois for an excellent job in assembling and typing the manuscript.

Trade names of materials or products of commercial or non-government organizations are cited where essential for precision in describing research procedures or evaluation of results. Their use does not constitute official endorsement or approval of the use of such commercial hardware or software.

INTRODUCTION

In 1981 the Endevco Corporation introduced a "miniature" single axis angular accelerometer approximately $0.75\ in.^3$, weighing 17 grams. The quoted dynamic range was 50,000 radians/sec^2 rendering it potentially very useful for certain types of biodynamic research such as crash simulations and ejection event instrumentation. Based on some encouraging early reports (ref. 1, 2) Naval Biodynamics Laboratory (NBDL) purchased one of these devices in 1982 and has been performing a comprehensive evaluation for the past year. This evaluation consisted of two parts:

a. Development and validation of a calibration technique that is both accurate and amenable to automated operation.

b. Evaluation of the accelerometer itself.

This report summarizes the findings resulting from the evaluation program.

CALIBRATION DEVICE EVALUATION

Because high level angular accelerations cannot be sustained for any lengthy period of time, the only practical means of calibrating angular accelerometers is to impart some sort of oscillatory stimulus. An optical scanner was chosen by NBDL due to the high accuracy inherent in these devices. An optical scanner is a precision moving coil galvanometer generally used for the accurate positioning of mirrors. The specific device selected is General Scanning Corporation's G300 PD® scanner. In addition to its ruggedness and accuracy, it is equipped with a position transducer which provides not only feedback for closed loop control, but also provides a means of monitoring angular deflection. Its excursion range is ± 12.5°, which is sufficient to generate full scale drive down to 80 Hz and significant drive (3000 r/s/s) at 20 Hz. The scanner, mounted on a heavy duty base and with accelerometer in place is shown in Figure 1. The characteristics of the position measuring transducer and its signal conditioning were first measured statically, by means of the setup shown in Figure 2: The scanner shaft was coupled to a graduated 3" cylinder via a pair of gears with a 8:1 ratio, thus increasing the effective readout resolution of the scanner's position by a factor of 8.

A d.c. source was used to deflect the scanner via its power amplifier (GS 600 PD) through its range in 2° increments. The output voltage of the feedback circuit was monitored and recorded, and a linear regression analysis performed on the data. A representative plot of the results is shown in Figure 3. Three replications of this procedure produced the results in Table I.

Table I. Summary of Scanner Sensitivity Evaluation

Replication #	Sensitivity (v/deg)	Correlation (r^2)
1	.16135	1
2	.16106	1
3	.16114	1

Mean Sensitivity: .16118 v/deg Std. Dev: 1.5×10^{-4} v/d

The calibration obtained agrees well with the manufacturer's specification of 0.16 volts/deg., and the results show the scanner to have excellent linearity and repeatability.

Examination of the position pickoff and its associated electronics indicated the possibility of a frequency dependency for the position measurement, therefore a test was designed to establish what this dependency might be. A high quality, front surface mirror was attached to the scanner shaft and a laser placed so that its beam would reflect off the mirror (Figure 4) into a screen approximately 10 feet away. The mirror was then excited at a number of discrete frequencies, causing the laser beam to describe a line along the screen. It was then a matter of simple geometry to compute the actual deflection angle and to compare it with the measured value from the position pickoff. The results are summarized in Figure 5, which shows that there is indeed a frequency dependency. Thus, before the scanner position circuitry can be used to establish input acceleration to the accelerometer, a correction factor must be applied.

ACCELEROMETER EVALUATION

Principal Axis Sensitivity. The overall test setup used to evaluate the angular accelerometer is shown in Figure 6, which is self explanatory. The procedure followed for sensitivity determination was to calibrate the accelerometer at seven discrete frequencies from 20 to 250 Hz. At each frequency, seven different acceleration levels were applied, and in order to minimize experimental variability the entire experiment was replicated three times. The data obtained were corrected for the previously described scanner variation and then subjected to linear regression analysis. Figures 7-13 are representative results for this procedure for each frequency. Figures 7 and 8 in particular, indicate that linearity and resolution remain excellent even at low levels of acceleration.

The results of the regression analysis are summarized in Table II; Figure 14 depicts the mean sensitivity as a function of frequency, indicating some frequency dependency. The variability of the procedure, based on the three replications is shown in Figure 15. The mean sensitivity at 100 Hz is 7.68 v/r/s/s, which is almost 4% higher than the manufacturer's calibration, but since the detailed methodology of the latter is not known, no conclusion can be drawn at this time. As will be seen, variations in ambient temperature alone may account for a significant part of the difference.

Crossaxis Sensitivity. In order to determine this parameter, a fixture was built to hold the accelerometer with its sensitive axis perpendicular to the scanner shaft axis. The accelerometer was again calibrated as before, the results being shown in Figure 16. Additionally, the accelerometer was then rotated about its sensitive axis in 60° increments to determine if any asymmetry existed. As shown in Figure 17, the crossaxis response is indeed asymmetric, with the most sensitive orientation being 180° from the reference (serial number up) position.

In order to ascertain whether the crossaxis response was due to spurious inputs, a front surface mirror was bonded to the fixture and the laser again employed as depicted in Figure 18. Any spurious input into the sensitive axis while the fixture was being vibrated should have resulted in an elliptical trajectory for the laser beam, or at least a widening of the beam. The response magnitudes shown in Figures 16 and 17 would require inputs resulting in a vertical displacement of the laser beam ranging from .25 to .5 inches. No such displacements were observed, thus the response appears to be true crossaxis sensitivity of the accelerometer. However, even the worst case value is on the order of 1% of full scale, well within the manufacturer's specification of 2%; further, since the crossaxis sensitivity is proportional to input, the ratio remains invariant for lesser values of input. Spot checks at frequencies other than 100 Hz showed no significant frequency dependency.

Linear Acceleration Sensitivity. For these measurements, NBDL's 12" linear accelerator was used in conjunction with a lightweight sled. The accelerometer was rigidly fixed to the sled and the latter fired at levels up to 140G's; the sensitive axis was oriented both along and perpendicular to the thrust vector. If a transducer is truly acceleration sensitive, it should exhibit an output similar in shape to that measured from a linear accelerometer. No such response was noted as shown in Figures 19 (142.5G's) and 20 (122G's). These were tests in which the accelerometer sensitive axis was parallel with the thrust vector. Similar results were obtained for the perpendicular orientation.

Unfortunately, there is no way to ascertain whether the oscillatory response that is present is due to transducer sensitivity or a true input from the sled. Due to the necessary clearance between the sled slippers and the rail and the natural vibration modes of the sled, it is quite possible that the response shown is sled induced. This hypothesis tends to be reinforced by the data presented in Figure 21, a low level (8.8G) test with the transducer axis perpendicular to the thrust vector. The large negative peak occurs at end of the acceleration pulse which is the time of sled-piston separation. It

Table II. Summary of 7302 Sensitivity Evaluation

Frequency (Hz)	20		50		80		100		150		200		250	
Replication #	Sen.(v)	r^2	Sen.	r^2	Sen.	r^2	Sen.	r^2	Sen.	r^2	Sen.	r^2	Sen.	r^2
1	7.6725	.998	7.677	.999	7.592	1	7.691	1	7.712	1	7.807	1	8.109	1
2	7.637	.999	7.671	.999	7.60	1	7.678	1	7.715	1	7.804	1	8.099	1
3	7.648	1	7.672	.999	7.603	1	7.677	1	7.707	1	7.802	1	8.099	1

is quite likely that upon separation the sled "settled" causing the angular output. Also, the oscillatory mode sensed by the sled accelerometer appears to be the same frequency as that predominant frequency present in the angular accelerometer traces. Finally, it is evident on the high level tests (Figures 19 and 20) that the oscillatory response mode begins only after reversal of the input acceleration pulse, an additional possible indication of sled induced input.

Temperature Sensitivity. The steady state temperature dependency was determined by letting the transducer stabilize at three different temperature levels. The results, normalized to ambient (24.7°C) are shown in Figure 22. The variation of approximately 0.2%/deg.C corresponds to the manufacturer's "typical" specifications and is well within the published "maximum" range.

Temperature shock sensitivity was observed by instrumenting the accelerometer with a temperature probe and then rapidly cooling and heating the two transducers while recording their outputs. As is typical of solid state devices of this type (ref. 3), the accelerometer exhibited sudden large changes in output as depicted in Figures 23 and 24.

Response Fidelity. Figure 25 compares the accelerometer's output (bottom trace) with its input, i.e. the scanner's output. The apparent good match is verified by a spectral analysis (Figure 26) which again compares the transducer output with scanner position. The two signals appear spectrally identical; the slight increase in the amplitude of the harmonics may be due to the previously discussed sensitivity increase with frequency.

Resonant Frequency. The 7302 accelerometer is specified as having a resonant frequency of 2000-2250 Hz with an overshoot of approximately 12 db. As seen in Figure 27, the NBDL sample closely matches these values. The secondary peak, between 4 and 5 KHz, appears to be an artifact induced by the scanner, whose response between 3.5 and 5.5 KHz is shown in Figure 28: It is evident that there is a distinct discontinuity in the 4-4.5 KHz region. The overall transducer response appears to be that of an underdamped second order system with a damping ratio of 0.1.

Transient Response. Because of its underdamped nature, the 7302 accelerometer is susceptible to "ringing" when subjected to input transients. This is illustrated in Figure 29, where the top trace is the input to the transducer, and the bottom one is the latter's unfiltered response showing the "ringing" at the natural frequency. The results of filtering this signal with 1 KHz and 0.3 KHz filters respectively, are illustrated in Figure 30.

CONCLUSIONS

Calibration Method. The optical scanner with position feedback, as described herein, has proven to be an effective and accurate device for calibration of miniature angular accelerometers. It is, however, a low frequency device and beyond 300 Hz the angular displacements required to generate maximum output are so small that resolution deteriorates rapidly. This bandwidth, however, is amply sufficient for the type of experiments envisioned by NBDL, i.e. the type where no direct impact occurs. If higher frequency calibrations are desired, a lightweight disc may be installed concentrically with the accelerometer and its tangential acceleration monitored with a subminiature linear accelerometer mounted on its rim. The two monitoring devices would complement each other, each being used in its region of maximum resolution.

Accelerometer. The physical and electrical characteristics of the Endevco 7302® angular accelerometer are such as it seems to be a viable candidate to compete with currently used methods of instrumenting test subjects in biodynamics research of the type conducted at NBDL. Several cautions should be observed however:

a. Units should be calibrated at or near the expected temperature at time of test.

b. Sharp temperature transients should be avoided. In tests in which a steep temperature gradient is expected, the transducers should be thermally insulated.

c. Careful attention should be paid to filtering, preferably on-line filtering at the time of acquisition. The typical resonant peak of 12-14 db represents a 4 to 5-fold increase in output at resonance. If saturation is to be avoided the data path must be scaled such that expected data not exceed 20% of the acquisition system dynamic range, unless on-line filtering is used. Once saturation occurs, no amount of post-filtering will recover the data lost during that period.

RECOMMENDATIONS

1. A three-dimensional package consisting of three each orthogonal linear and angular accelerometers should be developed and tested in "side-by-side" experiments with currently used packages and evaluated by comparison to simultaneously acquired photographic data.

2. The calibration method described herein should be automated so that the angular accelerometers, if adopted can be routinely calibrated with the same ease as the currently used packages.

REFERENCES

1. Sill, R. D., Measurement of Angular and Linear Acceleration Sensitivities of the Endevco Model 7302, Proceedings of the 9th Annual International Workshop on Hman Subjects for Biomedical Research, 27 Sept. 1981, pp. 51-58.

2. Begeman, P. C. and King, A. I., Evaluation of the Endevco Model 7302 Angular Accelerometer, Proceedings of the 9th Annual International Workshop on Human Subjects for Biomedical Research, 27 Sept. 1981, pp. 51-58.

3. Willems, G., A Detailed Performance Evaluation of Subminiature Piezoresistive Accelerometers, Proceedings of the 23rd ISA Internatonal Instrumentation Symposium, May 1-5, 1977, pp. 531-540.

FIG 1-ACC. CALIBRATION FIXTURE

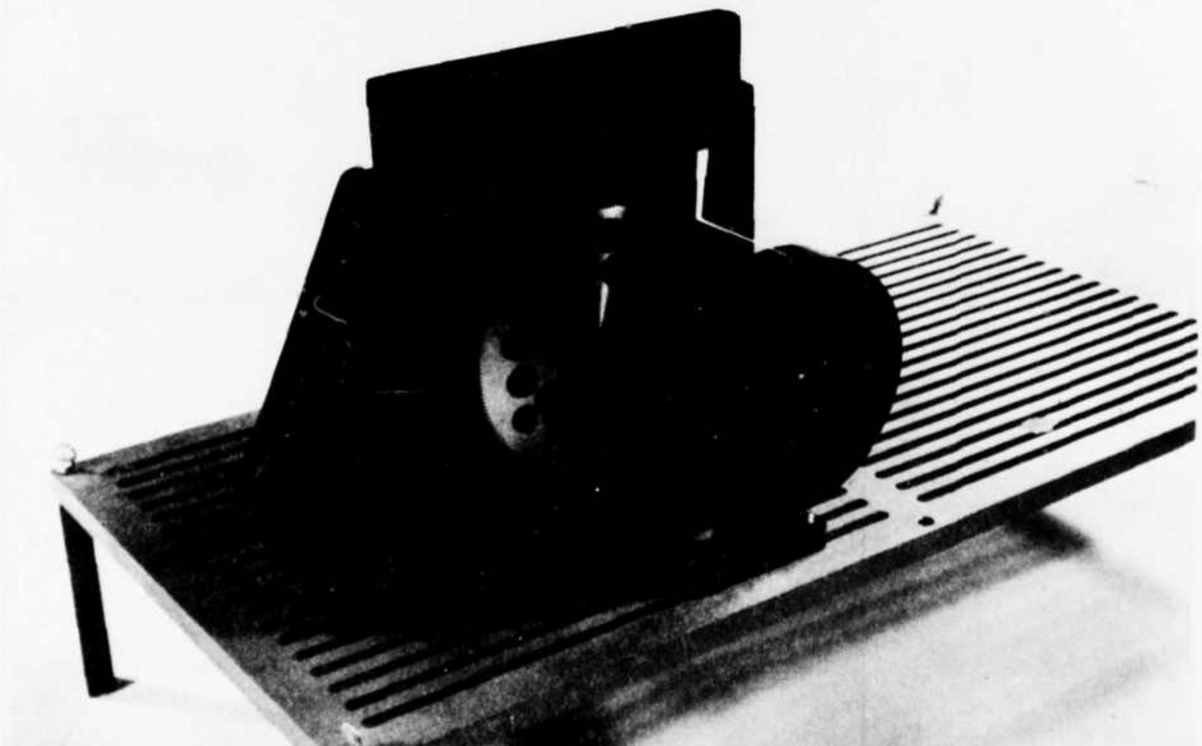
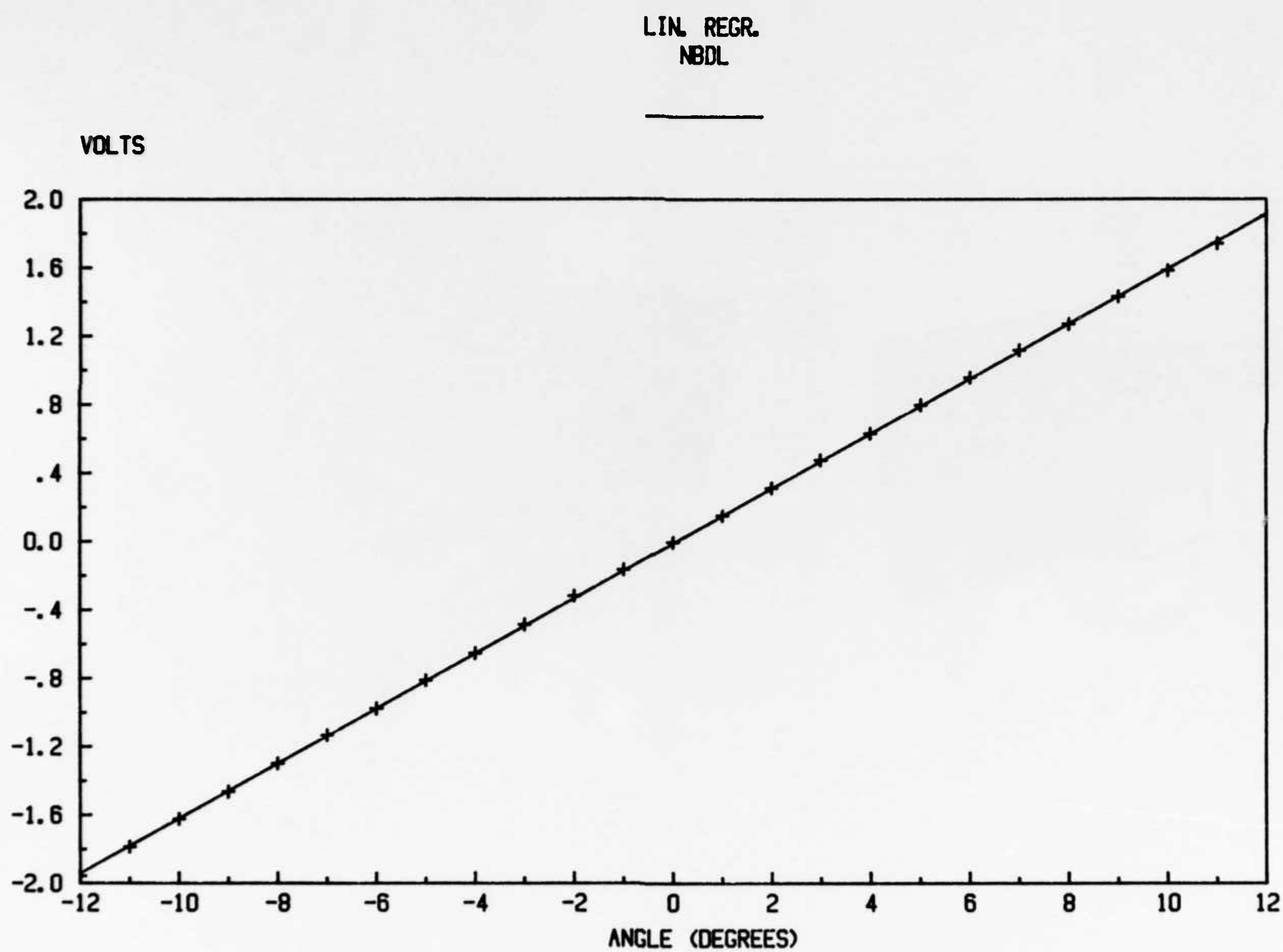


FIG 2-STATIC CALIBR. SETUP

FIG 3-SCANNER STATIC CALIBR. #3



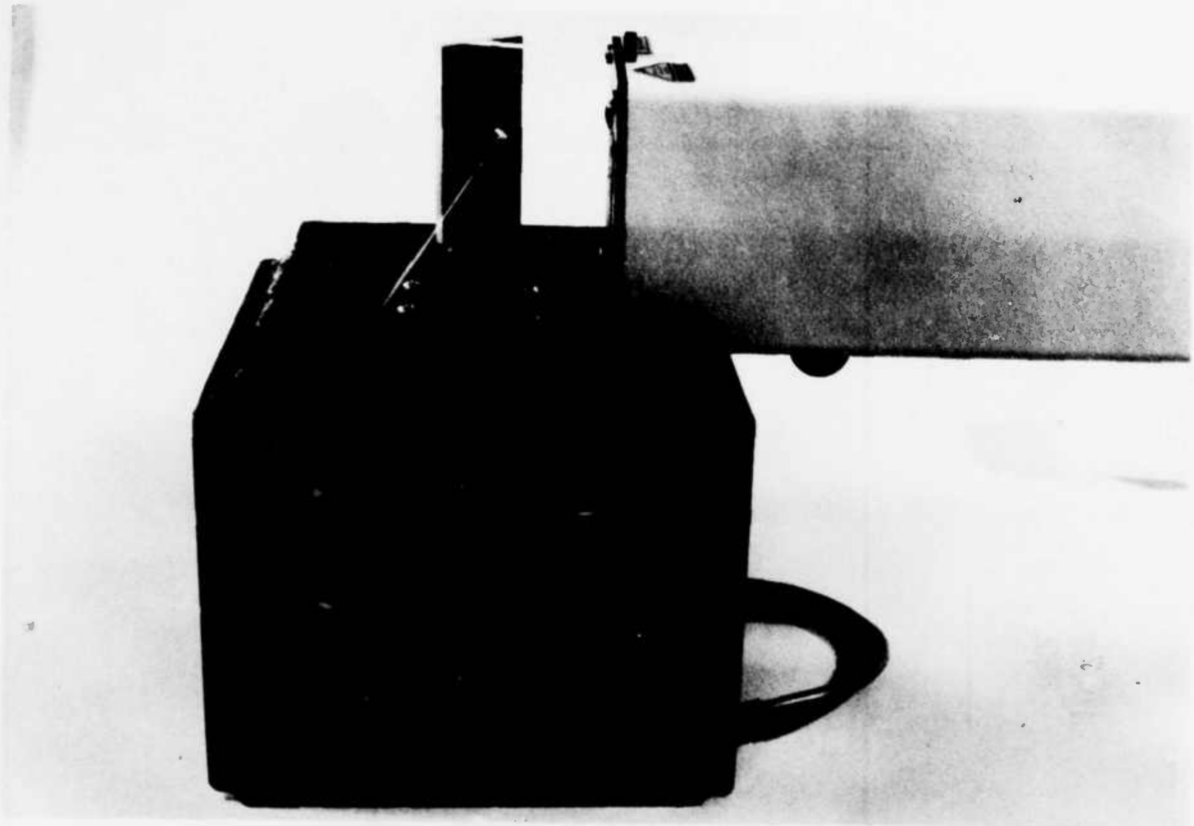
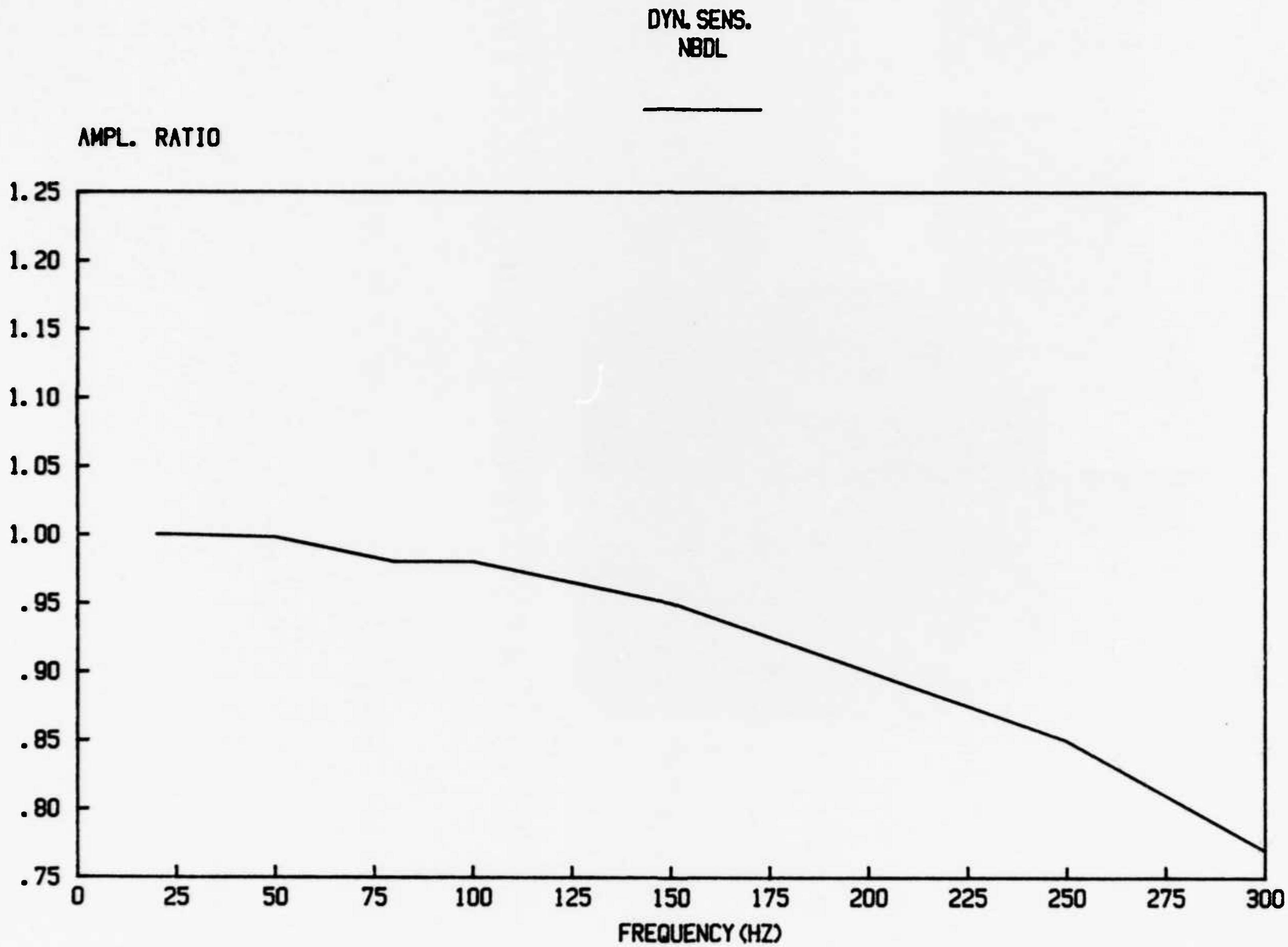


FIG 4-SCANNER DYNAMIC CALIBR.

FIG 5-SCANNER DYNAMIC CALIBR.



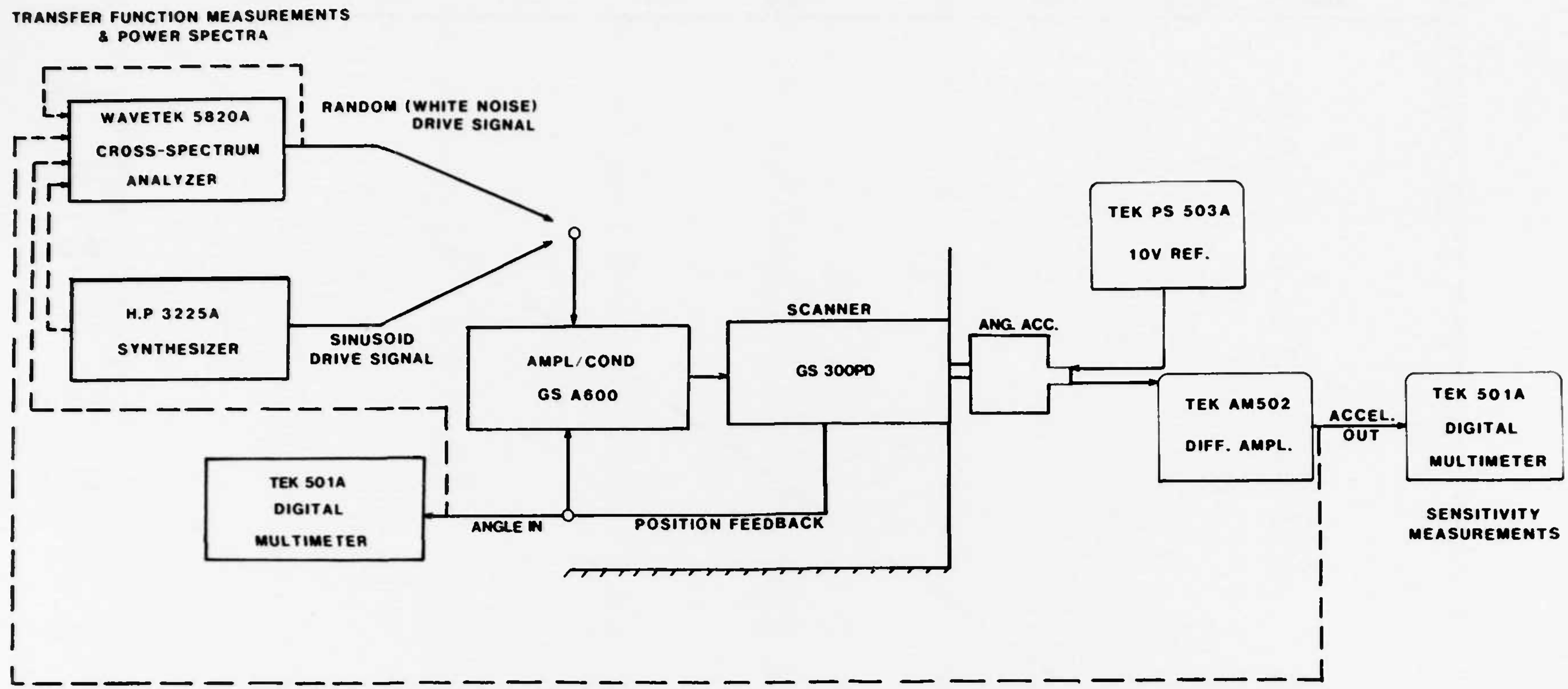


FIG 6-EVALUATION TEST SETUP
SCANNER AND ACCELEROMETER

FIG 7-7302 ANG. ACCELEROMETER CALIBR.

CALIBR. #2, 26 JAN '83 (20HZ)

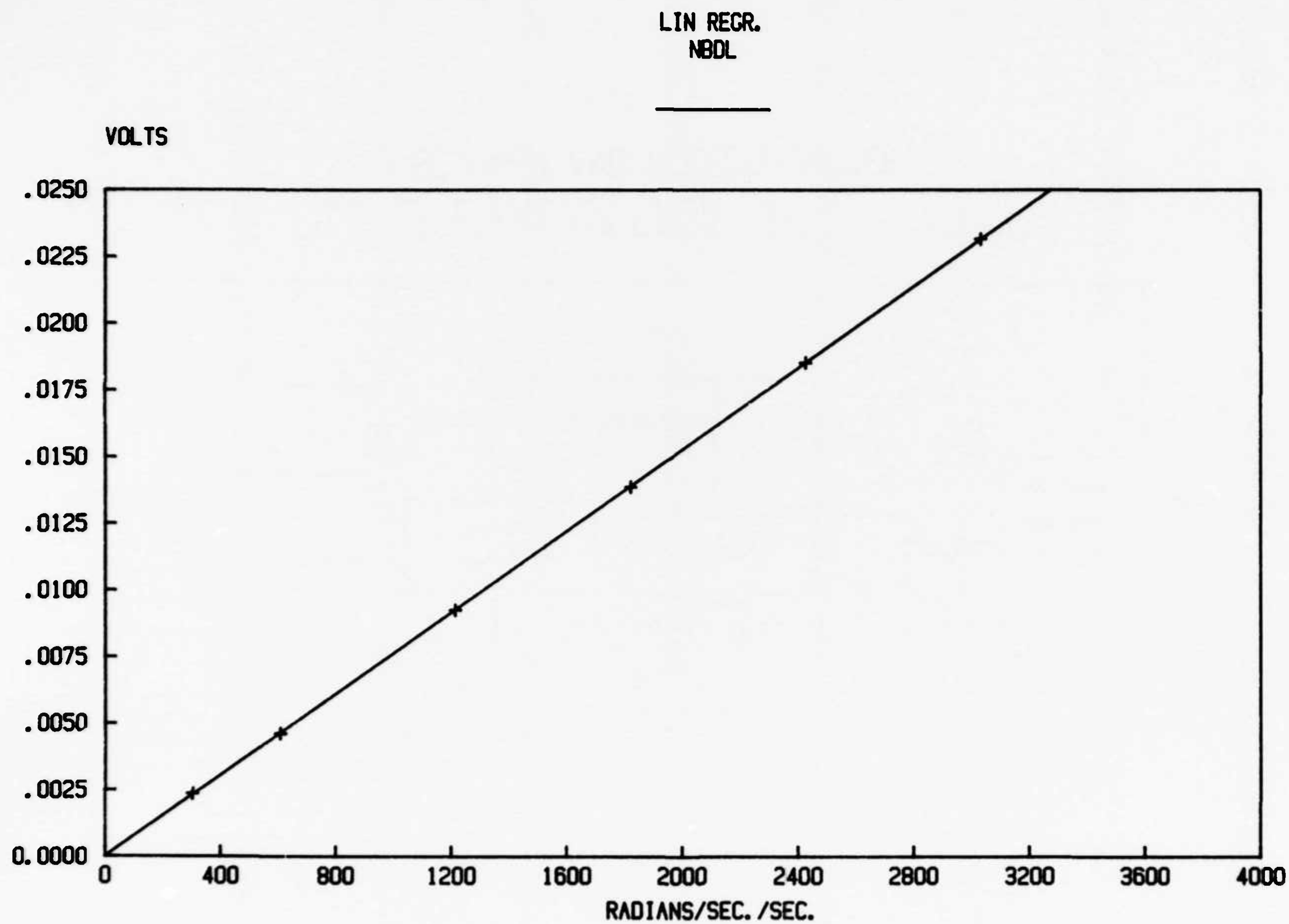


FIG 8-7302 ANG. ACCELEROMETER CALIBR.

CALIBR. #4, 25 JAN'83 (50HZ)

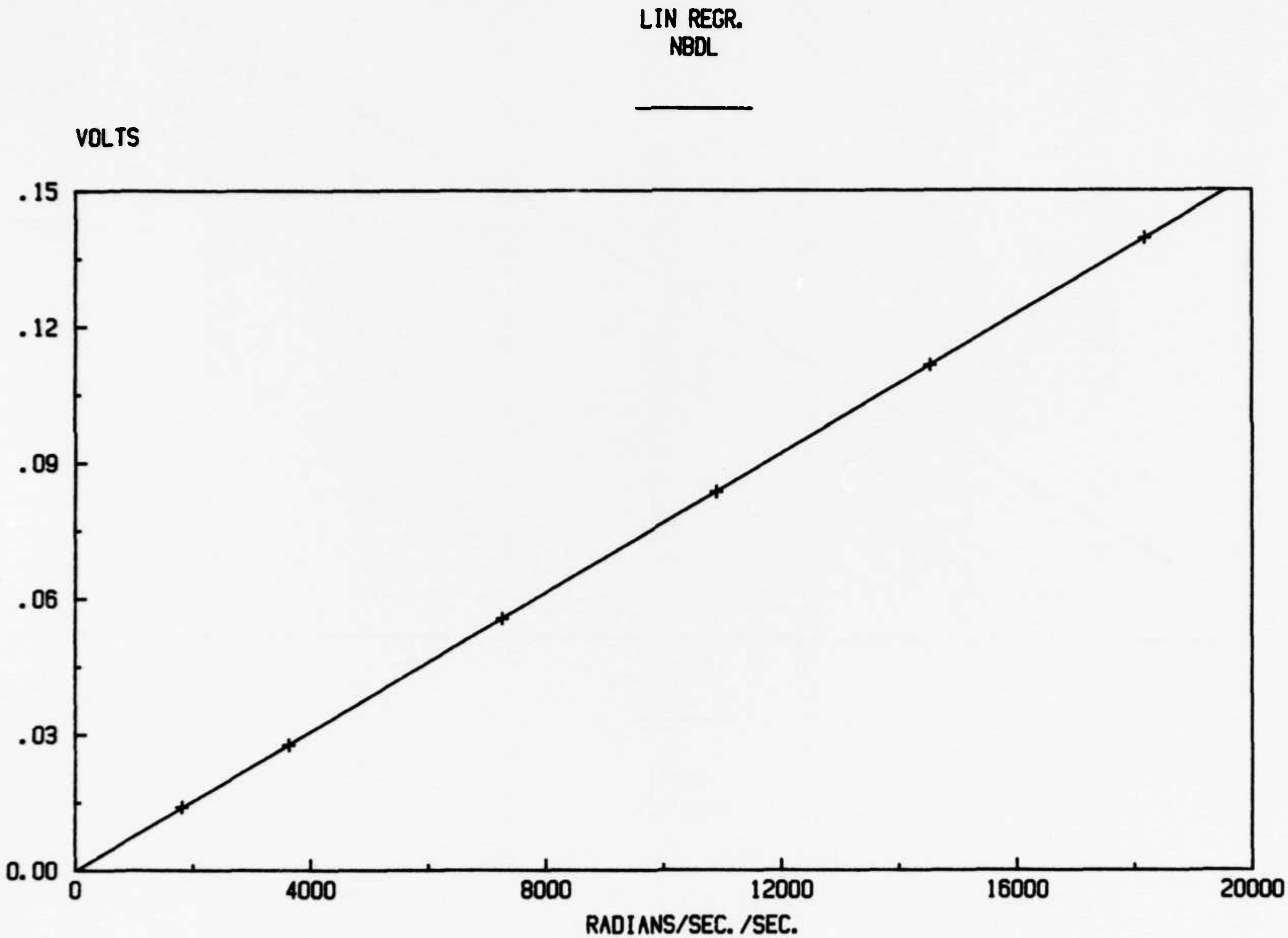


FIG 9-7302 ANG. ACCELEROMETER CALIBR.

CALIBR. #7, 25 JAN '83 (80HZ)

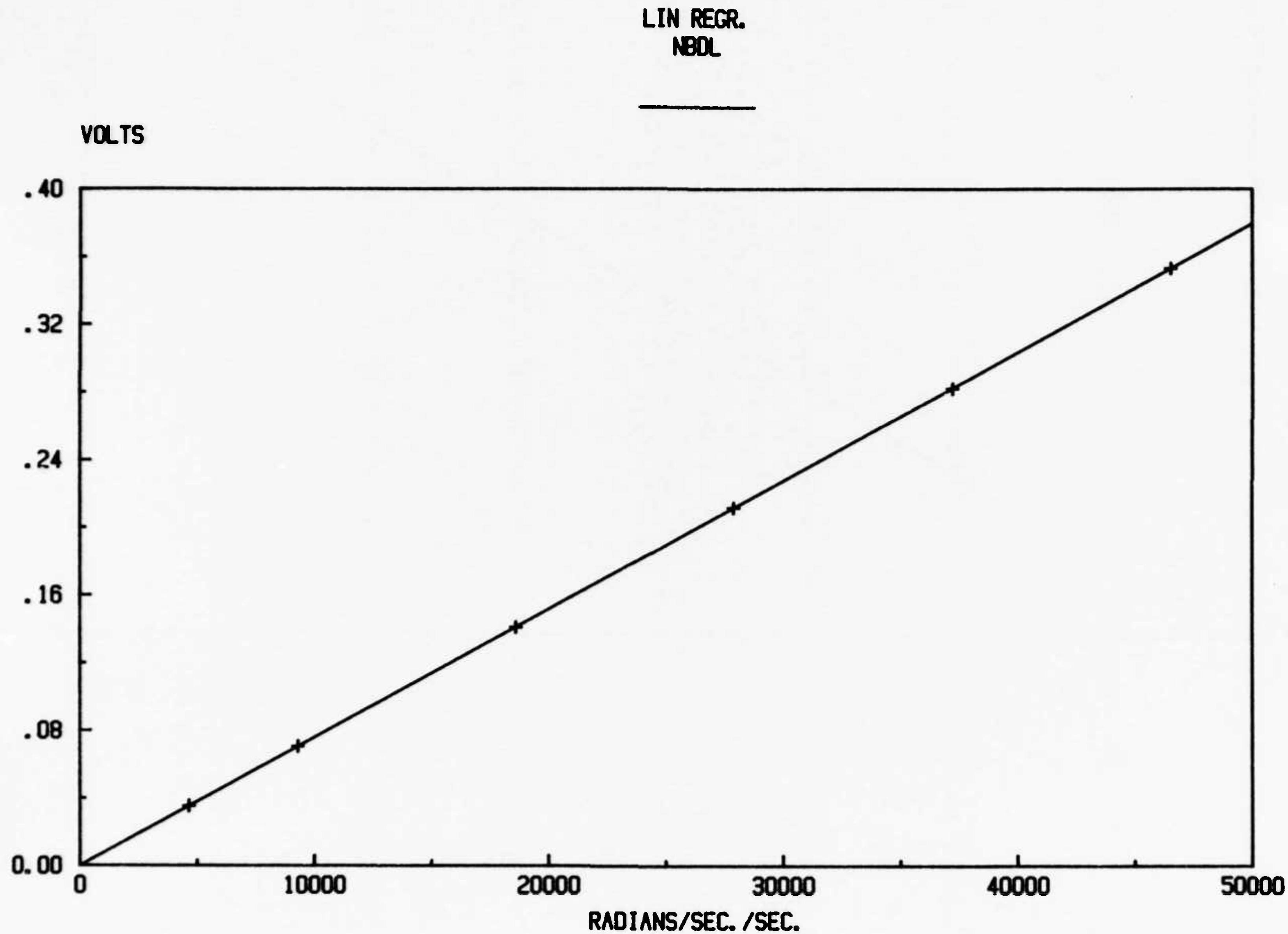


FIG 10-7302 ANG. ACCELEROMETER CALIBR.

CALIBR. #9, 20 JAN '83 (100 HZ)

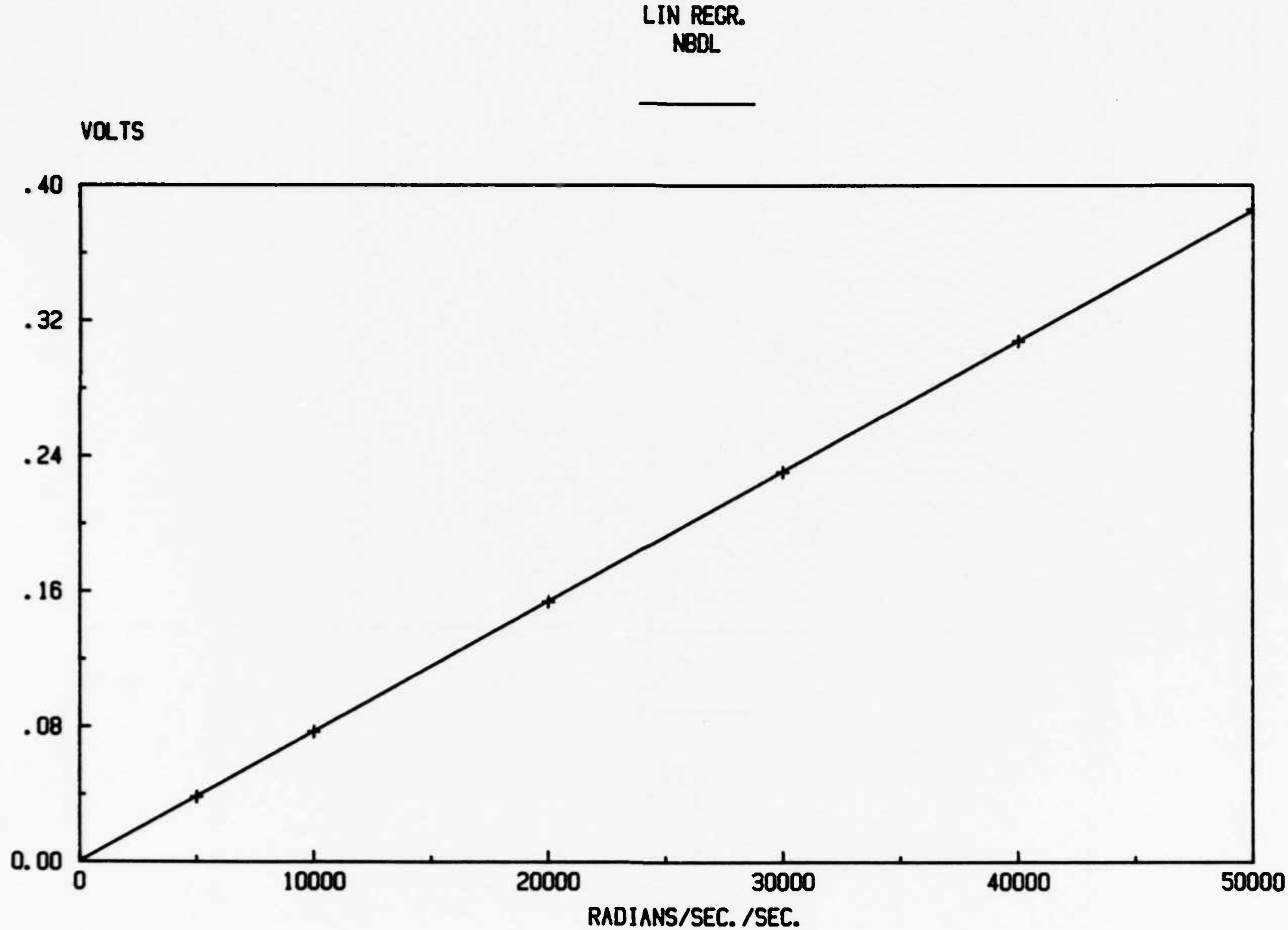


FIG 11-7302 ANG. ACCELEROMETER CALIBR.

CALIBR. #12, 3 FEB '83 (150HZ)

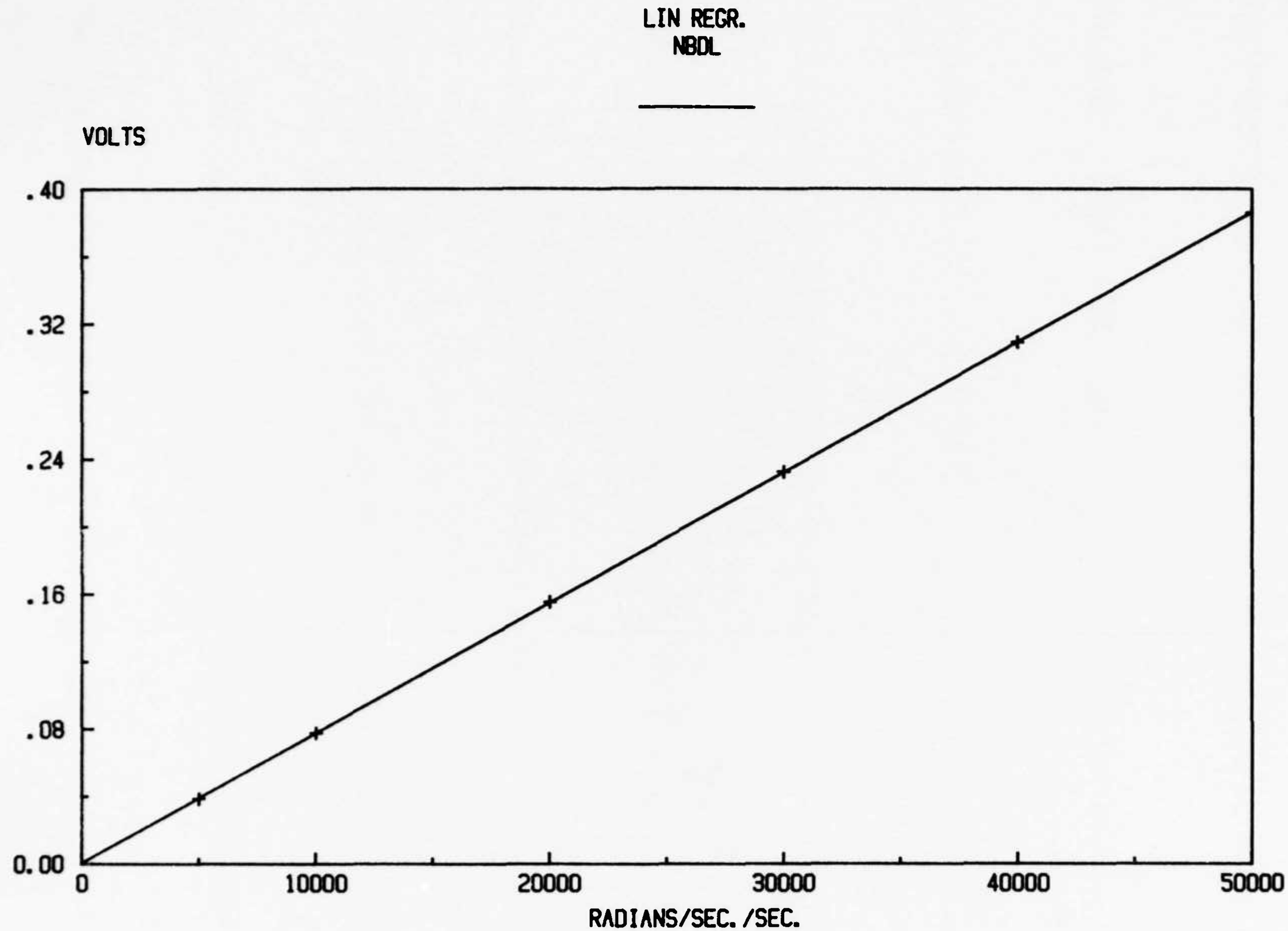


FIG 12-7302 ANG. ACCELEROMETER CALIBR.

CALIBR. #16, 21 JAN '83 (200HZ)

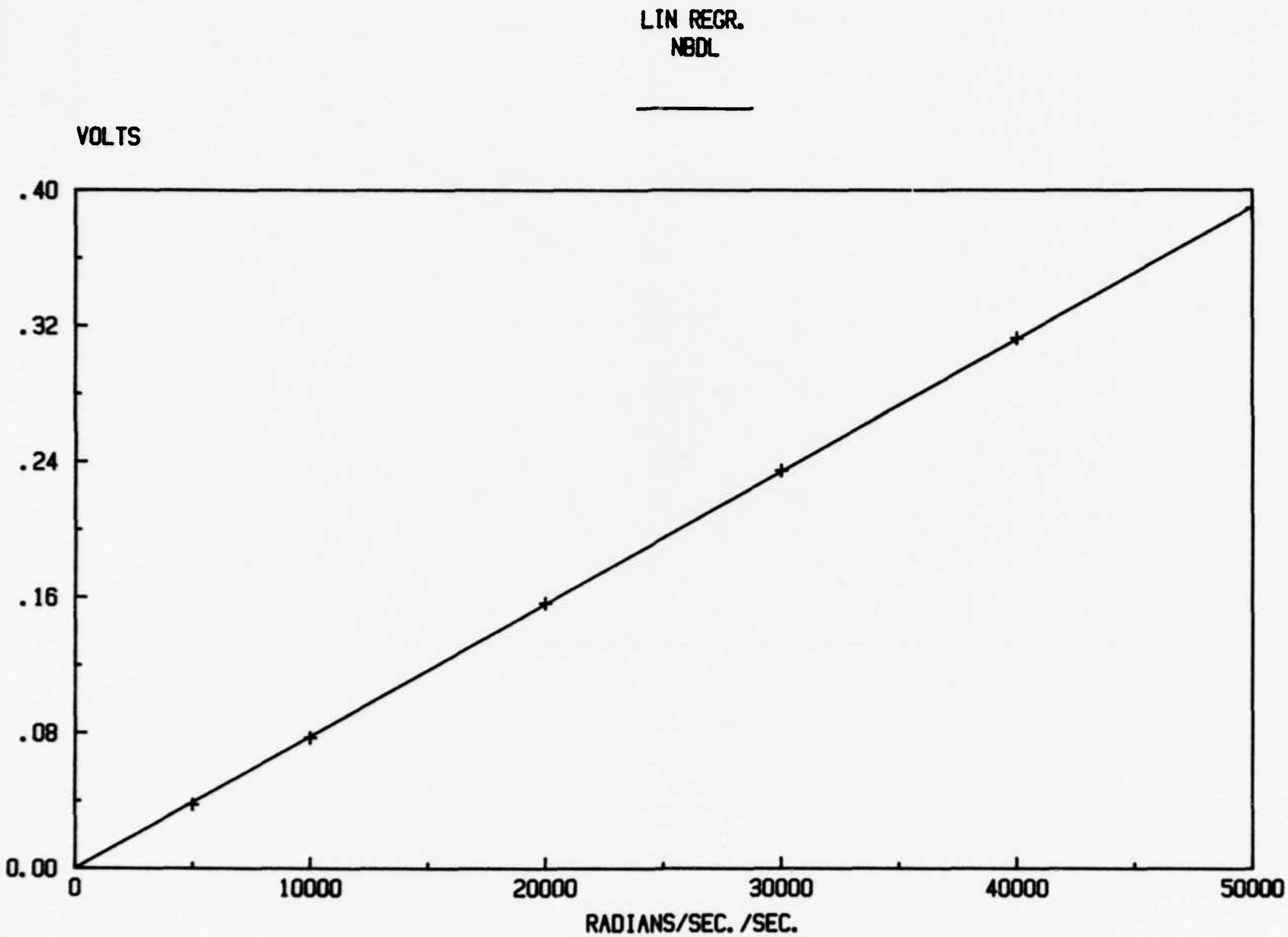


FIG 13-7302 ANG. ACCELEROMETER CALIBR.

CALIBR. #18, 25 JAN '83 (250HZ)

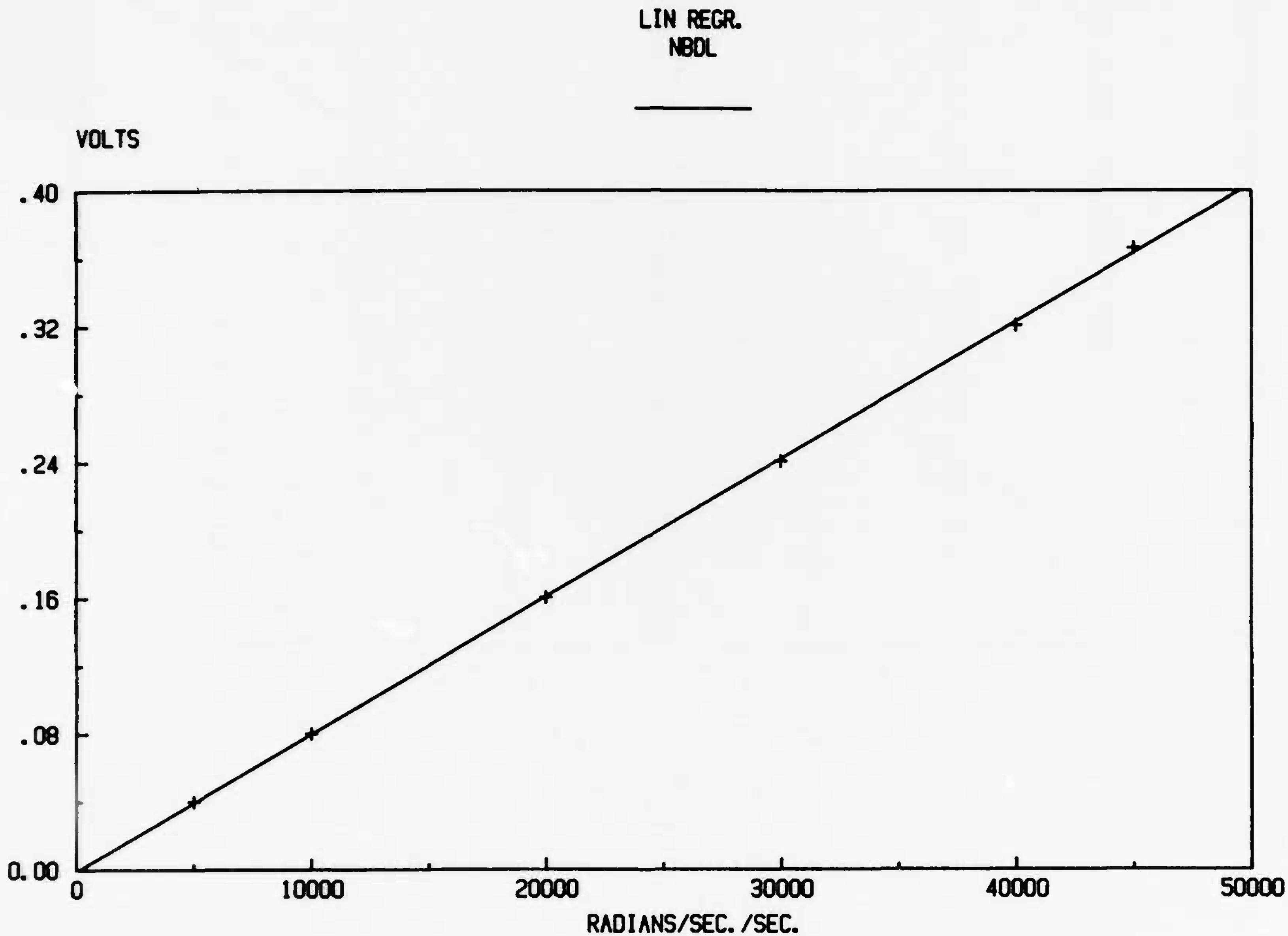


FIG 14-7302 SENSITIVITY VAR. WITH FREQ

DATA CORRECTED FOR SCANNER VAR.

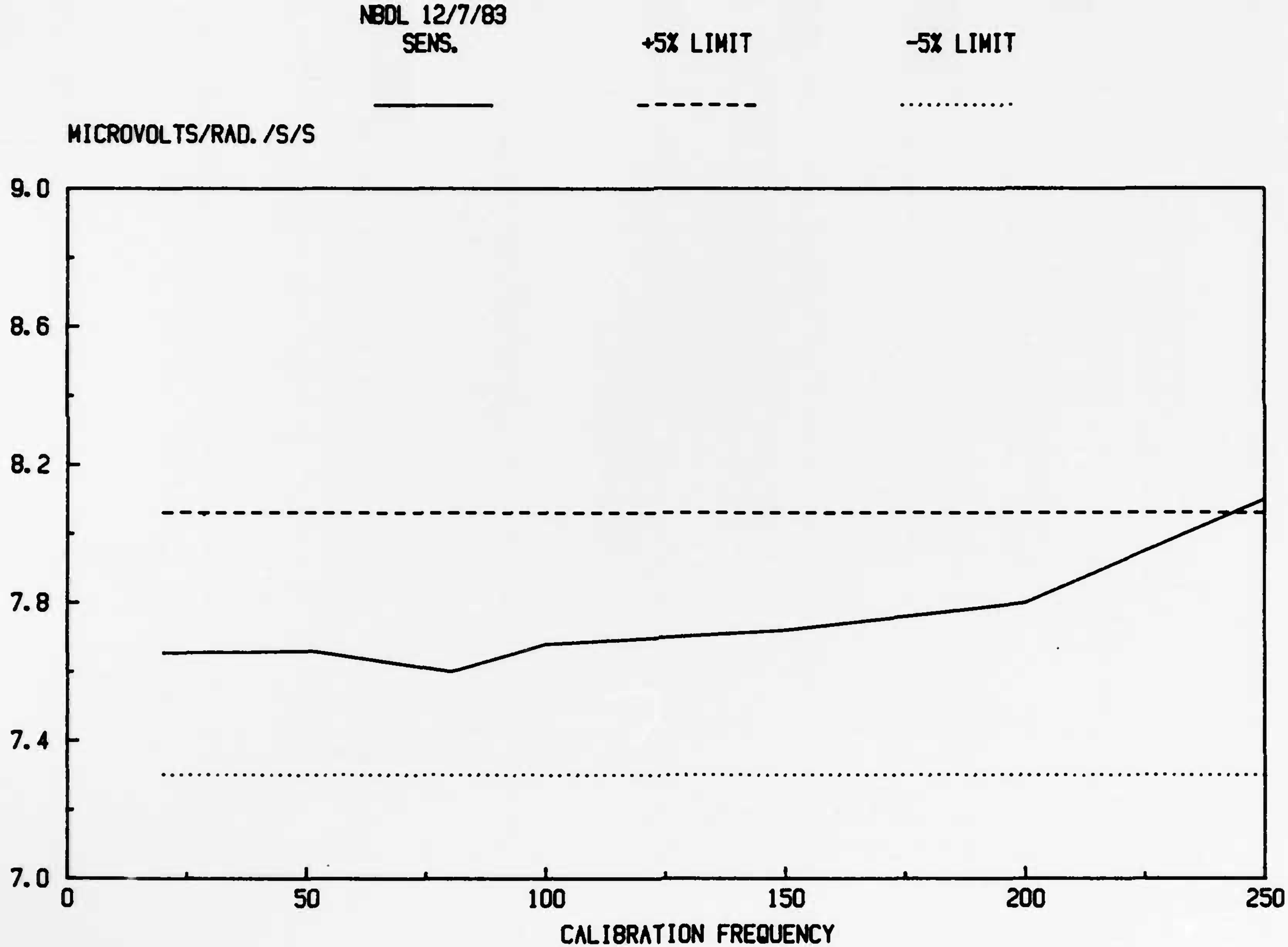


FIG 15-7302 ANGULAR ACCELEROMETER
CALIBRATION VARIABILITY

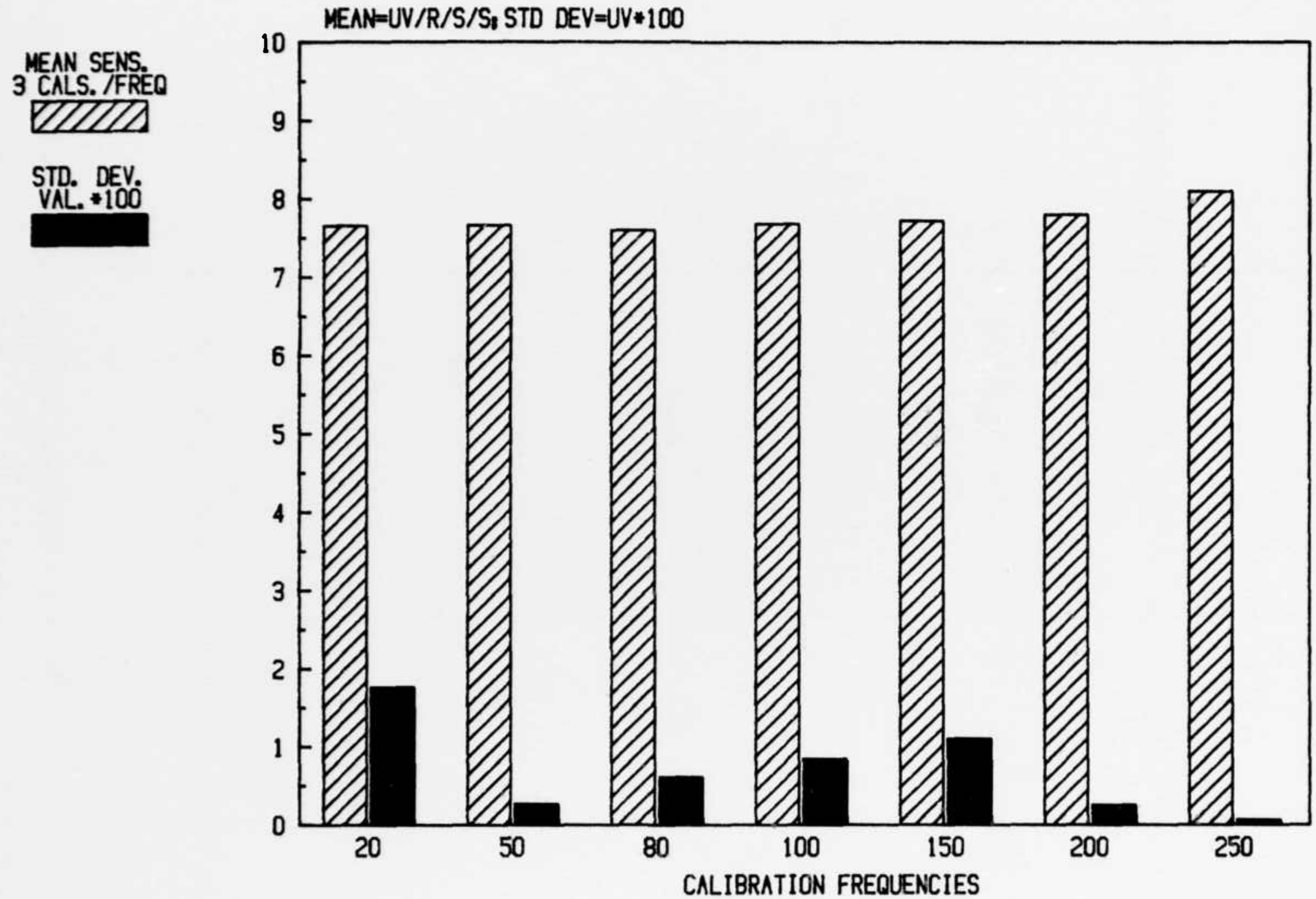


FIG 16-7302 CROSS AXIS SENSITIVITY

100 HZ CAL. REF. POS S.N. "UP"

LIN. REGR.
NBDL 7/12/83

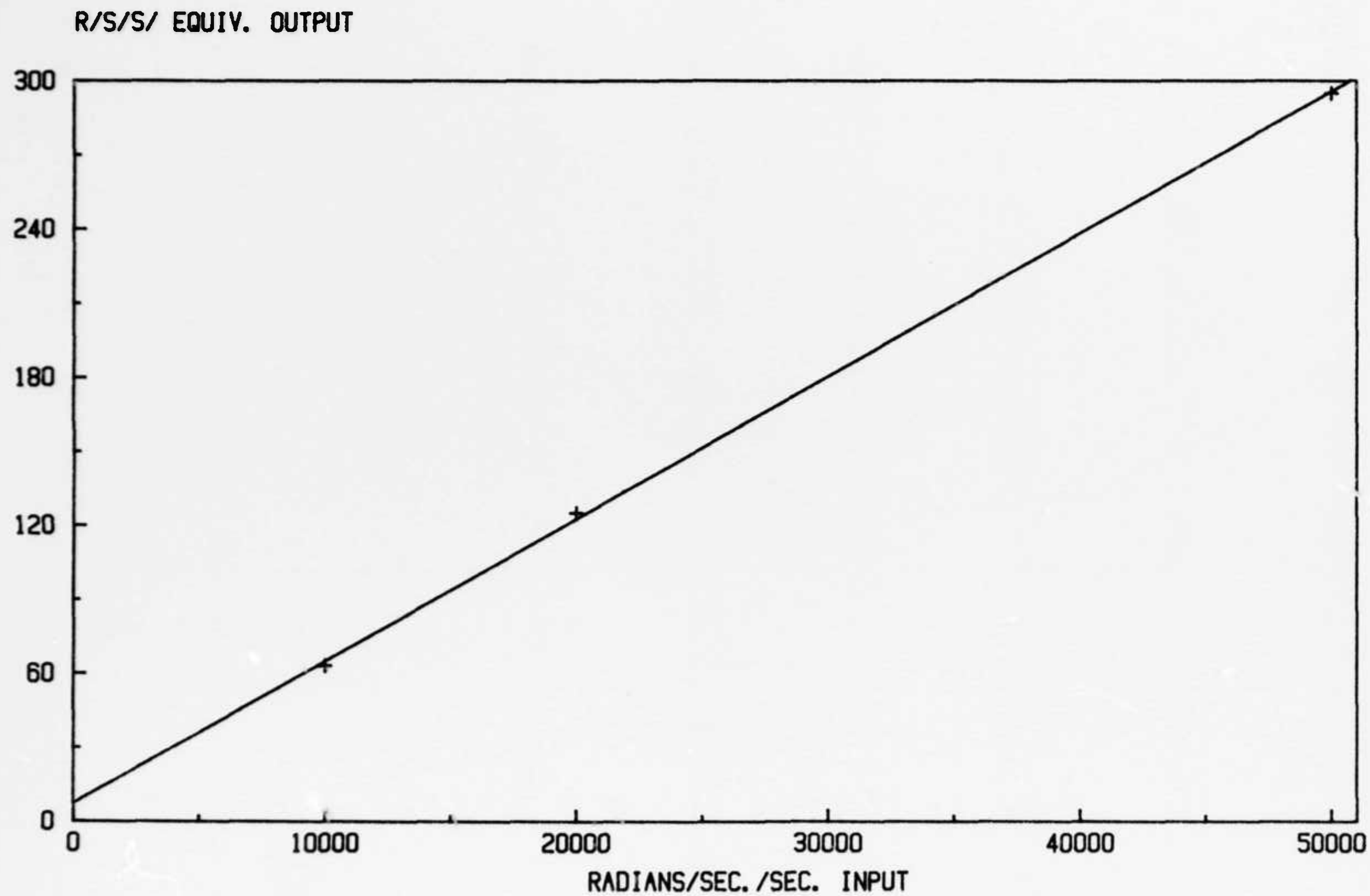
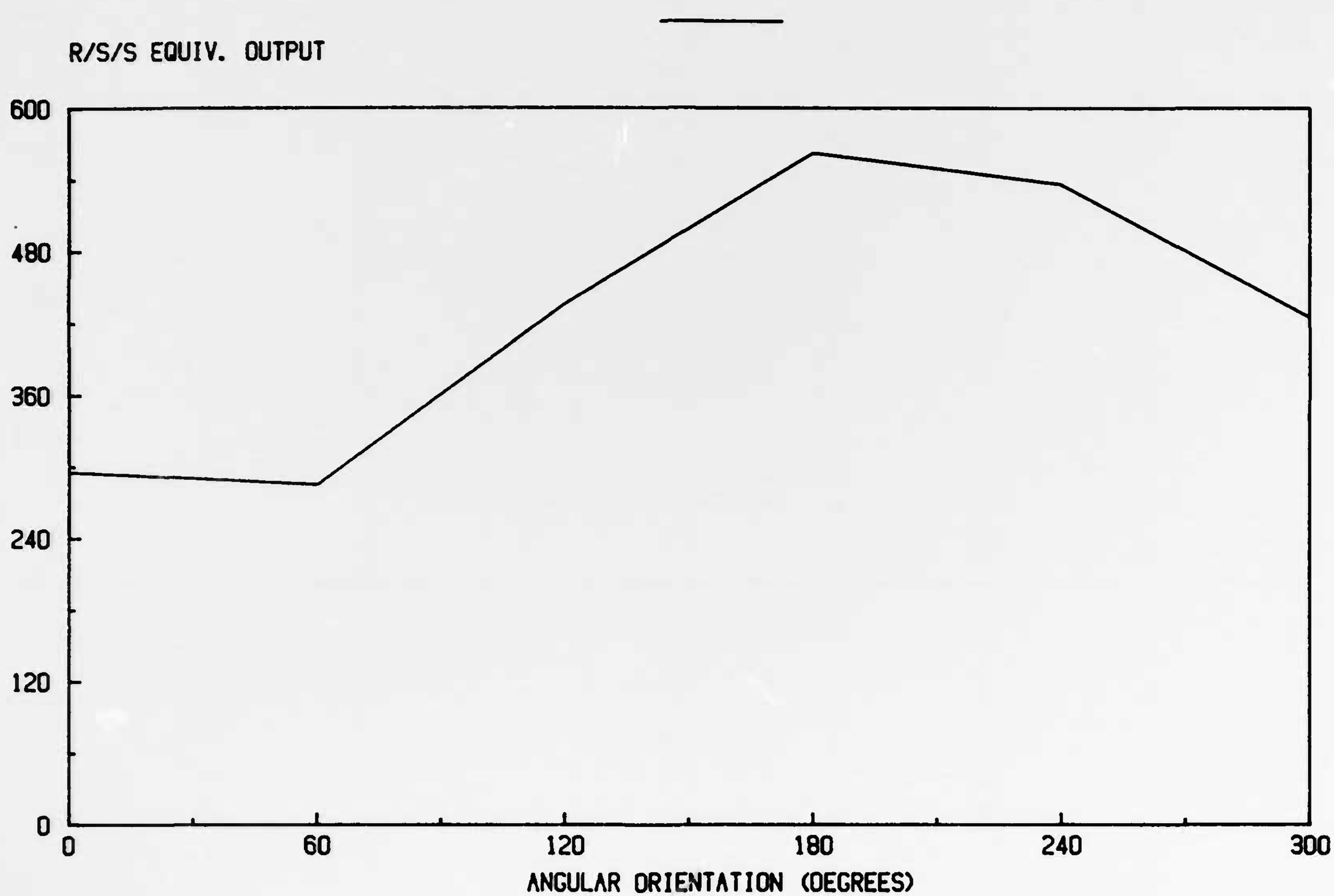


FIG 17-7302 CROSS AXIS SENSITIVITY

50000 R/S/S IN--OUTPUT VS POS.

100 HZ CAL
NBDL 7/12/83



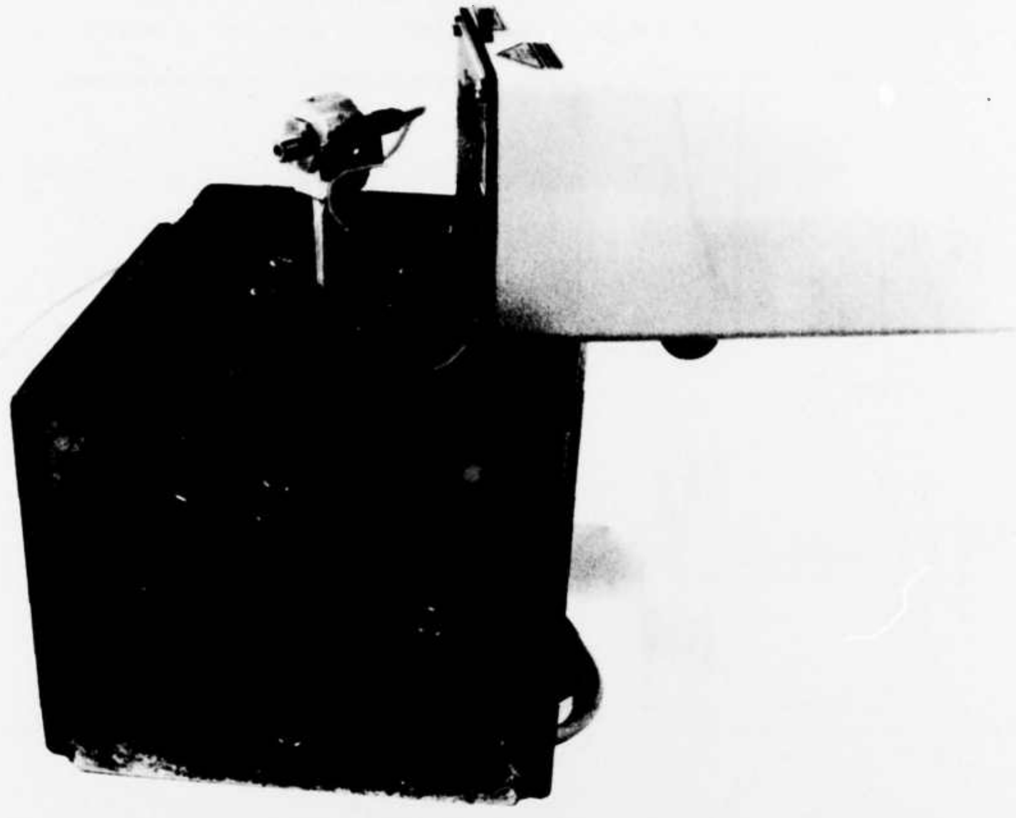


FIG 18-CROSSAXIS TEST SETUP

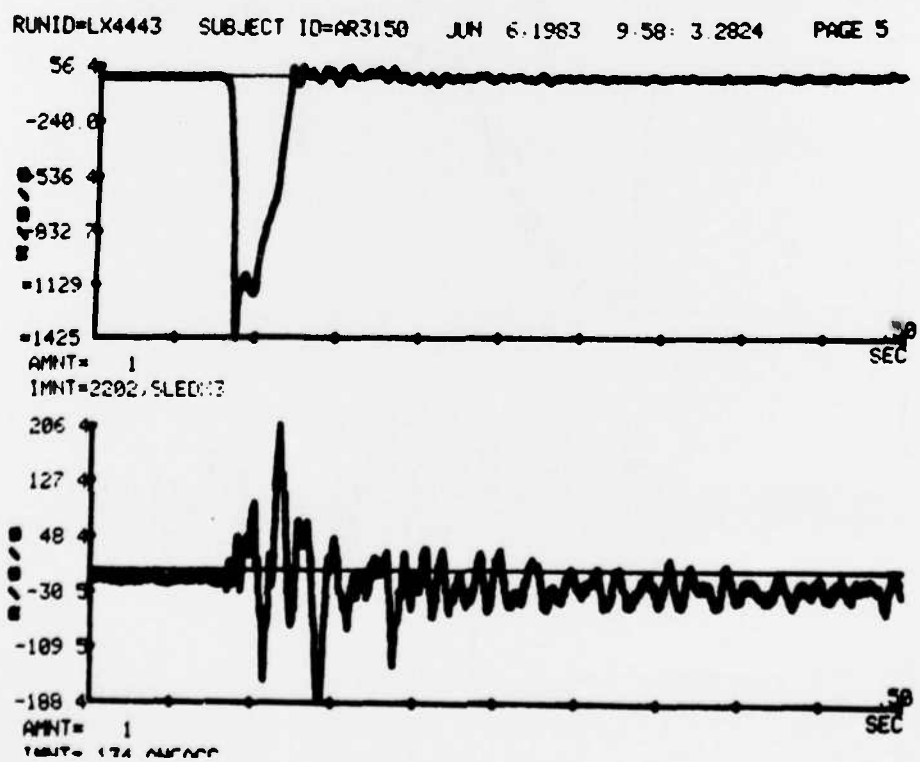


FIG 19-LINEAR ACC. TEST RESULTS

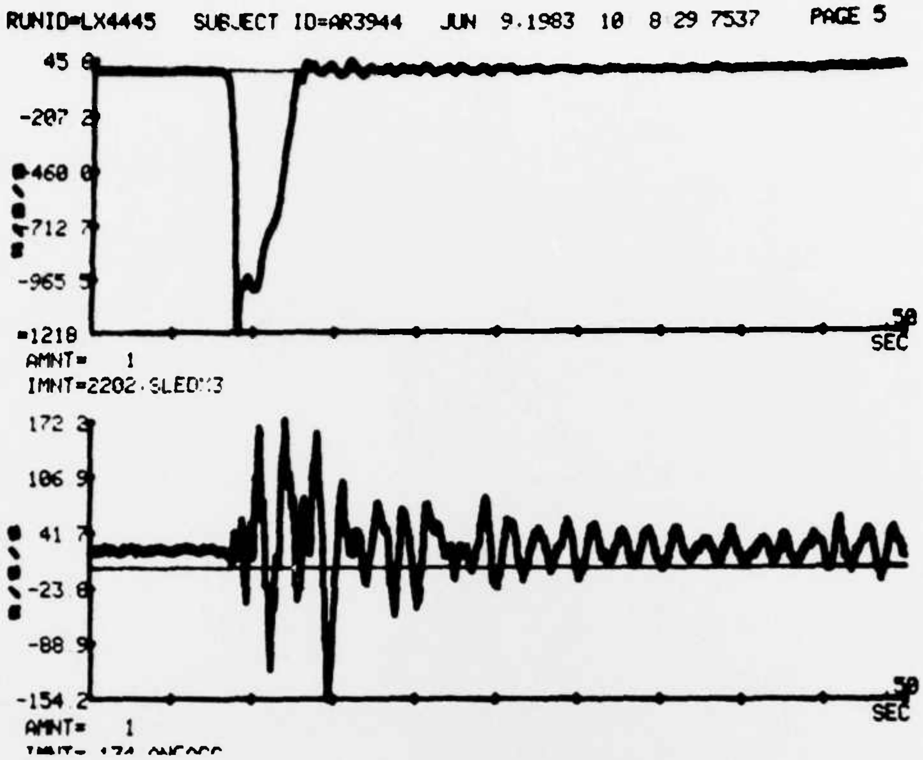


FIG 20-LINEAR ACC. TEST RESULTS

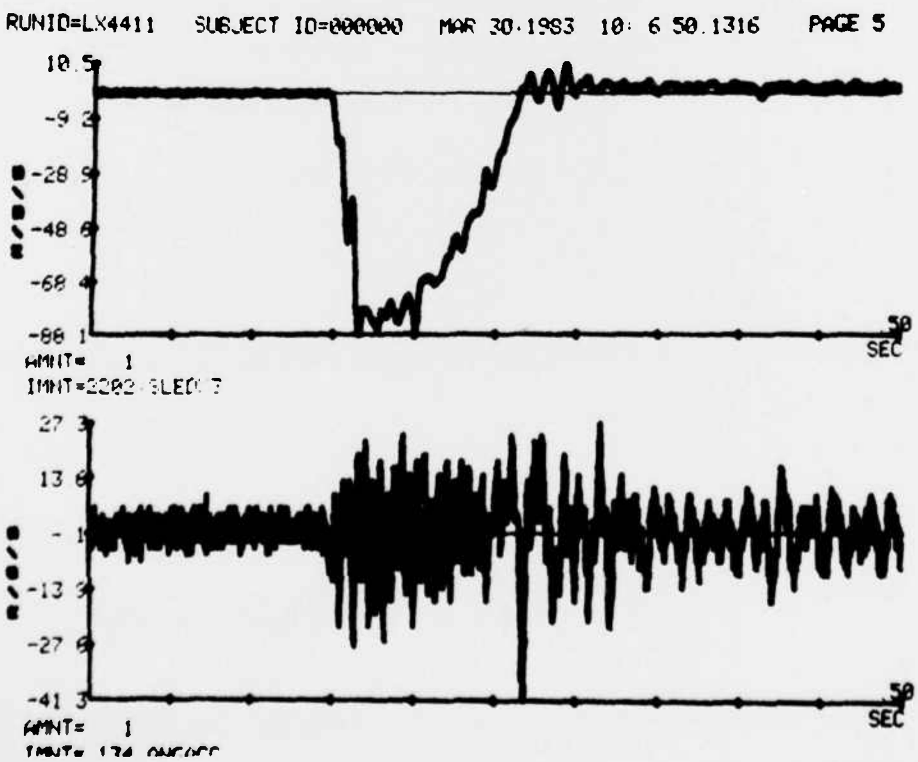
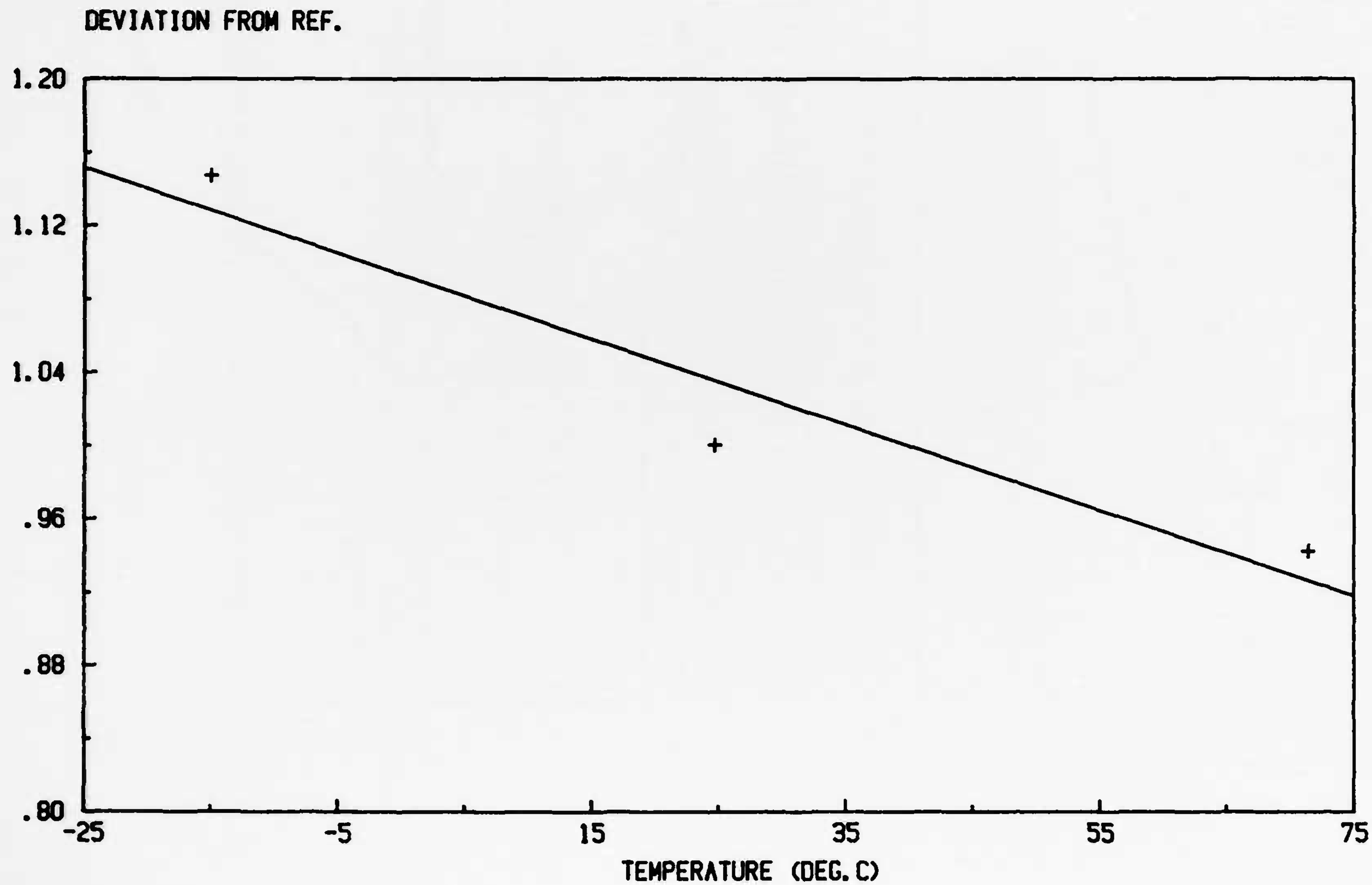


FIG 21-LINEAR ACC. RESPONSE
LOW LEVEL INPUT

FIG 22- 7302 ANGULAR ACCELEROMETER

STEADY STATE TEMP. SENSITIVITY

NBDL
7/26/83



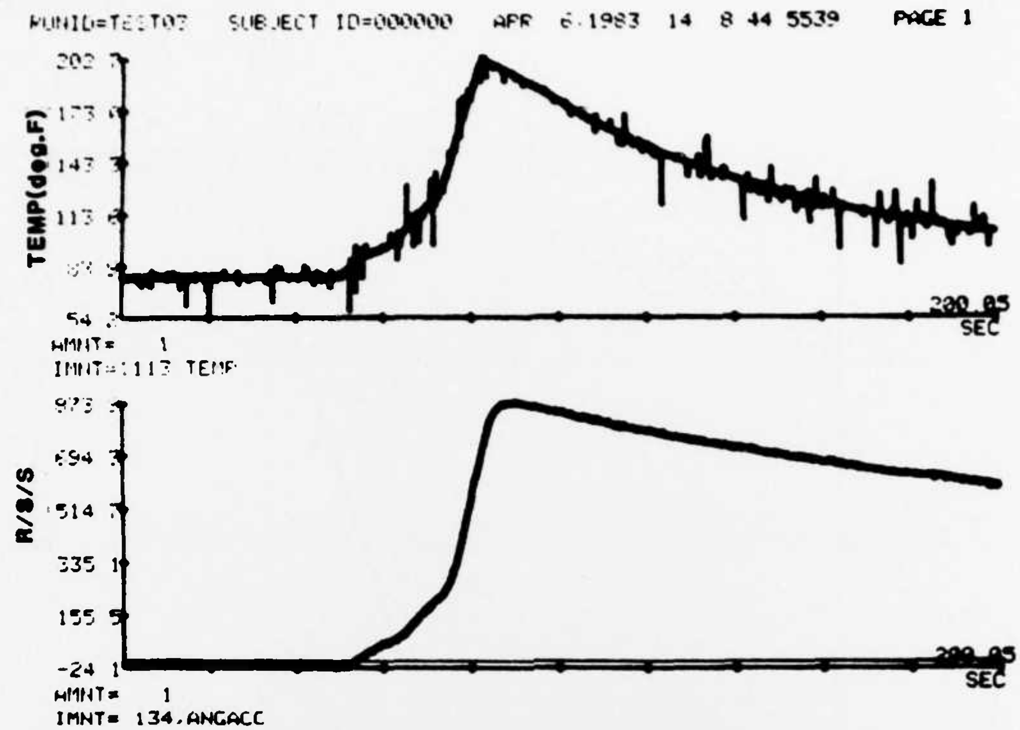


FIG 23-TEMP. SHOCK RESPONSE

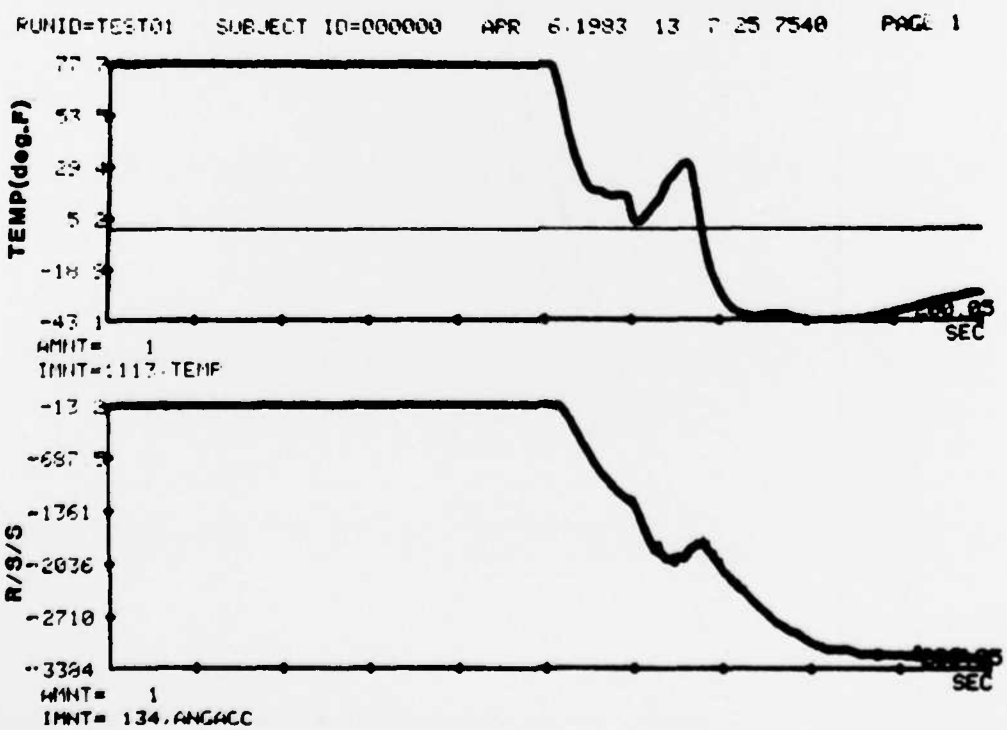
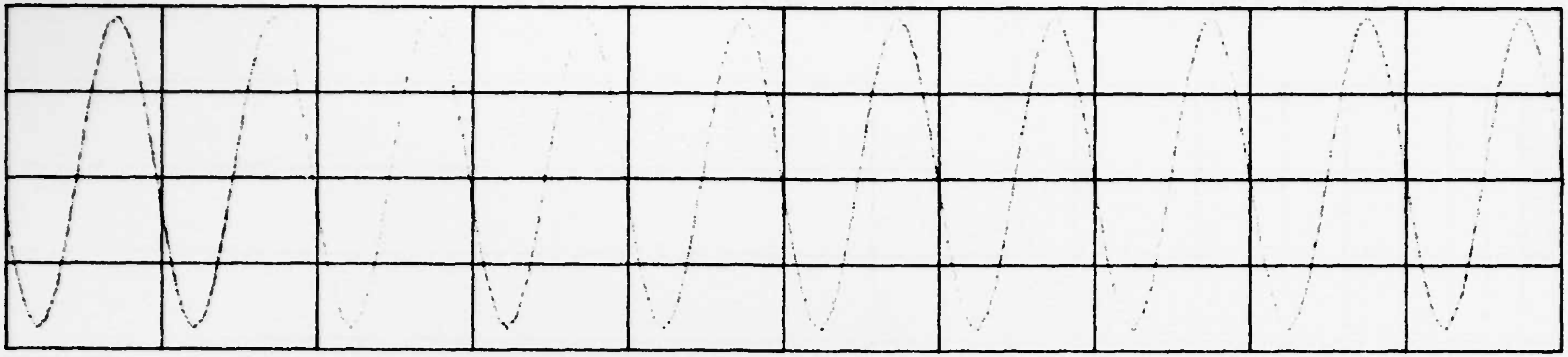


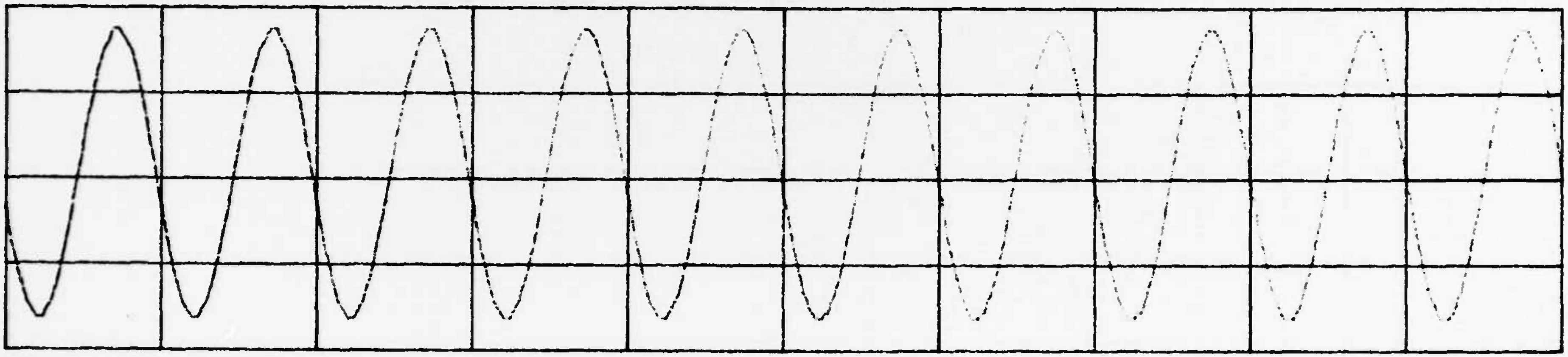
FIG 24-TEMP. SHOCK RESPONSE

INPUT: A   OUTPUT: B



TIME A: 10.00mSEC/

SPAN: 0.000HZ -2.0000KHZ   SN: 5.6-01V   FS: ±8.0-01V   4.0-01V/

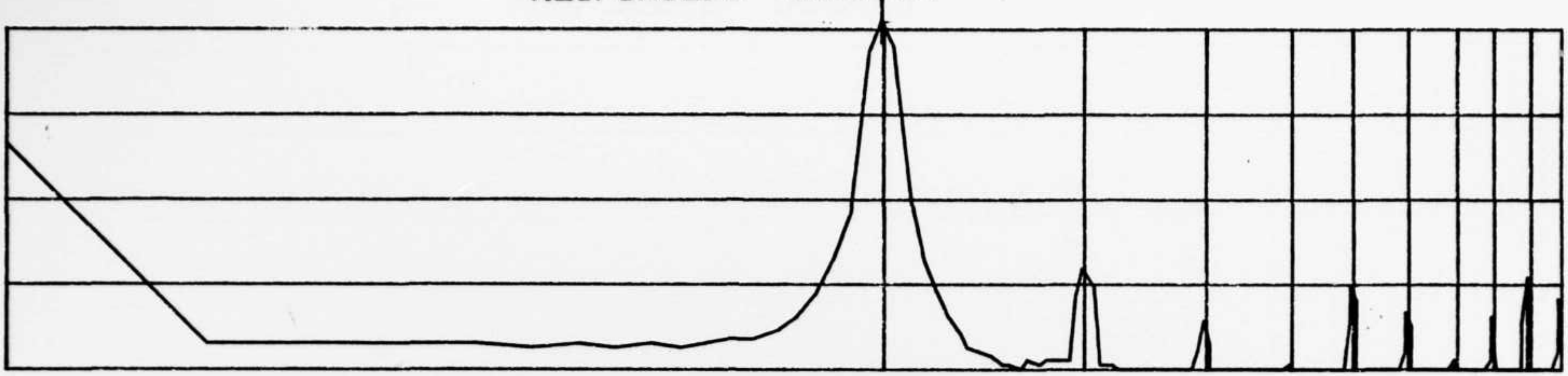


TIME B: 10.00mSEC/

SPAN: 0.000HZ -2.0000KHZ   SN: 1.0+00V   FS: ±1.4+00V   7.1-01V/

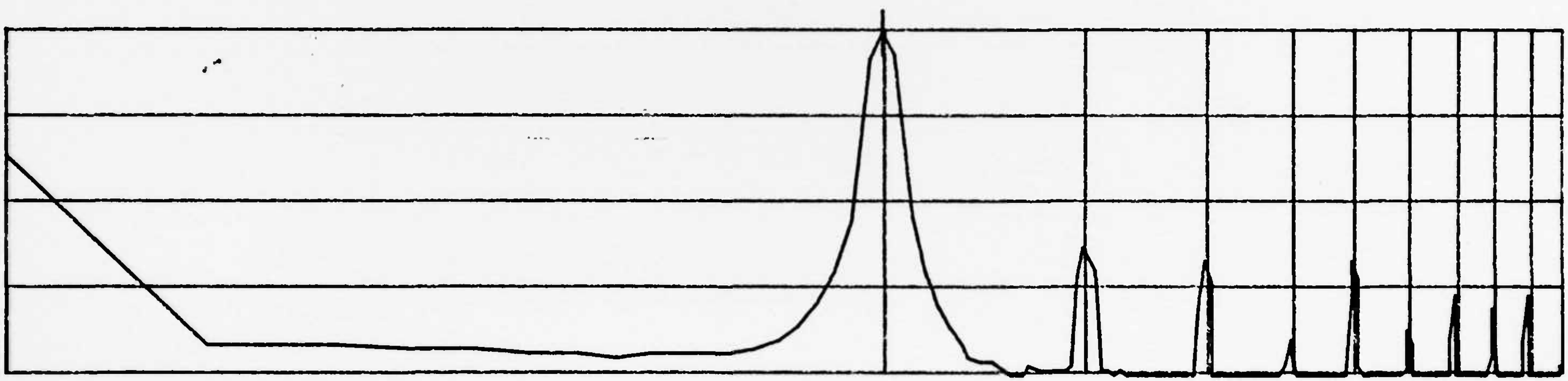
FIG 26-ANG. ACC. SPECTRAL RESP.

RESPONSE: B INPUT: A



PWR SPECT A :- 6.1dBV 100. HZ N: 256 P: 5HZ

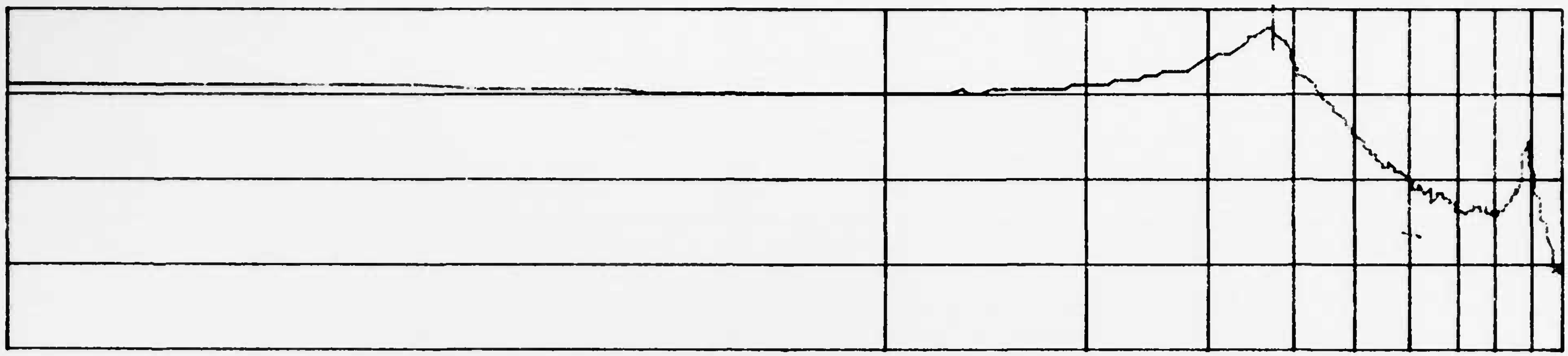
SPAN: 0.000HZ -1.0000KHZ SN: - 5dBV FS: - 6.00dBV 20dB/



PWR SPECT B :- 1.7dBV 100. HZ N: 256 P: 5HZ

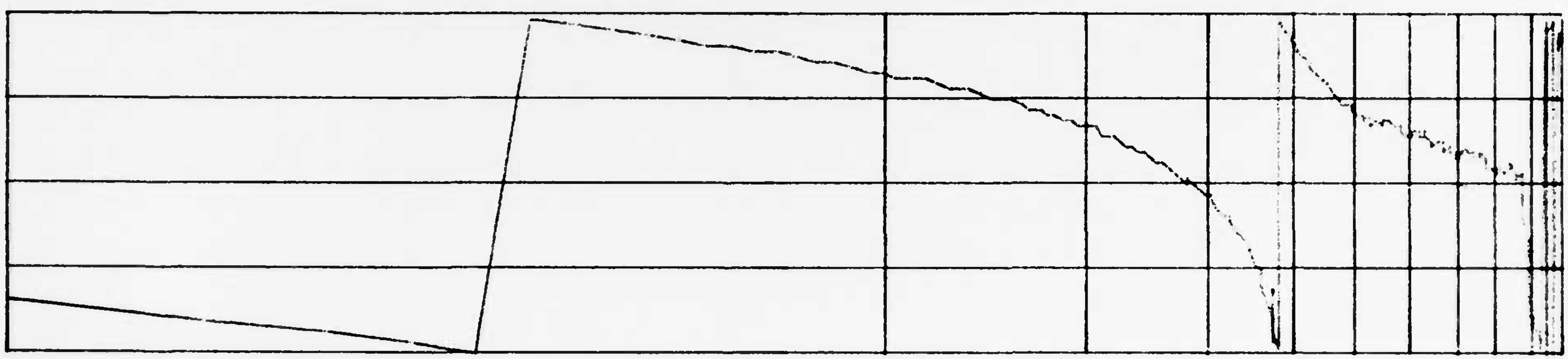
SPAN: 0.000HZ -1.0000KHZ SN: 0dBV FS: 0.00dBV 20dB/

FIG 27-ACC. TRANSFER FUNCTION



XFR FN MAG : 14.2dB 1.975 KHZ N: 64 P: 25HZ

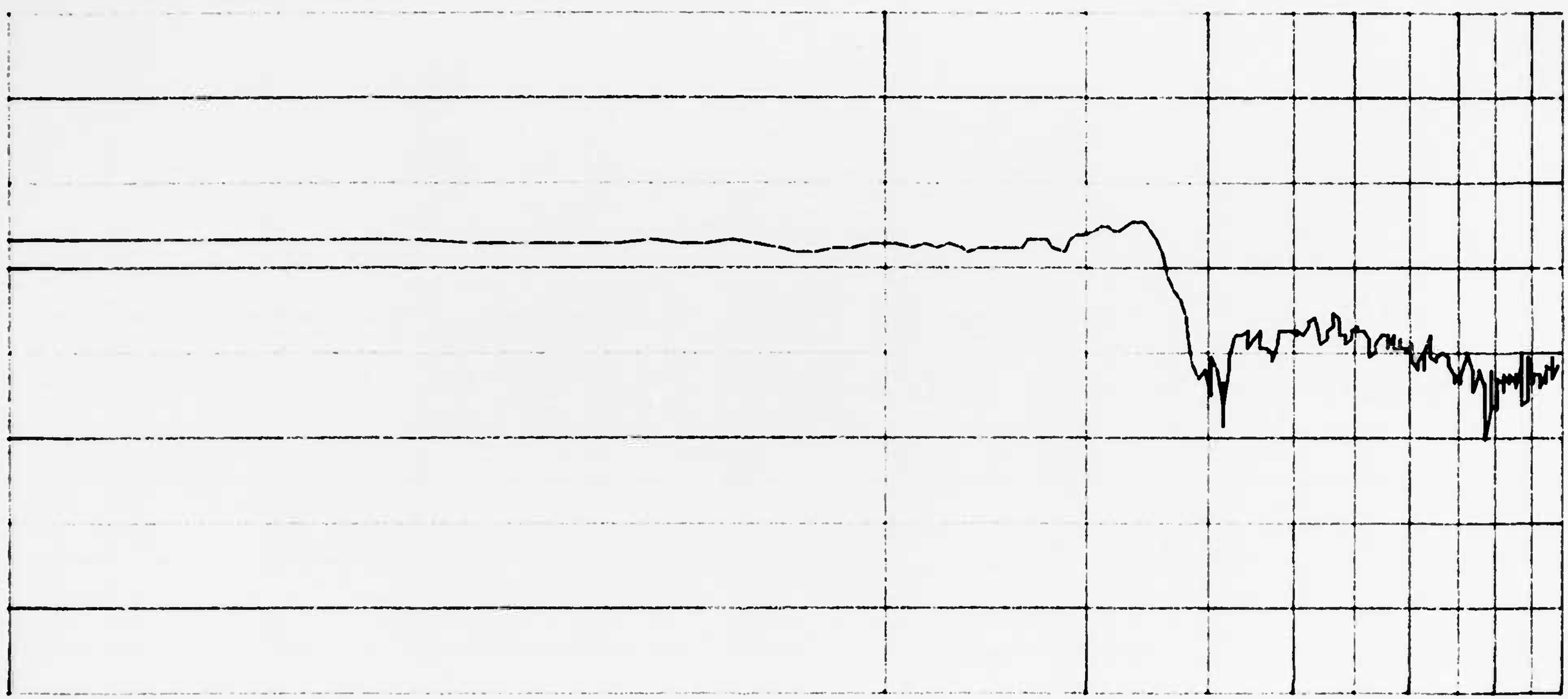
SPAN: 100.00HZ -5.1000KHZ FS: 20.00dB 20dB/



XFR FN PHASE : -137.5° 1.975 KHZ N: 64 P: 25HZ

SPAN: 100.00HZ -5.1000KHZ FS: ±180° 90°/

FIG 28-SCANNER FREQ. RESPONSE
3.5-5.5 KHZ REGION



XFR FN MAG :- 82.2dB 4.14 KHZ N: 64 P: 10HZ

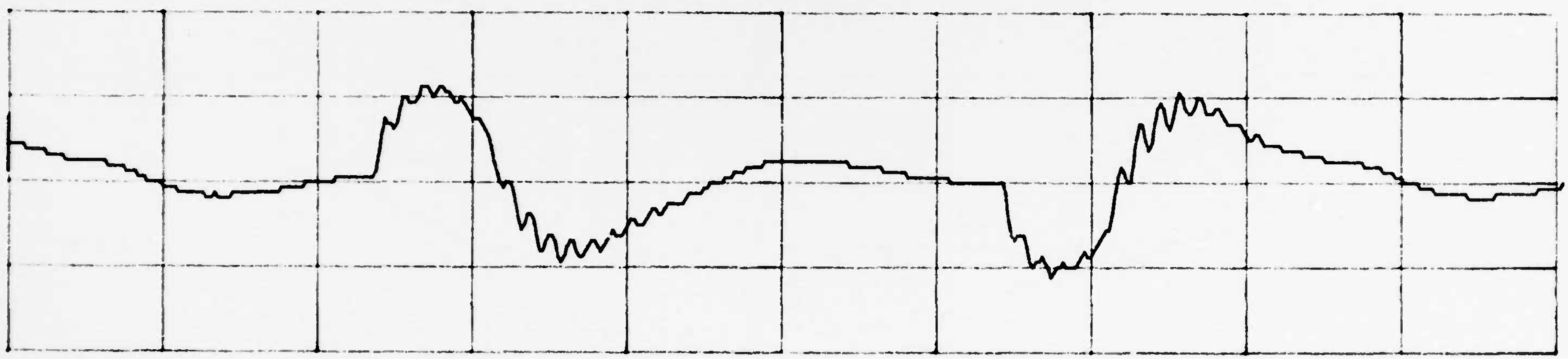
SPAN: 3.5000KHZ-5.5000KHZ FS: - 35.00dB 10dB/

FIG 29-ANG. ACC. TRANSIENT RESP.

INPUT: A OUTPUT: B UNFILTERED

TIME A: 2.0E+00V 0.00µSEC 4.00mSEC/

SPAN: 0.000HZ -5.0000KHZ SN: 3.2+00V FS: ±4.5+00V 2.2+00V/



TIME B: 7.0E-01V 0.00µSEC 4.00mSEC/

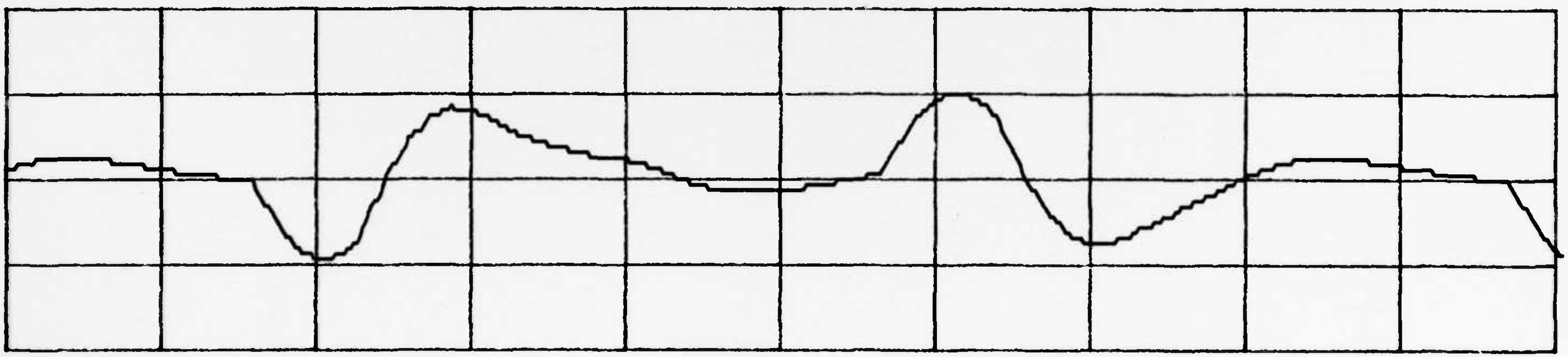
SPAN: 0.000HZ -5.0000KHZ SN: 3.2+00V FS: ±4.5+00V 2.2+00V/

FIG 30-FILTERED TRANSIENT RESP.

TOP: 1KHZ; BOTTOM: 300HZ FILTER

TIME B: -2.1E-01V 0.00µSEC 4.00mSEC/

SPAN: 0.000HZ -5.0000KHZ SN: 3.2+00V FS: ±4.5+00V 2.2+00V/



TIME B: 1.7E-01V 0.00µSEC 4.00mSEC/

SPAN: 0.000HZ -5.0000KHZ SN: 3.2+00V FS: ±4.5+00V 2.2+00V/

END

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