AAMRL-TR-90-027

IMPACT ACCELERATION RESPONSE OF THE SELSPOT MOTION ANALYSIS SYSTEM AND AN ENDEVCO ANGULAR ACCELEROMETER

Chris E. Perry
Laura A. Pytel
Dena M. Bonetti

February 1990

Final Report for the Period May 1989 - December 1989

Approved for public release; distribution is unlimited

ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-6573

NOTICES

TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-90-027

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

JAMES W. BRINKLEY
Director
Biodynamics and Bioengineering Division
Harry G. Armstrong Aerospace Medical Research Laboratory

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AAMRL-TR-90- 027

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Armstrong Aerospace Medical Research Laboratory

6b. OFFICE SYMBOL *(If applicable)*
AAMRL/BBP

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State, and ZIP Code)*
Wright-Patterson AFB OH 45433-6573

7b. ADDRESS *(City, State, and ZIP Code)*

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
62202F	7231	31	01

11. TITLE *(Include Security Classification)*
(U) Impact Acceleration Response of the Selspot Motion Analysis System and an Endevco Angular Accelerometer

12. PERSONAL AUTHOR(S)
Perry, Chris E.; Pytel, Laura A. and Bonetti, Dena M.

13a. TYPE OF REPORT
Final

13b. TIME COVERED
FROM May 89 TO Dec 89

14. DATE OF REPORT *(Year, Month, Day)*
1990 February

15. PAGE COUNT
126

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
23	01	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Impact Acceleration; Acceleration Response; Motion Analysis; Selspot; Angular Accelerometer

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

A motion analysis system is a critical component in the evaluation of the dynamic response of the human body during impact testing of crew restraint and protection systems. The Selspot motion analysis system was obtained to test and evaluate its performance under impact accelerations produced by a horizontal impulse accelerator. A pendulum-like motion standard was designed and fabricated to be installed on the horizontal accelerator's impact sled. Tests were run to determine the accuracy and integrity of the Selspot system under acceleration levels up to 20 G. The accuracy of Selspot's analysis of the motion of the pendulum during impact was determined through comparison to the accepted motion of the pendulum as recorded by a high resolution potentiometer mounted at the pendulum's point of rotation. Results indicate the Selspot system has a motion error of less than 1% of the measuring range during impacts up to 20 G. Selspot's self-contained data collection and analysis capabilities are superior to the current AAMRL high-speed 16mm camera motion analysis system.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
Chris E. Perry

22b. TELEPHONE *(Include Area Code)*
(513) 255-3122

22c. OFFICE SYMBOL
AAMRL/BBP

PREFACE

The tests described within this report were accomplished by the Biomechanical Protection Branch, Biodynamics and Bioengineering Division of Harry G. Armstrong Aerospace Medical Research Laboratory. The test and evaluation effort was accomplished in cooperation with Mr. Manfred Berger, a technician from Selspot Incorporated.

The impact facilities, data acquisition equipment, and data processing system were operated by the Scientific Services Division of Dyncorp under Air Force contract F33615-86-C-0531. Mr. Marshall Miller was the Engineering Supervisor for Dyncorp.

Photographic data and documentation services were provided by the Technical Photographic Division of the 4950th Test Wing.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 BACKGROUND

The primary mission of the Harry G. Armstrong Aerospace Medical Research Laboratory's Biomechanical Protection Branch (BBP) is to conduct research to develop design criteria for protection systems that may be used to protect personnel against hazards encountered in an accident environment or during an emergency escape from an aircraft. Research is also conducted to define the human biodynamic response to impact accelerations, to develop and validate mathematical or physical models of that response, to define impact acceleration exposure limits, and to test and evaluate protection systems such as restraint harnesses. Motion analysis is used to determine the trajectories, displacements, velocities, and accelerations of body segments during impact acceleration testing. The motion analysis system is a critical part of the evaluation of the dynamic response of the human body.

Currently, motion analysis is done by photogrammetric techniques using high-speed film. Technicians use high-speed 16mm film cameras mounted on board the impact test sled (Figure 1) to record the motion of marked points of interest on the object being studied. After the film is processed, an x-y film digitizing system is used to track the marked points frame by frame, thereby determining their respective displacements. From these displacements, the trajectories, velocities, and accelerations of the points of interest can be determined.

The Selspot/MULTILab system (referred to as Selspot for the remainder of the report) is a motion analysis and data collection system composed of both hardware and software. Selspot (Figure 2) is very flexible because it will collect, process, and present motion data all under the control of the MULTILab software and computer system. The system uses very specialized cameras which contain a unique photodetector unit that registers the light pulses from infrared light emitting diodes (LEDs) attached at the points of interest on the object being analyzed during the impact event. When the light pulse passes through the lens of the camera, it strikes the photodetector and the camera records the x-y coordinates of the LED location in the field of view of the system. The camera digitizes the location and then transfers it to the computer system's hard disk for storage. The data can then be processed and presented by the MULTILab software, transferred to another computer system for analysis by other software, or transferred to magnetic tape for analysis at a later date.

Upgrading from the present high-speed film system to the Selspot system will result in many benefits. The man-hours required to process and digitize film will be eliminated along with much of the storage room needed for the film. Because these processes will be eliminated, the time necessary to receive results will be decreased from approximately one week to approximately one hour. In addition, Selspot will not only be less expensive to operate, but will provide data accuracies equal to or better than the previous high-speed film system.

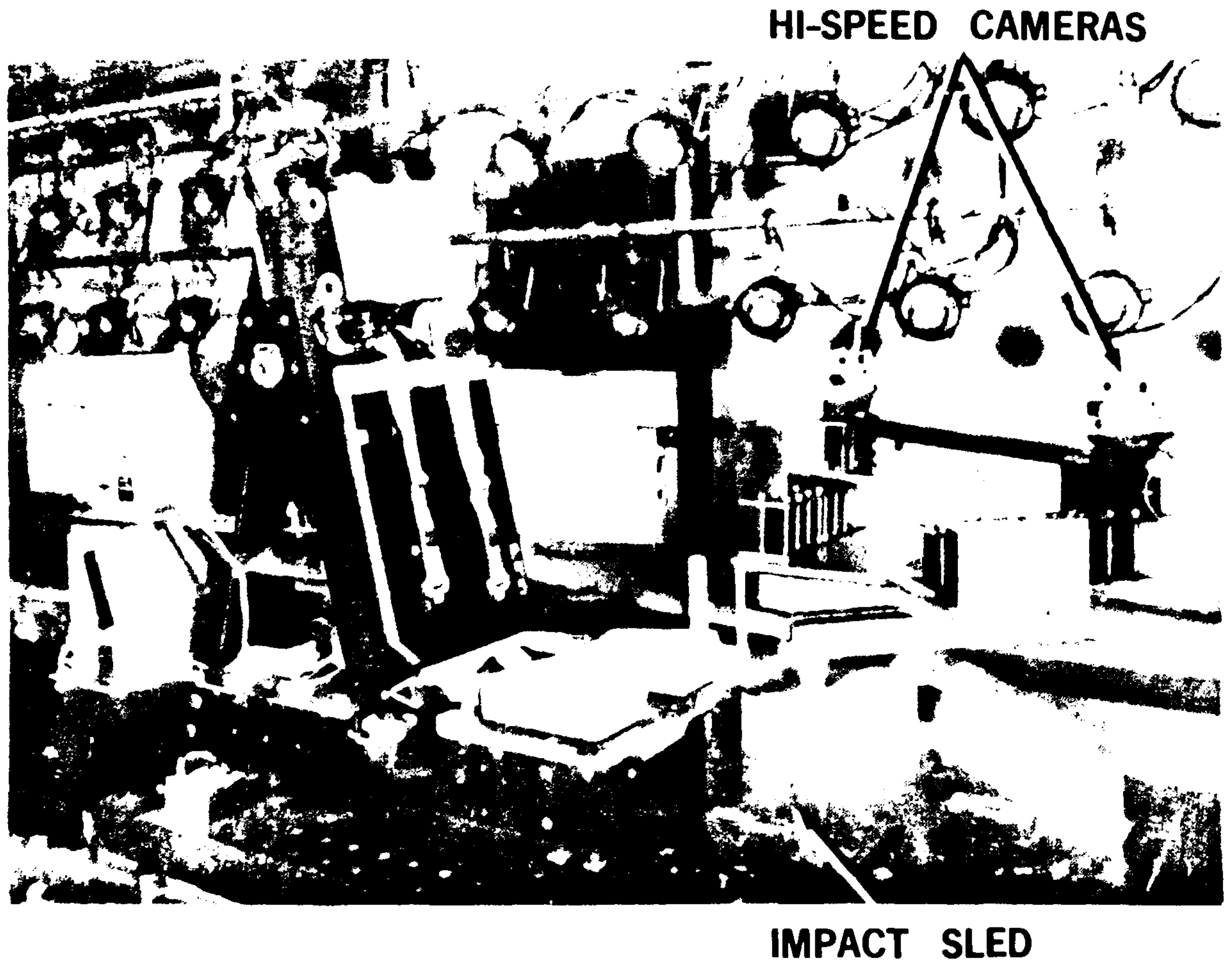


FIGURE 1. HORIZONTAL ACCELERATOR TEST PROGRAM USING HIGH-SPEED FILM CAMERAS

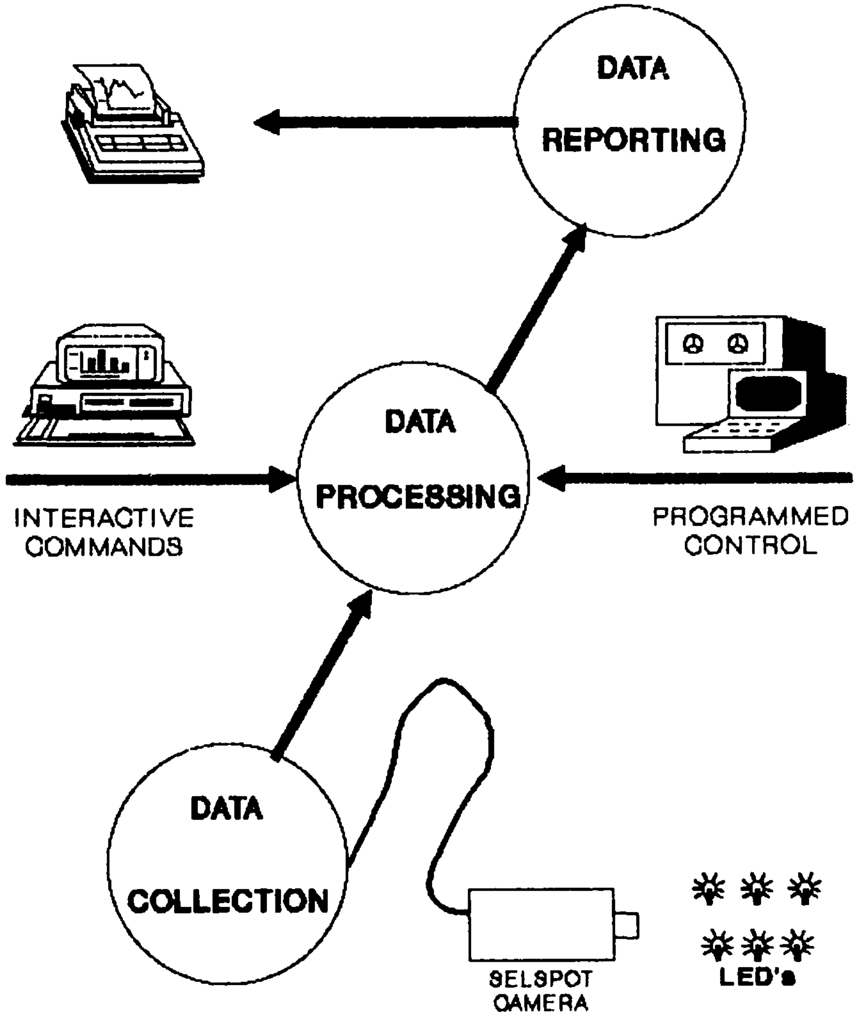


FIGURE 2 - SELSPOT/MULTILab SYSTEM OVERVIEW

Prior to this study, the Selspot system's qualifications had been verified only when the cameras were stationary. The cameras had not been subjected to use in a dynamic environment. This introduced the need for testing of Selspot under impact acceleration conditions if it was to be used as a motion analysis system for BBP.

In addition to a motion analysis system, transducers are also used to determine the human biodynamic response to impact. One such sensor is the Endevco 7302B angular accelerometer which produces a voltage output proportional to the sensed angular acceleration input (in rad/sec^2). Some recent technical reports in the field have presented data suggesting that the Endevco angular accelerometer does not perform to specifications. It was therefore decided to check the accuracy of the Endevco (Model 7302B) angular accelerometer during the testing of the Selspot/MULTILab motion analysis system.

1.2 OBJECTIVES

The primary objective of this experimental effort was to evaluate the accuracy and structural integrity of the Selspot system under impact acceleration conditions. A secondary objective of this research effort was to examine the accuracy of using an angular accelerometer for acceleration and displacement measurements while under impact acceleration conditions.

To help meet the primary objective, a motion analysis system must possess the following critical characteristics: (1) the system must have an accuracy level less than 0.7% of the measuring range or field-of-view of the camera, (2) the integrity of the system mounted in a dynamic environment must be maintained through repeated impacts, (3) the tracked targets must be able to adhere to the test object without falling off or restraining the natural movement during the impact, (4) the system must be able to sample up to 10 targets at a sample rate of at least 350 Hz per target, and (5) the system must have a resolution of at least 0.10 inches.

Selspot's sample rate was not affected by impact and therefore already met one of the critical characteristics. The resolution of the system is set by the specialized photodetector unit inside each camera and was specified to be 0.025% of the measuring range of the camera. In BBP's application, the Selspot system had a resolution of approximately 0.014 inches which satisfied this requirement. However, to satisfy the remaining requirements, the Selspot system had to be tested under impact conditions before it could be accepted to replace the current motion analysis system.

2. METHOD

2.1 EXPERIMENTAL DESIGN

To meet the stated objectives, a series of mid-range duration acceleration tests with short rise times were conducted at BBP using the Horizontal Accelerator. The acceleration conditions varied in magnitude and the acceleration profile approximated a half-sine pulse. The Selspot system and associated test fixtures were exposed to acceleration pulses in a progressive order from 6 G to a maximum of 24 G. Table 1 shows the test matrix used for the Selspot evaluation.

TABLE 1. TEST MATRIX

ACCELERATION EXPOSURE (G)	PULSE DURATION (ms)	TEST CELL	# OF TRIALS
0	-	A	3
6	160	B	3
10	159	C	3
15	159	D	3
20	143	E	3
24	126	F	3

To determine the accuracy of the Selspot system during impact, a specially designed 'motion standard' was developed. A diagram of this device is shown in Figure 3. The standard consisted of a nineteen inch long pendulum made from hollow square aluminum tubing. The pivot point of the pendulum was at one end of the tube and was located on a suspended shaft which allowed the pendulum to rotate freely about the shaft's longitudinal axis. A mount was then constructed to keep the shaft axis parallel to the y-axis of the impulse accelerator's test sled. The mount was connected to the shoulder clevis of the '40 G seat' test fixture which was fixed to the test sled. The pendulum was free to move through a 180° arc in the x-z plane. Foam stops were placed on the shaft mount to cushion the impact of the pendulum. A Helipot (Model L.25) 50 kohm potentiometer and a Clarostat (Model 600-128) optical encoder were attached to either side of the pendulum's pivot-point using mechanical couplers. The angular accelerometer was mounted to the pendulum at a point three inches from the pendulum pivot-point. Three Selspot LED's (Model #7) were attached to the side of the pendulum with one at each of three locations facing the Selspot cameras. Their locations were at six, twelve, and eighteen inches from the pendulum pivot point. In addition

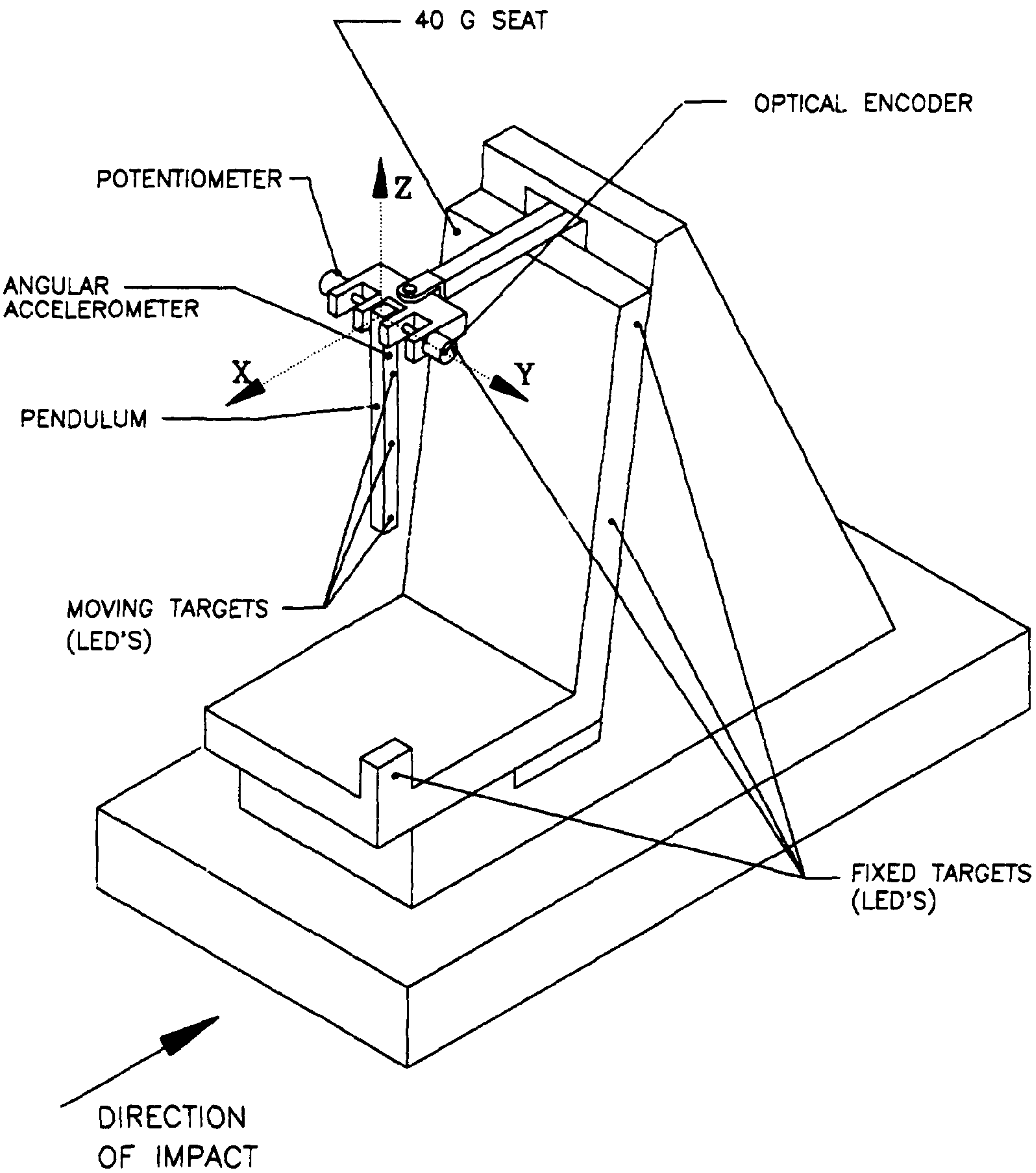


FIGURE 3 – MOTION STANDARD TEST FIXTURE

to the LEDs on the pendulum, four LEDs were positioned at fixed locations on the 40 G seat as shown in Figure 3.

The Selspot cameras were also fixed to the impact test sled. The cameras were contained in specially designed housings and were attached to the sled using the high-speed film camera mounts (Figure 4). Since the two Selspot cameras were viewing the LEDs from different angles, the system could determine the 3-D coordinates of motion of each LED during the impact testing.

Prior to the start of testing, a proof test was conducted at an acceleration level of 24 G to determine the structural integrity of the camera housings and the camera mounts. For this test, a ballast equivalent to the weight of the Selspot camera was placed in each housing to test for structural failure. The potentiometer and the optical encoder were also analyzed to insure that they were correctly integrated into the test fixture. For each impact test, the test fixtures (pendulum, shaft, clevis, camera mounts, cameras) were inspected for proper placement and operation. The LEDs were examined with an infrared viewer to insure their proper operation. A calibration of the potentiometer and the Selspot system was then performed. Upon a successful calibration, the impulse accelerator parameters would then be set to provide the proper acceleration rise time and pulse duration and a test would commence.

2.2 ANALYSIS

Data acquisition for the program was provided by BBP's Analog Data Acquisition system and the Selspot system. The analog system collected measurements of the sled acceleration and velocity, and measurements of the motion of the pendulum as indicated by the potentiometer, optical encoder, and angular accelerometer. The Selspot system measured the position of the four stationary LEDs fixed to the test seat, and also measured the position of the three LEDs fixed to the moving pendulum. All data were filtered (if required) at 120 Hz and transferred to BBP's VAX 11/750 for final processing. The analog data were digitized before the transfer. The electronic and Selspot data acquisition systems, software analysis routines, and data processing functions are described in detail in Appendix A.

The "accepted" motion of the pendulum (displacement of the pendulum over time during the acceleration pulse) was determined by the high resolution potentiometer mounted at the pivot point for each test. As mentioned previously, the two Selspot cameras allowed the calculation of motion of the LEDs in 3-D coordinates. From the 3-D coordinates, the displacements were found at given time intervals for each LED on the pendulum. Camera motion due to vibration of the camera mount during acceleration of the sled was corrected for by analyzing the motion of the four fixed LEDs during a dynamic test, and then rotating the camera positions such that the fixed LEDs appeared stationary. This correction was done at every time interval on each test and was software controlled.

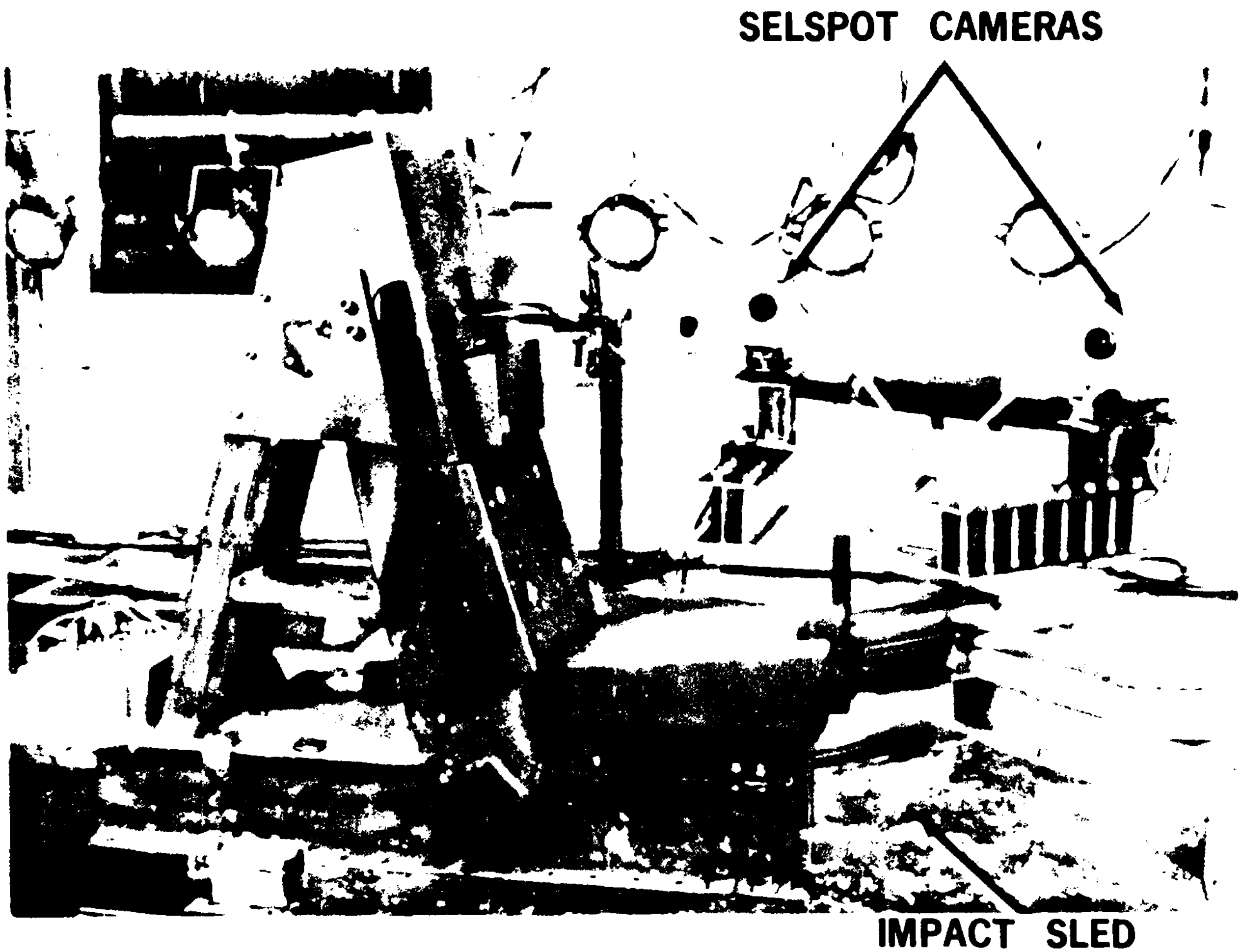


FIGURE 4. SELSPOT IMPACT ANALYSIS TEST SET-UP ON HORIZONTAL ACCELERATOR

Figures 5 and 6 show an example of the correction for camera vibration for LED position data from a 20 G test. In each figure, LEDs four thru seven are stationary on the sled, and LEDs one thru three are mounted on the pendulum.

To evaluate the accuracy of the Selspot system, an error value was calculated to be the difference between the Selspot pendulum displacement value and the potentiometer pendulum displacement value at each Selspot time interval. The error values were calculated over a specified portion of the time history of each of the three perdulum mounted LEDs. These values were then averaged for each test and compared to the other test averages at the same acceleration level. The hypothesis for statistical analysis was that the error value per acceleration level would be greater than or equal to 0.7% of the measuring range of the Selspot system.

The integrity of the Selspot system was determined by visual inspection of the camera housings, camera mounts, and all electrical connections after every test. In addition, immediate post-test data were checked for unusual or extreme data points after every test. Any discrepancies were recorded.

To evaluate the accuracy of the Endevco angular accelerometer, an error value similar to the Selspot error value was calculated per test. Initially, the accelerometer output was integrated twice to get the displacement of the pendulum over the duration of the impulse acceleration provided to the sled and test fixture. The displacement values as determined by the angular accelerometer were compared to the accepted displacement values from the potentiometer. The difference between the two displacements as a function of time was computed as the error of the angular accelerometer. The error value was calculated to be the average error over a specified portion of the time history.

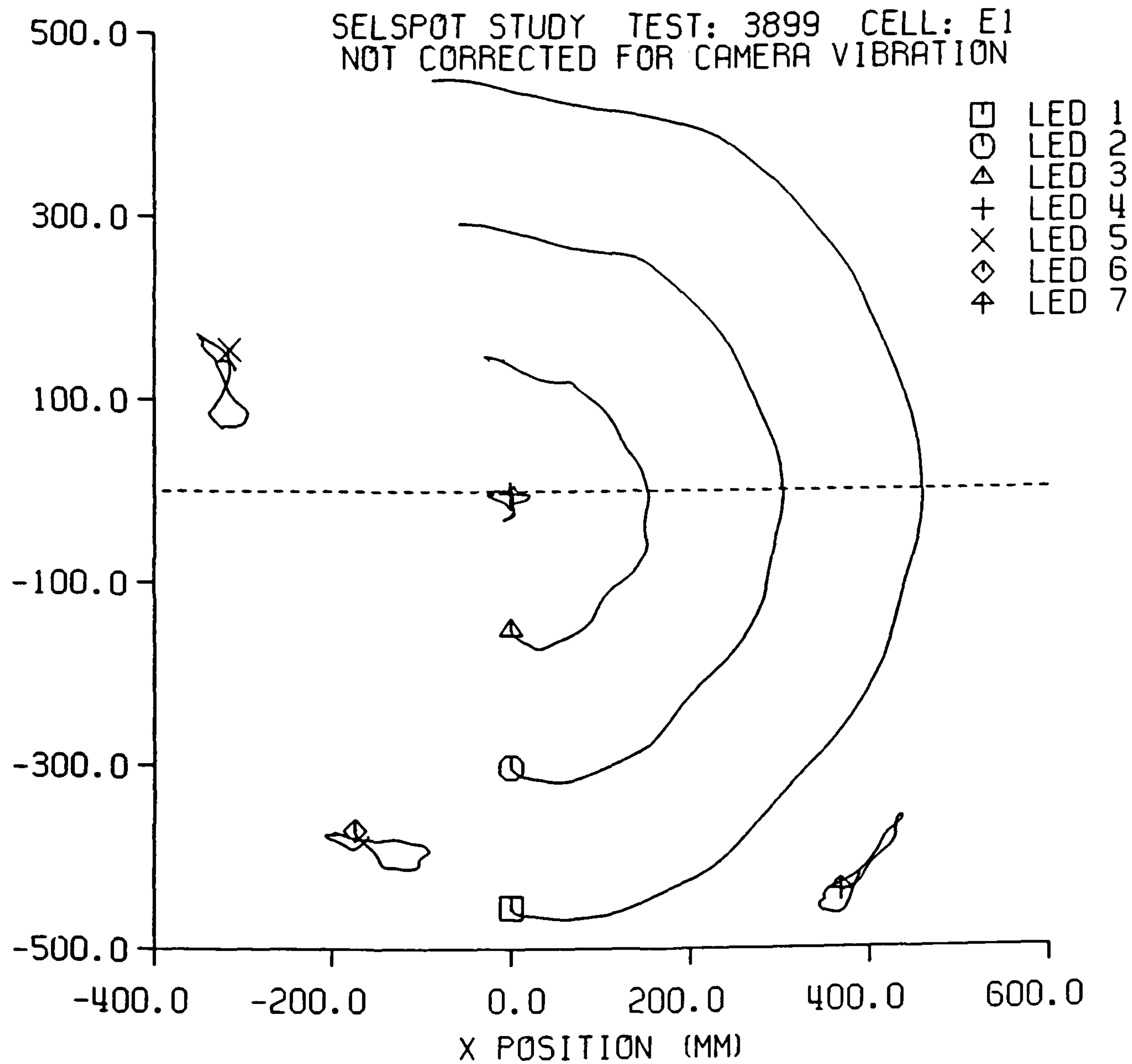


Figure 5 - Selspot LED Location Before Vibration Correction

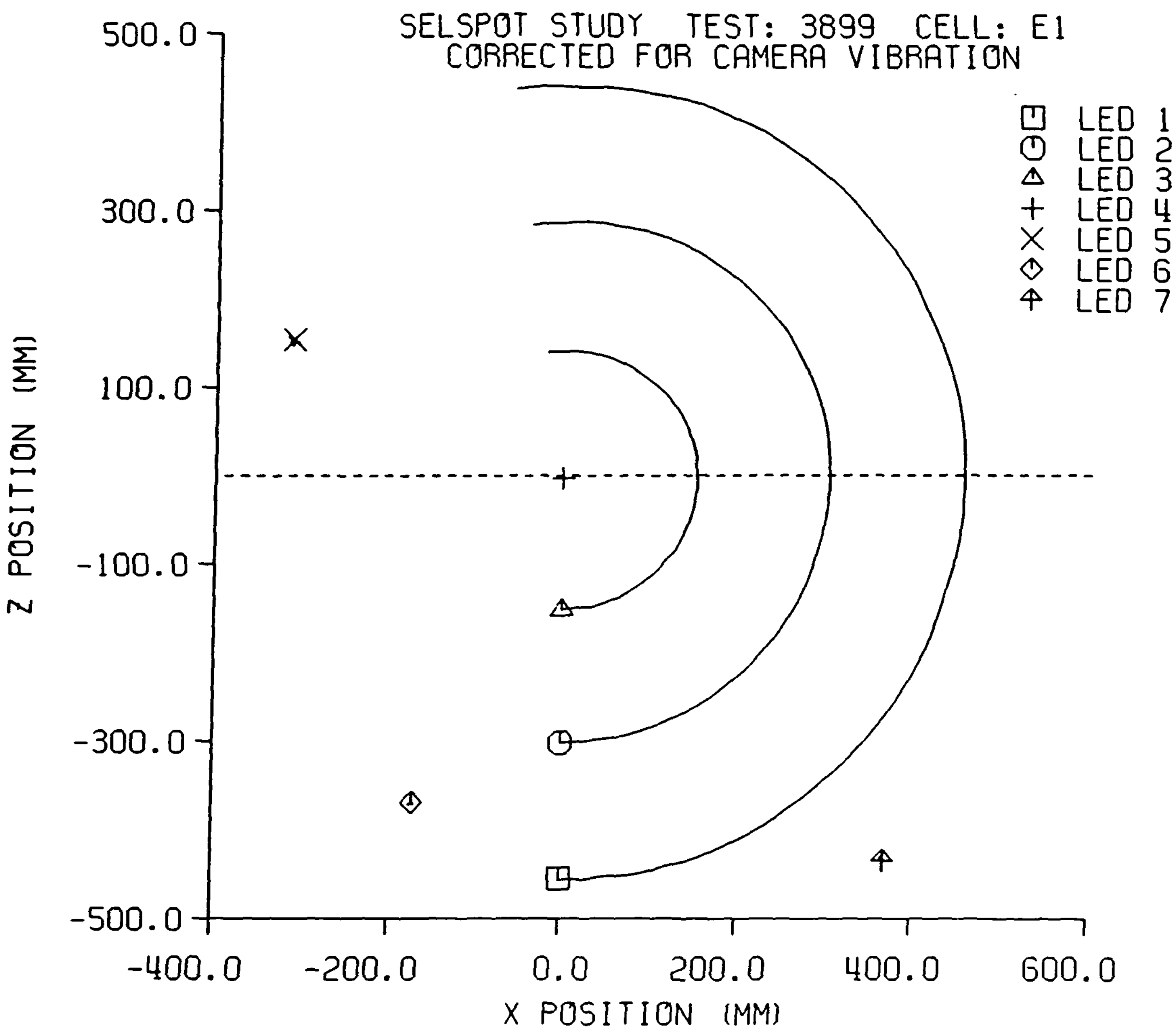


Figure 6 - Selspot LED Location After Vibration Correction

3. RESULTS

The test results are summarized in Tables 2 and 3 in terms of the means and standard deviations of the error values for the Selspot system and the angular accelerometer at each G level. Appendix B provides typical sets of electronic data from tests at each acceleration level.

The results of the Selspot analysis in Table 2 were evaluated at the chosen confidence level of 97.5 percent (alpha = 0.025). The Null hypothesis stated that the mean error between the Selspot and potentiometer displacement value will be greater than or equal to 0.7 percent of the measuring range of the Selspot system (H_o: μ_o=9.8 mm). The Alternate hypothesis stated that the mean error would be less than 0.7 percent of the Selspot measuring range (H_a: μ_a<9.8 mm). A 'Student t distribution' value less than 2.306 would reject the Null hypothesis at the chosen confidence level.

TABLE 2. SELSPOT ACCURACY ANALYSIS

G Level	Mean Error x (mm)	Std. Dev. s (mm)	Corresponding t Value	Conclusion
6	2.106	0.471	$t < 0$	Reject H_o
10	2.411	0.392	$t < 0$	Reject H_o
15	2.249	0.393	$t < 0$	Reject H_o
20	2.437	0.298	$t < 0$	Reject H_o

TABLE 3. ANGULAR ACCELEROMETER ACCURACY ANALYSIS

G Level	Mean Error x (deg)	Std. Dev. s (deg)
6	0.1490	0.0630
10	0.0802	0.0086
15	0.0859	0.0143
20	0.0917	0.0470

In terms of the structural integrity, there were no problems with the Selspot camera mounts or the system connections (computer to camera to LCU) up to the 20 G acceleration test level. At the 20 G level, it was discovered that the motion data contained errors such that the system was recording an LED(s) at an incorrect location. This occurred on two of the three tests at this acceleration level. At the 24 G test level, it was discovered that the camera mounts were structurally damaged and the motion data contained errors similar to that at the 20 G test level. Based on these findings, it was decided to discontinue testing at the 24 G level and continue tests at the 20 G level to solve the data error problem.

4. DISCUSSION

Events of less than one second that occur in an aerospace environment are often associated with escape system accelerations and aircraft and surface vehicle crash and impact dynamics. BBP has been conducting research to assess the effectiveness of various restraint and protection systems by evaluating the biodynamic responses of manikins and humans in experimental simulations of these escape and crash environments. To adequately describe the motion of body segments during dynamic testing, it became necessary to quantitatively analyze the time displacements of defined points on the various body segments. The high-speed film motion analysis system was originally designed to ride on board the impact sled and satisfy this requirement. However, over time, the film system became expensive to operate and slow to provide data as the schedule of dynamic testing increased. This initiated a study to analyze alternative motion analysis methods of which Selspot was the result. The Selspot impact analysis program was initiated to determine its acceleration tolerance levels for use as BBP's motion analysis system.

The data shows that the Selspot system would be very suitable as a motion analysis system for use on the horizontal acceleration sled and vertical drop tower at a maximum acceleration level of 20 G's.

The highest average error value as shown in Table 2 was 2.437 mm which was well below the criterion value of a maximum 9.779 mm for a measuring range of approximately 1400 X 1400 mm. The structure of the system was adapted to perform multiple tests under an acceleration level of 20 G without any signs of structural damage or motion data error. Modifications to the test fixture included providing additional support to the Selspot camera housings and integrating a system connector interface box mounted on the impact sled. The interface box received input and output lines from the computer system, the Selspot cameras, and the LCU. This alleviated the need to stack multiple ribbon connectors on the back of a Selspot camera which was thought to be the cause of the data spikes at the 20 and 24 G test levels. The systems resolution and sample rate both remained at constant acceptable values during testing.

The angular accelerometer results were also very good. The highest error value for displacement readings was 0.149 degrees of circular motion. Although no criterion value was set for the angular accelerometer, this accuracy was deemed acceptable for continued use of the angular accelerometer in impact tests.

5. CONCLUSION

The horizontal accelerator tests have shown that the Selspot system performs motion analysis with acceptable accuracy levels while maintaining its structural integrity in an impact environment. Some recommendations for final implementation of the Selspot system are as follows:

1. The Selspot calibration fixture should be redesigned to include at least six targets for better accuracy.

2. The LED Control Unit (LCU) should be remounted so the LED connections are oriented parallel to and in the direction of the acceleration. Also a removable isolation box should be placed over the LCU to cover the 20 volt potential that remains on the LED connections.

3. A warning label should be placed on the back of the two cameras and LCU box to remind technicians to turn off power before disconnecting or connecting the cameras or LCU. This will avoid possible damage to the cameras and LEDs.

4. The vibration correction program and the correction program for extreme data points should be rewritten to run on the Selspot computer system.

5. The true principal distance for the 24 mm focal length lenses which are currently in use should be determined and implemented in the calibration procedure.

6. An abort system must be devised to stop the test countdown in case a power loss or other problem occurs within the Selspot system.

7. A storage system for Selspot text and data files should be acquired and implemented.

8. A user's manual specific to BBP applications should be written to clarify the MULTILab software and the command files used for acceleration testing.

9. Procedures for using Selspot during a test program should be documented.

With these recommendations implemented, the processing speed, accuracy, sample rate, overall cost, and convenience of the Selspot system make it ideal for use as a motion analysis system in a limited impact environment.

REFERENCES

1. Barnes, J. Wesley, Statistical Analysis for Engineers: A Computer-Based Approach, Englewood Cliffs, NJ, Prentice Hall, Inc. Publishers, 1988.

2. Graf, P.A., Mohlman, H.T., Reboulet, R.C., Photometric Methods for the Analysis of Human Kinematic Responses to Impact Environments, AMRL-TR-78-94, October 1978.

3. McKenzie, I., Practical Application of the Selspot Motion Analysis System - A User's Guide, "Royal Air Force Institute of Aviation Medicine (IAM) Technical Memorandum", No. 385, 1987.

4. Perry, Chris E., Motion Analysis System Upgrade," AAMRL/BBP FASCAP Proposal", 1988.

5. Selspot AB, MULTILab Reference Documentation, 1988.

6. Selspot AB, MULTILab Dictionary, 1988.

7. Selspot AB, Selspot Sensor System Manual, 1988.

8. Shigley, Joseph Edward, and Mitchell, Larry D., Mechanical Engineering Design, Fourth Edition, McGraw-Hill, Inc.,1983.

APPENDIX A

Data Acquisition System and Software

APPENDIX A

TEST CONFIGURATION AND DATA ACQUISITION SYSTEM FOR THE INVESTIGATION OF SELSPOT MOTION ANALYSIS SYSTEM RESPONSE TO IMPACT CONDITIONS TEST PROGRAM

(Selspot Study)

Prepared under
Contract F33615-86-C-0531

December 1989

Prepared by
Stephen E. Mosher

DynCorp
Scientific Support Division
Building 824, Area B
Wright-Patterson AFB, Ohio 45433

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

FIGURE PAGE

INTRODUCTION

This report was prepared by DynCorp for the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL/BBP) under Air Force Contract F33615-86-C-0531.

The information provided herein describes the test facility, test fixture, data acquisition, instrumentation and computer software that were used in the Investigation of Selspot Motion Analysis System Response to Impact Conditions Test Program (Selspot Study). Twenty-nine dynamic tests were conducted during August, October and November 1989 on the Horizontal Accelerator test facility. Three static tests (tests with no impact) were also conducted.

The Selspot Motion Analysis System tracks the three dimensional motion of infrared LED markers by analyzing the camera images from two different Selspot cameras. The image coordinates of the LEDs are determined by the Selspot cameras and transferred to a microcomputer for real-time storage. In the past, three dimensional motion was determined by tracking the positions of black and white targets. The positions of the targets were obtained by digitizing the films from two high speed cameras using the Nova 3/12 minicomputer and the automatic film reader.

The Selspot Motion Analysis System offers several advantages over the previous method of tracking three dimensional motion. The test results from the Selspot System can be displayed immediately following the test without waiting for film to be developed. Calibration to determine the camera orientations and locations can be performed immediately preceding the start of testing since there is no need to wait for film development. The expense involved in adjusting and loading the high speed cameras, developing the film and digitizing the film is eliminated.

1. TEST FACILITY

The AAMRL Horizontal Accelerator Facility was used for all of the twenty-nine tests. The Horizontal Accelerator Facility consists of the 24-inch HYGE actuator, the test sled and 240 feet of track. The Horizontal Accelerator is designed to simulate an impact profile by accelerating the test sled down the track.

The energy required to produce the impact acceleration is generated within the actuator cylinder (Figure 1) by means of differential gas pressures acting upon a thrust piston. This thrust piston is attached to a thrust column assembly which is used to impact the sled. As pressure moves the thrust assembly, the sled is accelerated from an initial stationary position to a predetermined peak acceleration level and is then allowed to decelerate by coasting or by brake application. Various acceleration profiles may be obtained by changing the differential pressures, the travel length of the thrust assembly and the metering structure on the thrust piston. The sled glides along the track rails on twelve glide pads. The sled braking system consists of caliper brakes which grip the track rails when activated by onboard compressed nitrogen gas. The track rails are one inch thick and the total track length is 240 feet. Metering pin number 16 was used to obtain the desired acceleration profile.

2. TEST FIXTURE

The test fixture for this test program was constructed by attaching a pendulum to the F-4 seat fixture from the F4LB test program. The seat fixture was mounted on the Horizontal Accelerator Sled and oriented to provide a -Gx acceleration vector. The pendulum was constructed from a nineteen inch section of square aluminum tubing. The pendulum was connected to the shoulder harness mounting bracket by a mount which allows the pendulum to swing upward through a 190 degree angle. Rubber stops were positioned above and below the pendulum pivot point to limit the pendulum angle. The pendulum pivot point was 13-1/2 inches forward from the shoulder harness mounting bracket. The test fixture is shown in Figures 2 and 3.

A potentiometer was mounted to one end of the pendulum shaft and an optical encoder was mounted to the other end of the shaft. An angular accelerometer was mounted three inches from the pendulum pivot point as shown in Figure 4. The potentiometer, optical encoder and angular accelerometer were used to compute the pendulum angle as a function of time. Two Selspot cameras were mounted onboard the sled to track the motion of infrared LEDs located on the test fixture.

3. INSTRUMENTATION

The electronic data collected during this test program is described in Sections 3.1 and 3.2. Section 3.1 discusses the sled instrumentation while Section 3.2 discusses the test fixture instrumentation. Section 3.3 discusses the calibration procedures that were used. The measurement instrumentation used in this test program is listed in Table 1. This table designates the manufacturer, type, serial number, sensitivity and other pertinent data on each transducer used. Table 2 lists the manufacturer's typical transducer specifications.

Accelerometers were chosen to provide the optimum resolution over the expected test load range. Full scale data ranges were chosen to provide the expected full scale range plus 50% to assure the capture of peak signals. All transducer bridges were balanced for zero output prior to the start of each test. The accelerometers were adjusted for the effect of gravity using computer processing software. The component of a 1 G vector in line with the force of gravity that lies along the accelerometer axis was added to each accelerometer.

The sled coordinate system is shown in Figure 5. The x axis is horizontal and positive down track from the Horizontal Accelerator. The z axis is vertical and positive upward. The y axis is perpendicular to the x and z axes according to the right hand rule.

The sled linear accelerometers were wired to provide a positive output voltage when the acceleration experienced by the accelerometer is applied in the +x, +y or +z directions, as shown in Figure 5.

The sled velocity tachometer was wired to provide a positive output voltage when the sled moves in the +x direction, as shown in Figure 5.

The test fixture coordinate system, shown in Figure 5, is related to the initial position of the pendulum prior to the start of the test. The test fixture coordinate system is right-handed with the z axis parallel to the pendulum arm and positive upward. The x axis is perpendicular to the z axis in the plane defined by the pendulum trajectory. The y axis is perpendicular to the x and z axes according to the right hand rule. The origin of the test fixture coordinate system is located at the pendulum pivot point.

The angular accelerometer was wired to provide a positive output voltage when the angular acceleration experienced by the angular accelerometer is in the +y direction according to the right hand rule as shown in Figure 5.

The potentiometer was wired to provide a positive output voltage as the pendulum swings forward from its initial position. This results in a positive angle for the pendulum motion.

3.1 Sled Instrumentation

This section describes the sled instrumentation as required in the AAMRL/BBP test plan.

Sled accelerations were measured using three Endevco linear accelerometers: one Model 2262A-200 for accelerations in the x direction and two Models 2264-200 for accelerations in the y and z directions. Two separate aluminum blocks were used to mount the three accelerometers, sled x on one block and sled y and z on the other block. Both blocks and their respective accelerometers were mounted on the underside center of the sled.

The Horizontal Accelerator ram x acceleration was measured using an Endevco Model 2262A-200 accelerometer. The accelerometer was mounted near the front surface of the ram, off the sled, and used as a backup to the primary sled mounted accelerometer. Sled velocity was measured using Globe Industries Tachometer Model 22A672-2. The rotor of the tachometer was attached to an aluminum wheel with a rubber "O" ring around its circumference to assure good rail contact. The wheel contacted the track rail and rotated as the sled moved, producing an output voltage proportional to the velocity.

3.2 Test Fixture Instrumentation
This section describes the test fixture instrumentation as required in the AAMRL/BBP test plan.

The pendulum angle was measured using a HELIPOT Model L.25 R50K ten turn potentiometer. The potentiometer was attached to the shaft of the pendulum as shown in Figure 4.

The pendulum angle was also measured using a CLAROSTAT Model 600-128 140-8913 optical encoder. The optical encoder had an output of 128 pulses per revolution. The encoder was attached to the shaft of the pendulum as shown in Figure 4.

The pendulum angular acceleration was measured using an Endevco Model 7302B angular accelerometer. The angular accelerometer was attached to the pendulum three inches from the pendulum pivot point as shown in Figure 4.

3.3 Calibration
Calibrations were performed before and after testing to confirm the accuracy and functional characteristics of the transducers. Pre-program and post-program calibrations are given in Table 3.

The calibration of the accelerometers was performed by DynCorp using the comparison method (Ensor, 1970). A laboratory standard accelerometer, calibrated on a yearly basis by Endevco with standards traceable to the National Bureau of Standards, and a test accelerometer were mounted on a shaker table. The frequency response and phase shift of the test accelerometer were determined by driving the shaker table with a random noise generator and analyzing the outputs of the accelerometers with a PDP 11/15 computer and 1923 Time Data Unit using Fourier analysis. The natural frequency and the damping factor of the test accelerometer were determined, recorded and compared to previous calibration data for that test accelerometer. Sensitivities were calculated at 40 G and 100 Hertz. The sensitivity of the test accelerometer was determined by comparing its output to the output of the standard accelerometer.

The velocity wheel is calibrated periodically by DynCorp by rotating the wheel at approximately 2000, 4000, and 6000 revolutions per minute (RPM) and recording both the output voltage and the RPM.

A voltage of ten volts was applied across the ten turn potentiometer, resulting in a sensitivity of one volt per revolution. The potentiometer calibration was verified by measuring the output voltage at each complete revolution as the potentiometer was turned.

The angular accelerometer was calibrated by comparing the angular accelerometer output to the output of a linear standard accelerometer. The angular accelerometer was mounted parallel to the axis of rotation of a Honeywell low inertia D. C. motor. The standard accelerometer was mounted perpendicular to the axis of rotation at a radius of one inch to measure the tangential acceleration. The D. C. motor motion was driven at a constant sinusoidal angular acceleration of 100 Hertz and the sensitivity was calculated by comparing the RMS voltages of the angular and linear accelerometers.

4. DATA ACQUISITION

Test data from the electronic transducers was collected using the Analog Data Acquisition System as described in Section 4.1. It was later converted from analog to digital format using the ADACS as described in Section 4.2. Test data describing the optical motion of LEDs mounted on the pendulum was collected using the Selspot Motion Analysis System as described in Section 4.3.

4.1 Analog Data Acquisition System

Electronic test data was acquired using the Analog Data Acquisition System. After proper amplification and filtering, all data were recorded and stored on one inch analog tape using the Ampex FR2000 14-channel recorder via the Vidar multiplex system.

Quick-look data were required for each test to determine the quality of data collected and to determine that expected trends were being achieved. The Honeywell oscillograph was used to record data from the analog tape for visual readout. Data acquisition was controlled by a comparator on the Master Instrumentation Control Unit in the Instrumentation Station. The comparator was set to start data collection at T = -14 seconds and the test was initiated when the comparator countdown clock reached zero. A reference pulse was electronically initiated to mark the ADACS and Selspot test data. A trigger signal was provided to start the Selspot test data collection at T = -1 seconds.

4.2 Automatic Data Acquisition and Control System (ADACS)

The electronic test data was converted from analog to digital format using the ADACS. Zero reference values for all transducers were sampled at time T = -7 seconds. The test data was digitized from time T = -1 seconds for three seconds.

The three major components of the ADACS system are the power conditioner, signal conditioners and the encoder. A block diagram of the ADACS is shown in Figure 6. The signal conditioners contain forty-eight amplifiers with programmable gain and filtering. Bridge excitation for accelerometers was 10 VDC. Bridge completion and balance resistors were added as required to each module input connector.

The forty-eight module output data signals were digitized and encoded into forty-eight 11-bit digital words. Two additional 11-bit synchronization (sync) words were added to the data frame making a fifty word capability.

Three synchronization pulse trains (bit sync, word sync and frame sync) were added to the data frame and sent to the computer via a junction box data cable.

The PDP 11/34 minicomputer received serial data from the ADACS. The serial data coming from the sled are converted to parallel data in the data formatter. The data formatter inputs data by direct memory access (DMA) into the computer memory via a buffered data channel where data are temporarily stored on disk. Data are later transferred to the VAX 11/750 and output to magnetic tape for permanent storage. The interrelationships among the data acquisition and storage equipment are shown in Figure 7.

Test data could be reviewed after it was converted to digital format using the "quick look" SCAN routine. SCAN was used to produce a plot of the data stored on any channel as a function of time. The routine determined the minimum and maximum values of any data plot. It was also used to calculate the rise time, pulse duration, sled acceleration and create a disk file containing significant test parameters.

4.3 Selspot Motion Analysis System

The Selspot Motion Analysis System utilizes photosensitive cameras to track the motion of infrared LED markers attached to different points on the test fixture. The three-dimensional motion of the LEDs is determined by combining the images from two different Selspot cameras. The two Selspot cameras were mounted onboard the sled. Camera 1, mounted perpendicular to the plane defined by the trajectory of the pendulum, was a SELSPOT Model 411-2 (S/N 385) with a 24mm lens. Camera 2, mounted oblique to the plane defined by the pendulum trajectory, was a Selspot Model 411-2 (S/N 384) with a 24mm lens. The Selspot cameras are shown in Figure 2.

The Selspot System includes a GraphOn GO-230 terminal and a Motorola 68010 VME based microcomputer with 1 Mb RAM, a camera interface module (MCIM), A 640 Kbyte floppy disk and a 65 Mb hard disk. The terminal and microcomputer are shown in Figure 8. The microcomputer uses the Motorola VERSADOS operating system. The Selspot data collection and processing are performed by the Selspot MULTILAB System software.

The Selspot System was calibrated by determining the camera locations and orientations prior to each test. The camera locations and orientations were expressed in the coordinate system of the Position Reference Structure (PRS). The PRS is shaped as a tetrahedron with reference LEDs 9, 10, 11 and 12 located at the vertices. The PRS is shown in Figure 9.

The LEDs can be displayed on the terminal during calibration as shown in Figure 10. The figure is a graph of the camera detector plate for Selspot Camera 1 during calibration. The outer frame defines the edge of the camera detector plate. The inner dashed frame defines the linear region of the detector. The numbers indicate the positions of the LED images on the camera detector plate. The PRS was positioned so that all of the LEDs were within the inner frame. The accuracy of the calibration is indicated by the merit value. The merit value was typically 2 mm or less for the calibrations done during this test program.

Three moving infrared LED markers numbered 1, 2 and 3 were mounted on the pendulum. The distance between LED 3 and the pendulum pivot point, LEDs 2 and 3, and LEDs 1 and 2 were all six inches. Four fixed LEDs numbered 4, 5, 6 and 7 were mounted on the seat fixture. The LED locations are shown in Figure 11.

Data was collected from the three moving and four fixed LEDs at a 500 Hz sample rate during the impact. Data collection started at T = -1 seconds for 1.5 seconds. The calibration data and the collected raw camera image data were transferred to the VAX 11/750 for analysis. On the VAX 11/750, the raw image coordinates were corrected for camera vibration, converted into three-dimensional coordinates and transformed into the test fixture coordinate system attached to the pendulum.

5. DATA ANALYSIS

Prior to the start of the test, the pendulum hangs vertically downward under the force of gravity. During a dynamic impact, the pendulum swings upward through a 190 degree angle. The potentiometer, optical encoder and angular accelerometer were used to compute the pendulum angle as a function of time.

LEDs 1, 2 and 3 were moving targets mounted on the pendulum. The pendulum angle was used to calculate the displacements of the three LEDs. The displacements of LEDs 1, 2 and 3 were also determined by the Selspot Motion Analysis System. The error of the Selspot System during dynamic impact was estimated by comparing the two values for the displacement. Fixed LEDs 4, 5, 6 and 7 were used to correct the Selspot camera image coordinates for camera vibration. Plots of the positions of the LEDs in the XZ plane before and after vibration correction are shown in Figures 12 and 13 respectively for a 20 G test.

The angular acceleration was integrated to calculate the pendulum angle. The integrated value was compared with the pendulum angle indicated by the potentiometer. A typical plot of the pendulum angles derived from the potentiometer and angular accelerometer is shown in Figure 14 for a 20 G test.

6. ANALYSIS SOFTWARE

The optical motion data was collected and stored on the Selspot Motion Analysis System as raw image coordinates. It was then transferred to the VAX 11/750 to be analyzed. The four Fortran programs SELSPOT_VIB, SELSPOT_CAL, SELSPOTØA and SELSPOTØB were developed on the VAX 11/750 to analyze the Selspot data. Operation of the four programs is detailed in Section 6.1. Section 6.2 describes the flowcharts for the four programs.

6.1 Program Operation

The Fortran program SELSPOT_VIB was developed on the VAX 11/750 to correct the raw camera image coordinates for camera vibration, transform the raw data for both cameras into three dimensional LED positions and output the results in a rotated coordinate system that was related to the pendulum position and independent of the position of the PRS. SELSPOT_VIB requests the user to enter the filenames for the camera parameter file, the pretest image coordinate file, the test image coordinate file and the output file. The user specifies whether the image coordinates should be filtered, whether a camera vibration correction should be performed and whether the coordinate system should be rotated. If requested, the three-dimensional positions of the LEDs are filtered with a 120 Hz FFT filter.

The program assumes that the lower LED numbers are moving LEDs, followed by the fixed LEDs. The computed three dimensional coordinates of the LEDs are output to a text file. The text file will be read by SELSPOTØB which does the rest of the analysis.

The Fortran program SELSPOT_CAL was developed to calibrate the Selspot Motion Analysis System on the VAX 11/750. SELSPOT_CAL solves for the camera locations and orientations that minimize the differences between the measured and computed positions of the LEDs on the PRS. SELSPOT_CAL uses many of the same algorithms that are used by the calibration program CAMSOLB for the photogrammetric film data.

The parameters that define the camera orientations are the camera location, principle distance and the unit vectors of a coordinate system attached to the camera image. The x axis of the coordinate system is to the right on the camera image, the y axis is upward on the camera image and the z axis is according to the right hand rule. SELSPOT_CAL can compute the optimal principle distance for each camera separately or for both cameras together.

The Fortran programs SELSPOTØA and SELSPOTØB were developed to analyze the ADACS and Selspot data from the Selspot Study. Program SELSPOTØA accepts user input and creates a DCL file which controls the processing of all of the specified tests. SELSPOTØA requests the user to enter the total number of tests to be processed and the test number for each test. The user specifies the test number, test date, cell type and nominal G level for each test.

SELSPOTØB reads the vibration corrected and uncorrected LED positions for the three moving and the four fixed LEDs from the files created by SELSPOT_VIB. The ADACS data for the sled x, y and z accelerations, sled velocity, pendulum angular acceleration, potentiometer and optical encoder are also read in and analyzed.

The potentiometer is filtered with a 120 Hz digital 4-pole Butterworth filter so that it can be compared with the angular accelerometer output, which was filtered with a 120 Hz analog 4-pole Butterworth filter. The angular acceleration is integrated twice to compute the pendulum angle. The absolute value of the difference between the potentiometer and angular acceleration angles is calculated as an estimate of the error from the angular accelerometer.

The potentiometer is filtered with a 120 Hz digital FFT filter so that it can be compared with the Selspot LED positions, which were filtered with a 120 Hz digital FFT filter. The displacements of the moving LEDs from their initial positions are calculated from the camera vibration corrected Selspot data. The displacements of the LEDs are also computed from the potentiometer angles by using the equation,

$$Disp = 2R \sin(\Theta/2)$$

where R is the pendulum radius to the LED and Θ is the pendulum angle .

The Selspot and ADACS times can be correlated with reference to the Selspot trigger signal. However, this results in a small difference in the times of the potentiometer and Selspot data due to filtering, uncertainty in sampling time, etc. Consequently, the time correlation was optimized by matching the time histories representing the Selspot and potentiometer displacements for LED 1. The absolute value of the difference between the potentiometer and Selspot displacements is calculated as an estimate of the error from the Selspot.

The optical encoder signal consists of pulses generated when an optical encoder disk breaks a beam between the light source and detector. SELSPOTØB finds the start of each pulse and computes the corresponding pendulum angle. The angle at the start of the first pulse is assigned the value that the potentiometer angle has at that time.

Values for the preimpact level and the extrema for each ADACS time history are stored in the test base file and printed out as a summary sheet for each test. The extrema for the LED positions and displacements, the displacement errors and the angle error are also printed out. The time histories are plotted and the time histories of the displacement and angle errors for a 100 ms window following the start of the impact are printed out. The means and standard deviations of the errors are also displayed.

For the static tests, time zero is defined as the time when the angular acceleration falls below -50 rad/sec2.

6.2 Program Flowcharts

Flowcharts of the four programs are shown in Figures 15 through 18. Each flowchart identifies the files used and the subroutines called by the program. Some of the subroutines which are not flowcharted are located in user libraries. Others have such a simple structure that they do not require flowcharting.

DYNCORP

ANALOG INSTRUMENTATION REQUIREMENTS

PROGRAM INVESTIGATION OF SELSPOT MOTION ANALYSIS SYSTEM RESPONSE TO IMPACT CONDITIONS **DATE** 09AUG89 **THRU** 14NOV89

FACILITY HORIZONTAL ACCELERATOR **RUN** 3888 **THRU** 3916

DATA CHANNEL	DATA POINT	XDUCER MFG & TYPE	SERIAL NUMBER	XDUCER SENS	EXCITE V	CHAN	CAL PROGRAM	AMPLIFIER MFG & S/N	AMP GAIN	F.S. SENS = 1 volt	FILTER	VCO	MUX NO.	TAPE REC CH	TAPE DIR/FM	SPECIAL NOTATIONS
1	SLED X	ENDEVCO 2262A-200	FR31	4.991 mv/G	10.045	1	100% = 40 G	NEWPORT 1 336107	5.009	40 G	3K	1	1	1	DIR	
2	SLED Y	ENDEVCO 2264-200	BQ47	3.194 mv/G	10.030	2	100% = 15 G	2 226927	20.87	15 G	3K	2	1	1	DIR	
3	SLED Z	ENDEVCO 2264-200	BN61	2.913 mv/G	10.030	3	100% = 15 G	3 336109	22.89	15 G	3K	3	1	1	DIR	
4	ANGULAR ACCEL.	ENDEVCO 7302B	PT47	3.596 uv/RAD/SEC^2	10.045	4	100% = 6000 RAD/SEC^2	4 335094	46.35	6000 RAD/SEC^2	3K	4	1	1	DIR	
5	POTENTIOMETER	HELIPOT L.25 R50K	1	1.00 VOLT/REV	10.00	5	-----	-----	-----	1 VOLT	----	5	1	1	DIR	
VTD	VTD VELOCITY	GLOBE 22A672-2	2	.010 VOLT/FT/SEC	--	--	-----	-----	-----	100 F/S	----	6	1	1	DIR	SCALED THROUGH VTD UNIT
	EVENT	-----	---	1.0 VOLT	--	--	-----	-----	-----	1 VOLT	----	7	1	1	DIR	USE AMP. 48 @ GAIN 8.8 TO SELSPOT
8	TRIGGER	-----	---	1.0 VOLT	10.00	8	-----	-----	-----	1 VOLT	----	--	--	8	FM	ACTUAL OUTPUT 10 TO 0 VOLT TO SELSPOT USING SUMMATION AND MAS. STA USE ATTENUATOR FOR DATA @ .1; T-01
9	OPTICAL ENCODER	CLAROSTAT 600-128 140-8913	1	1.0 VOLT	4.00	9	-----	-----	-----	1 VOLT	----	--	--	9	FM	ACTUAL OUTPUT 0 TO 3.49 VOLT USE ATTENUATOR @ .2
VTD	RAM X	ENDEVCO 2262A-200	EM75	.020 V/G	--	--	-----	-----	-----	50 G	----	1	2	2	DIR	
VTD	VTD CODE	-----	---	-----	--	--	-----	-----	-----	----	----	--	--	10	FM	
---	TIMING	-----	---	-----	--	--	-----	-----	-----	.8 VOLT	----	--	--	13	FM	+5 VOLT PULSES - USE TAPE CHANNEL 13 - ATTENUATED @ .167

TAPE RECORDER **TIME ON** -14 **OFF** +04 **SPEED** 60 IPS **MUX CAL** ± 1VOLT = ± 8KHz

SELSPOT TRIGGER @ -01, +01

PAGE 1 **OF** 1

TABLE 1: INSTRUMENTATION REQUIREMENTS

MANUFACTURER	MODEL	RANGE	SENSITIVITY (mv)	RESONANCE FREQ (Hz)	FREQUENCY RESPONSE (Hz.)	EXCITATION (Volt)	2 ARM or 4 ARM	ADDITIONAL NOTES
Endevco	2264-200	± 200 G	2.5/G	4700	0-1200	10	2 arm	Linear accelerometer
Endevco	2262A-200	± 200 G	2.5/G	7000	0-2000	10	4 arm	Linear accelerometer, .7 damping ratio
Endevco	7302B	± 50,000 Rad/Sec^2	.004 /Rad/Sec^2	3000	1-600	10	4 arm	Angular accelerometer X10 overrange
Clarostat	600-128, 140-8913	--------	128 Pulses/Rev	----	-----	4.0	-----	Optical Encoder
Globe	22A672-2	0-10,000 RPM	200 /Rev/Sec	----	0-100	--	-----	Velocity Tachometer
Helipot	L.25 R50K	10 Rev	1000/Rev	----	-----	10	-----	Potentiometer

TABLE 2: TYPICAL TRANSDUCER SPECIFICATIONS

DYNCORP PROGRAM CALIBRATION LOG

PROGRAM Investigation of Selspot Motion Analysis System Response to Impact Conditions **DATES:** 09 AUG 89 Thru 14 NOV 89

FACILITY Horizontal Accelerator **RUN NUMBERS:** 3888 Thru 3916

DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		%CHANGE	NOTES
			DATE	SENS	DATE	SENS		
SLED X	Endevco 2262A-200	FR31	21JUL89	4.991 mv/G	21NOV89	5.039 mv/G	+ 1.0	
SLED Y	Endevco 2264-200	BQ47	21JUL89	3.194 mv/G	21NOV89	3.184 mv/G	- 0.3	
SLED Z	Endevco 2264-200	BN61	21JUL89	2.913 mv/G	21NOV89	2.907 mv/G	- 0.2	
ANGULAR ACCELEROMETER	Endevco 7302B	PT47	14JUN89	3.596 uv/RAD/SEC^2	20NOV89	3.593 uv/RAD/SEC^2	- 0.1	
POTENTIOMETER	HELIPOT L.25 R50K	1	07AUG89	1.00 VOLT/REV	---	---	----	SENSITIVITY @ 10VOLTS CALIBRATED PERIODICALLY
VELOCITY	GLOBE 22A672-2	2	16JUN89	.010 VOLT/FT/SEC	---	---	----	SCALED THROUGH VTD UNIT. CALIBRATED PERIODICALLY
RAM X	Endevco 2262A-200	HM75	21JUL89	4.300 mv/G	21NOV89	4.311 mv/G	+ 0.3	
OPTICAL ENCODER	CLAROSTAT 600-128 140-8913	1	---	---	---	---	----	NO CALIBRATION REQUIRED - 128PULSES PER REVOLUTION

TABLE 3: TRANSDUCER PRE- AND POST-CALIBRATION

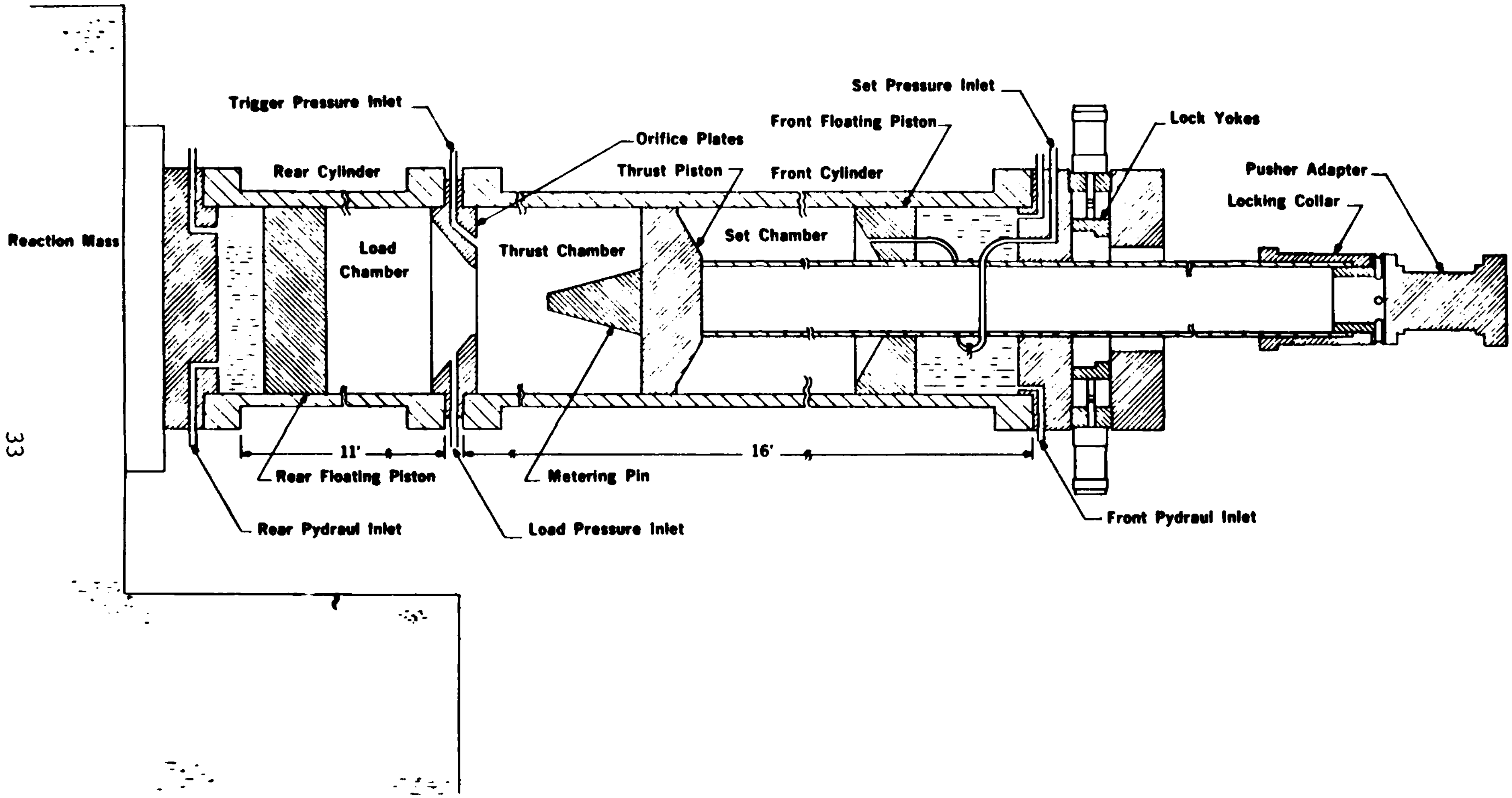


FIGURE 1: HORIZONTAL ACCELERATOR ACTUATOR

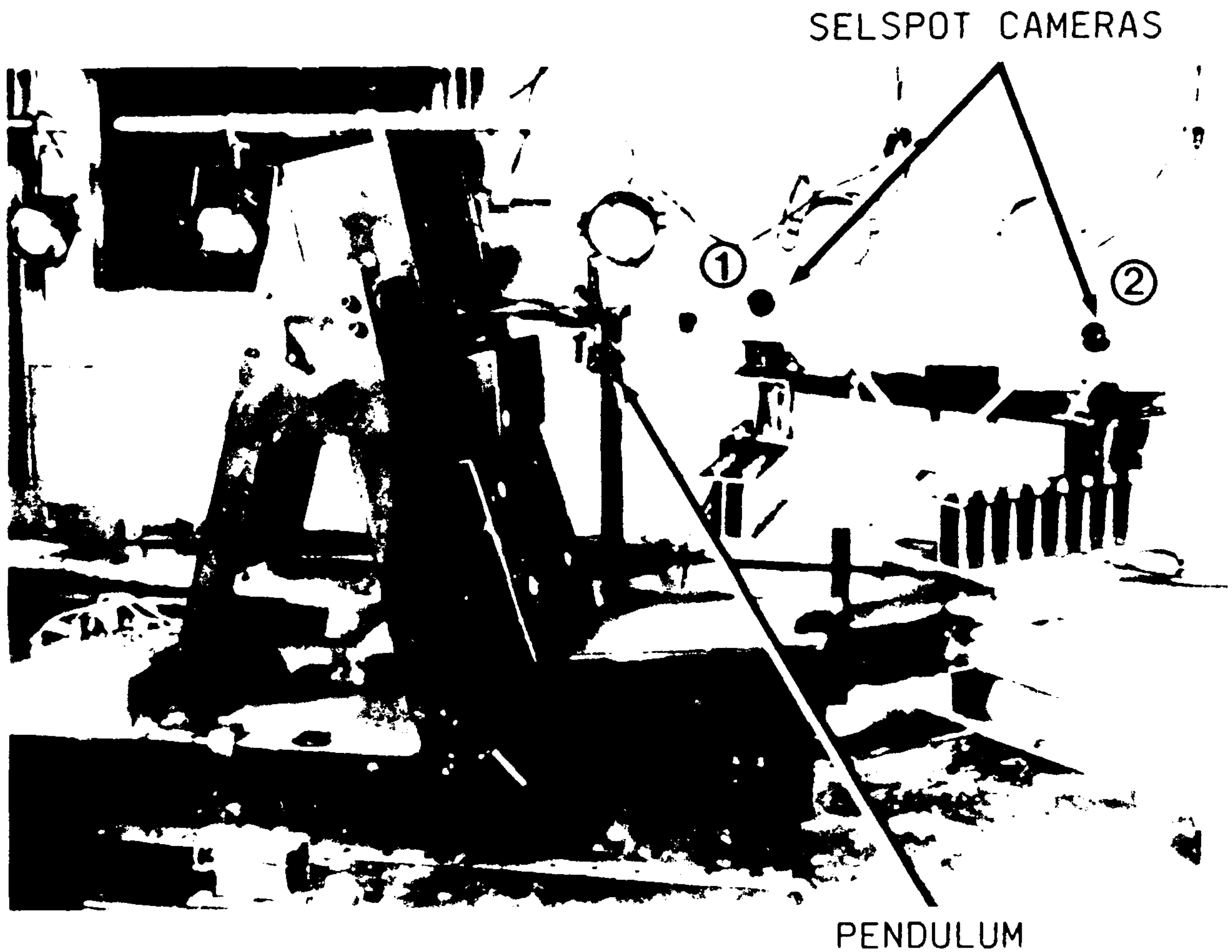


FIGURE 2: TEST FIXTURE

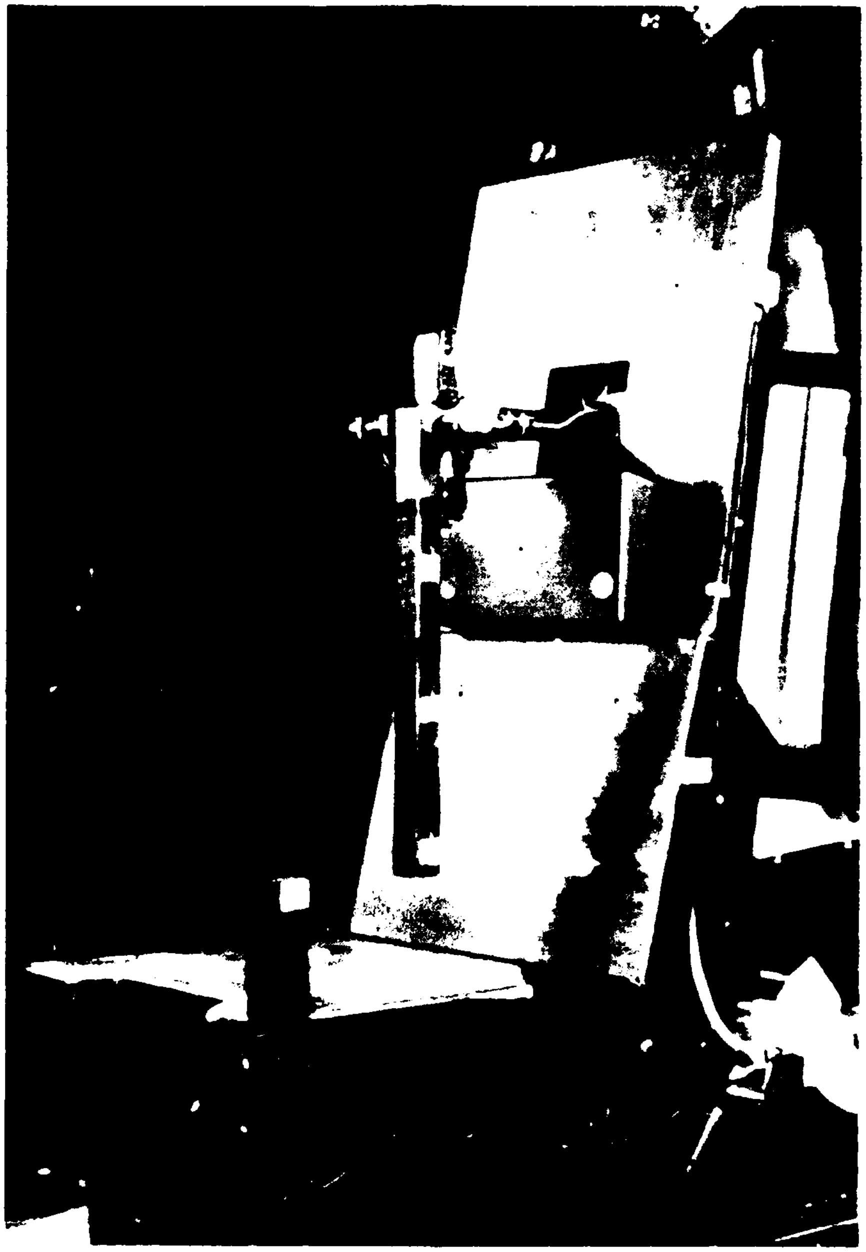


FIGURE 3: TEST FIXTURE

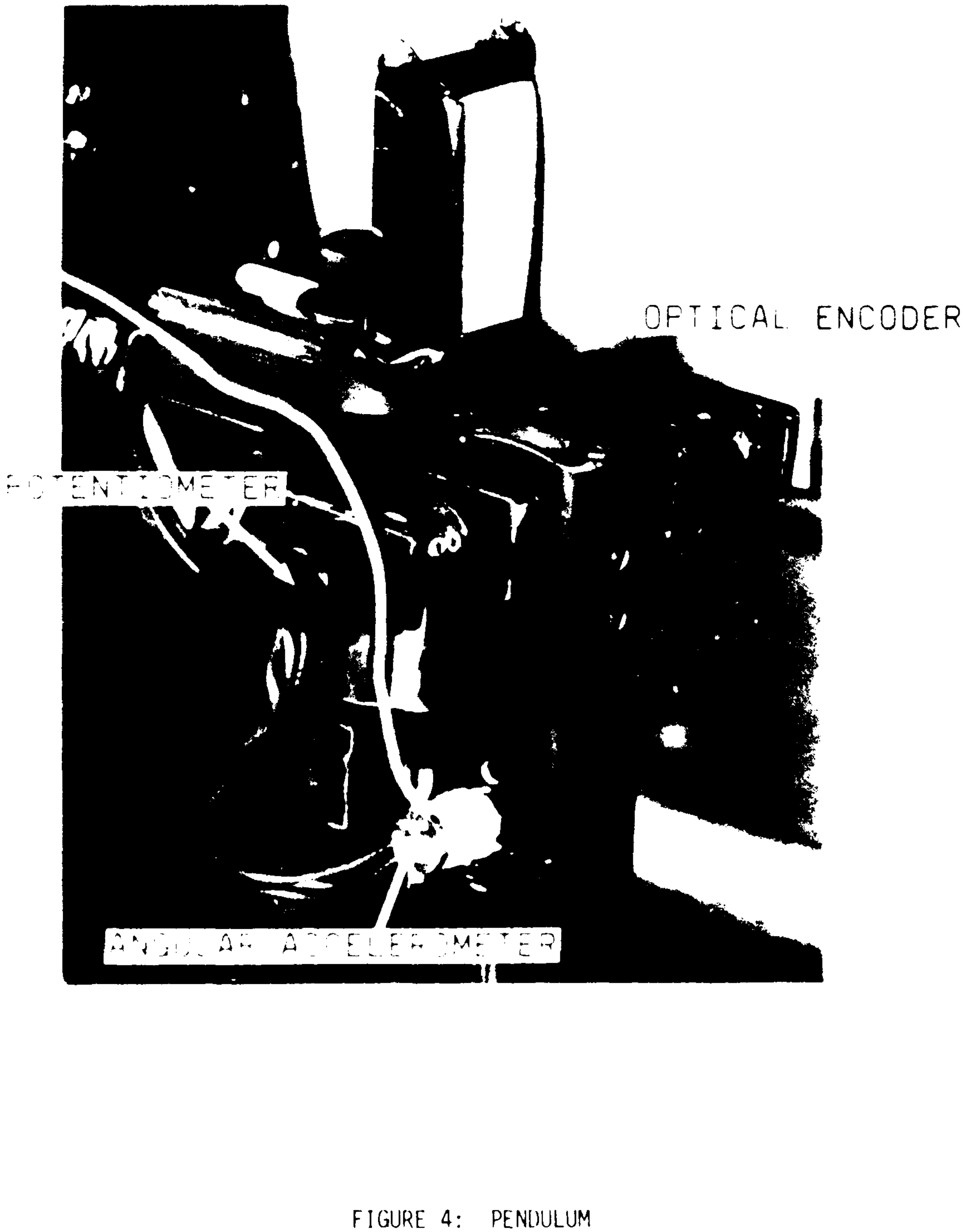
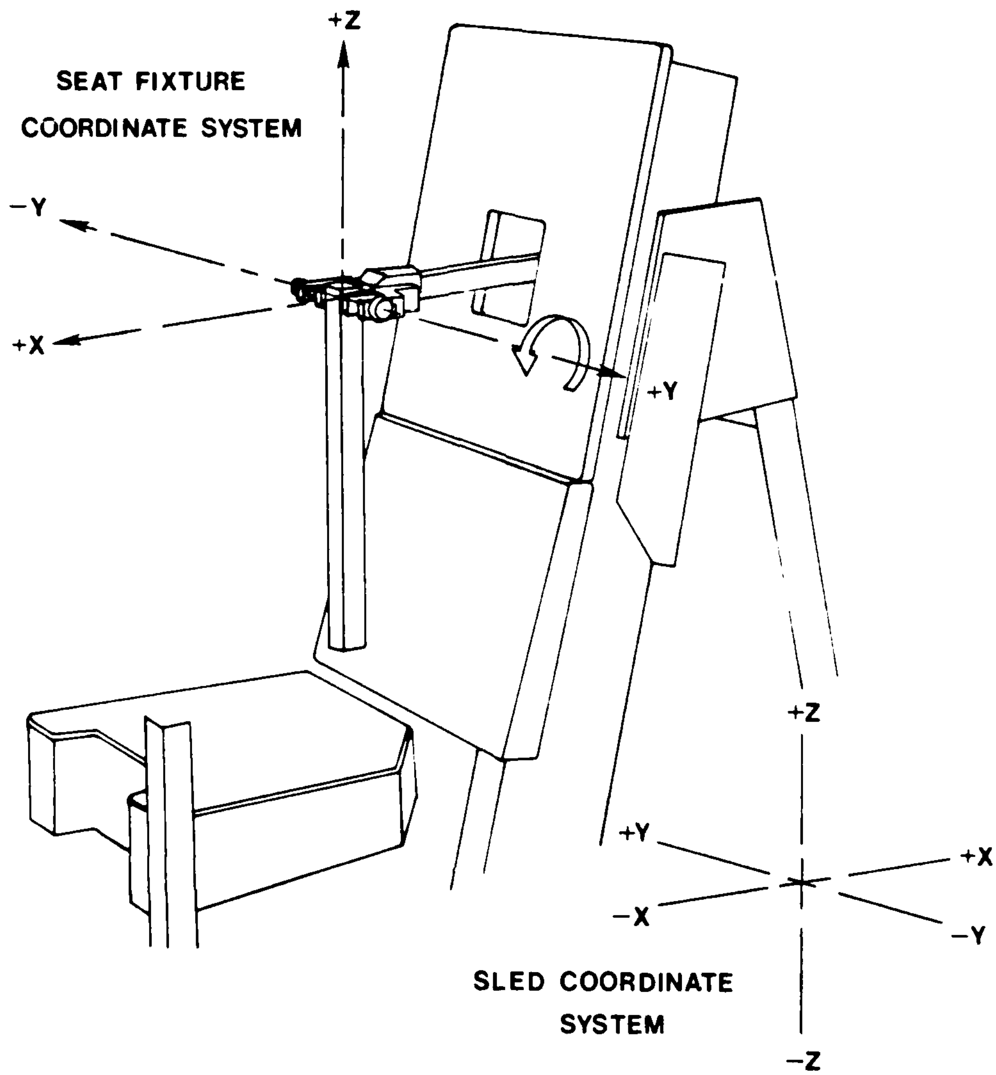


FIGURE 4: PENDULUM



1. THE SLED LINEAR ACCELEROMETERS WERE WIRED TO PROVIDE A POSITIVE OUTPUT VOLTAGE WHEN THE ACCELERATION EXPERIENCED BY THE ACCELEROMETER IS APPLIED IN THE +x, +y OR +z DIRECTIONS AS SHOWN.

2. THE SLED TACHOMETER WAS WIRED TO PROVIDE A POSITIVE OUTPUT VOLTAGE WHEN THE SLED MOVES IN THE +x DIRECTION AS SHOWN.

3. THE ANGULAR ACCELEROMETER WAS WIRED TO PROVIDE A POSITIVE OUTPUT VOLTAGE WHEN THE ANGULAR ACCELERATION EXPERIENCED BY THE ANGULAR ACCELEROMETER IS IN THE +y DIRECTION ACCORDING TO THE RIGHT HAND RULE AS SHOWN.

FIGURE 5: COORDINATE SYSTEMS

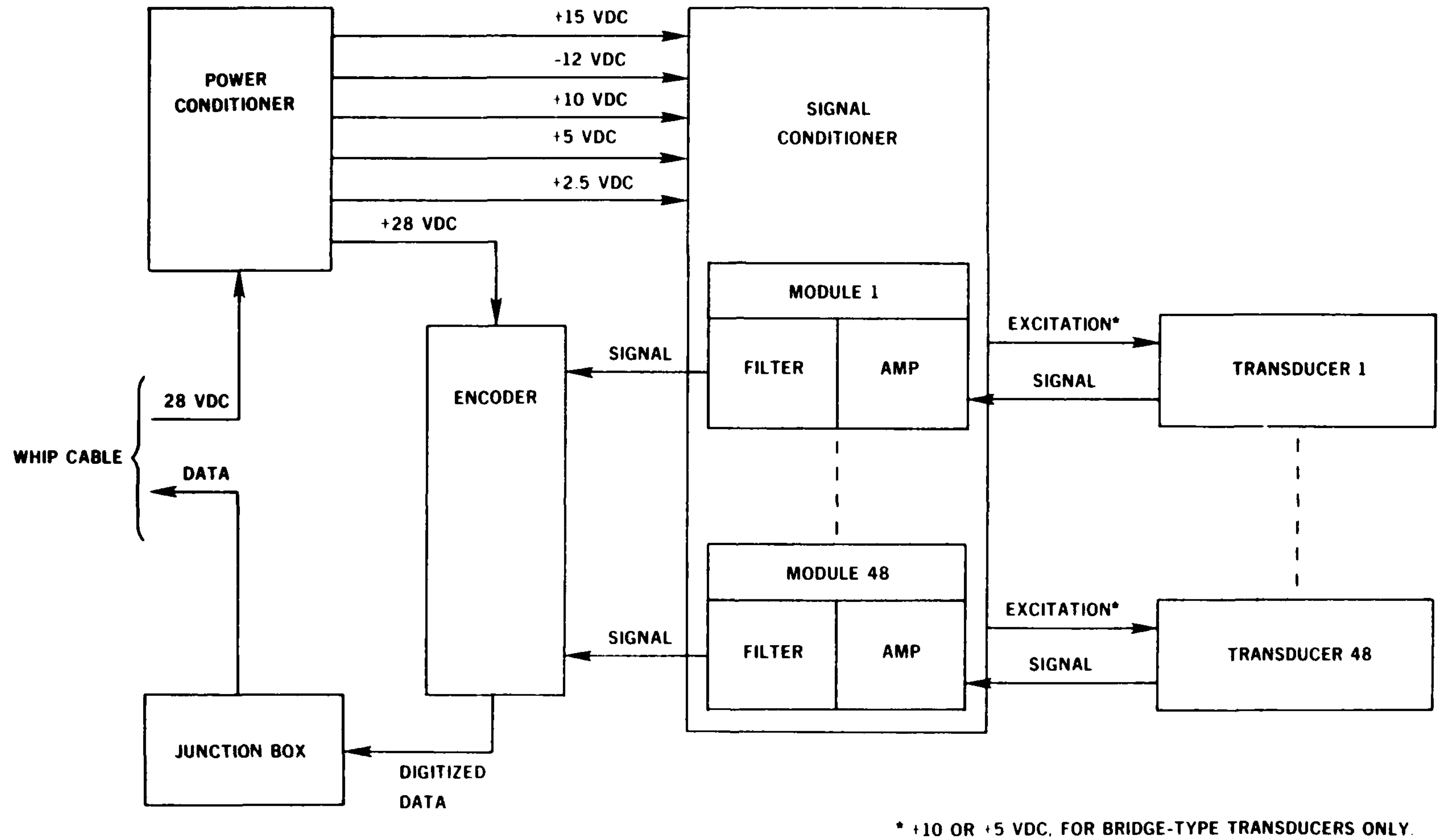


FIGURE 6: AUTOMATIC DATA ACQUISITION AND CONTROL SYSTEM

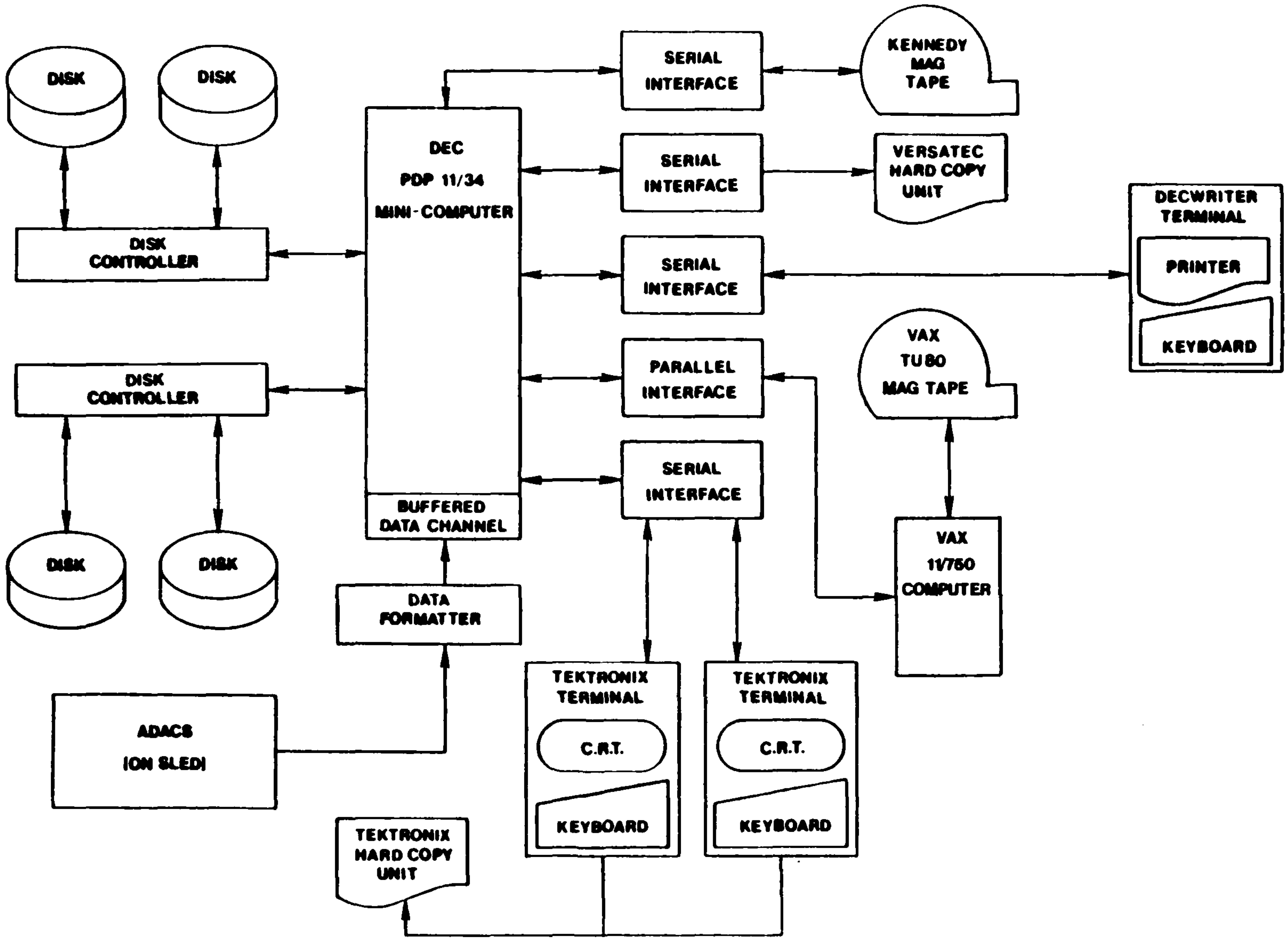


FIGURE 7: DATA ACQUISITION AND STORAGE SYSTEM BLOCK DIAGRAM

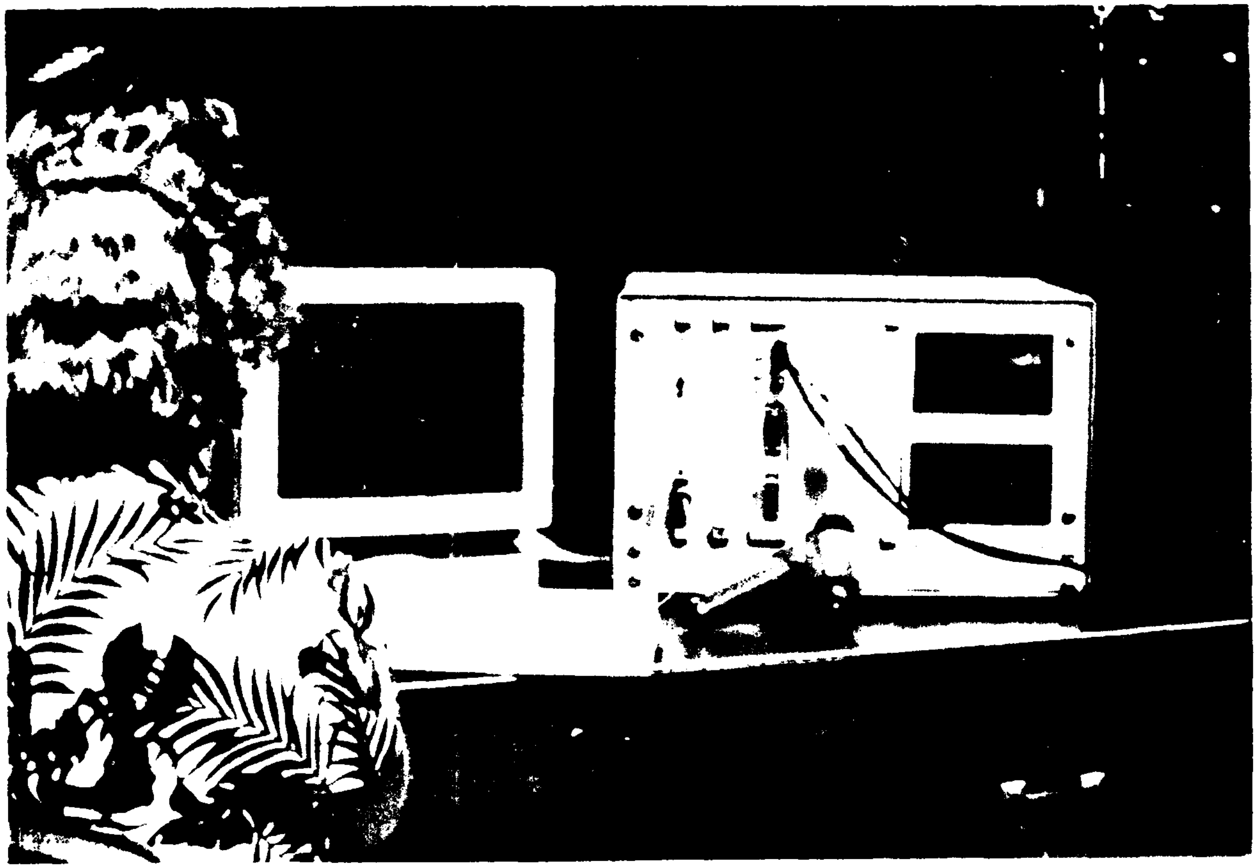


FIGURE 8: SELSPOT MOTION ANALYSIS SYSTEM

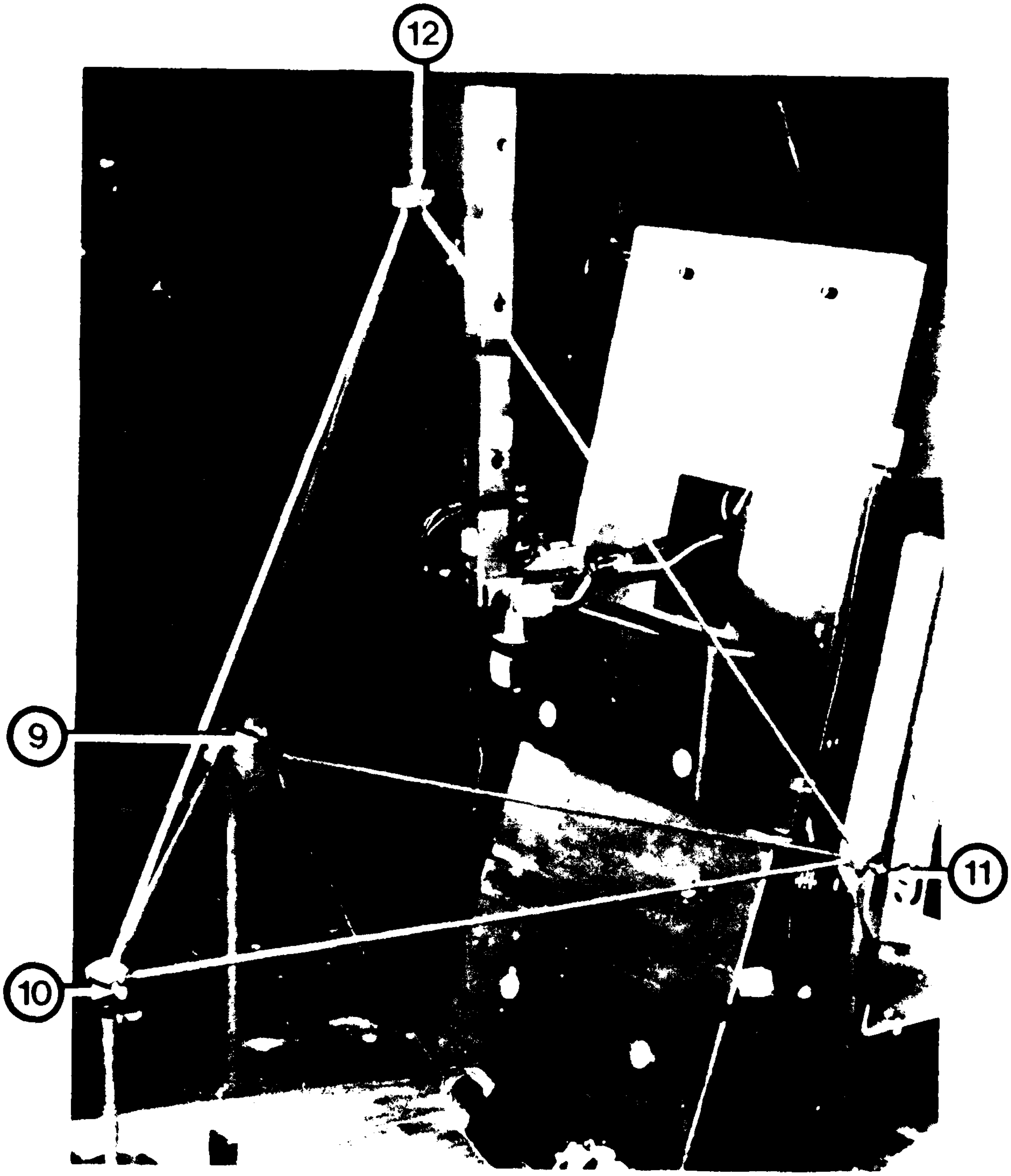


FIGURE 9: POSITION REFERENCE STRUCTURE

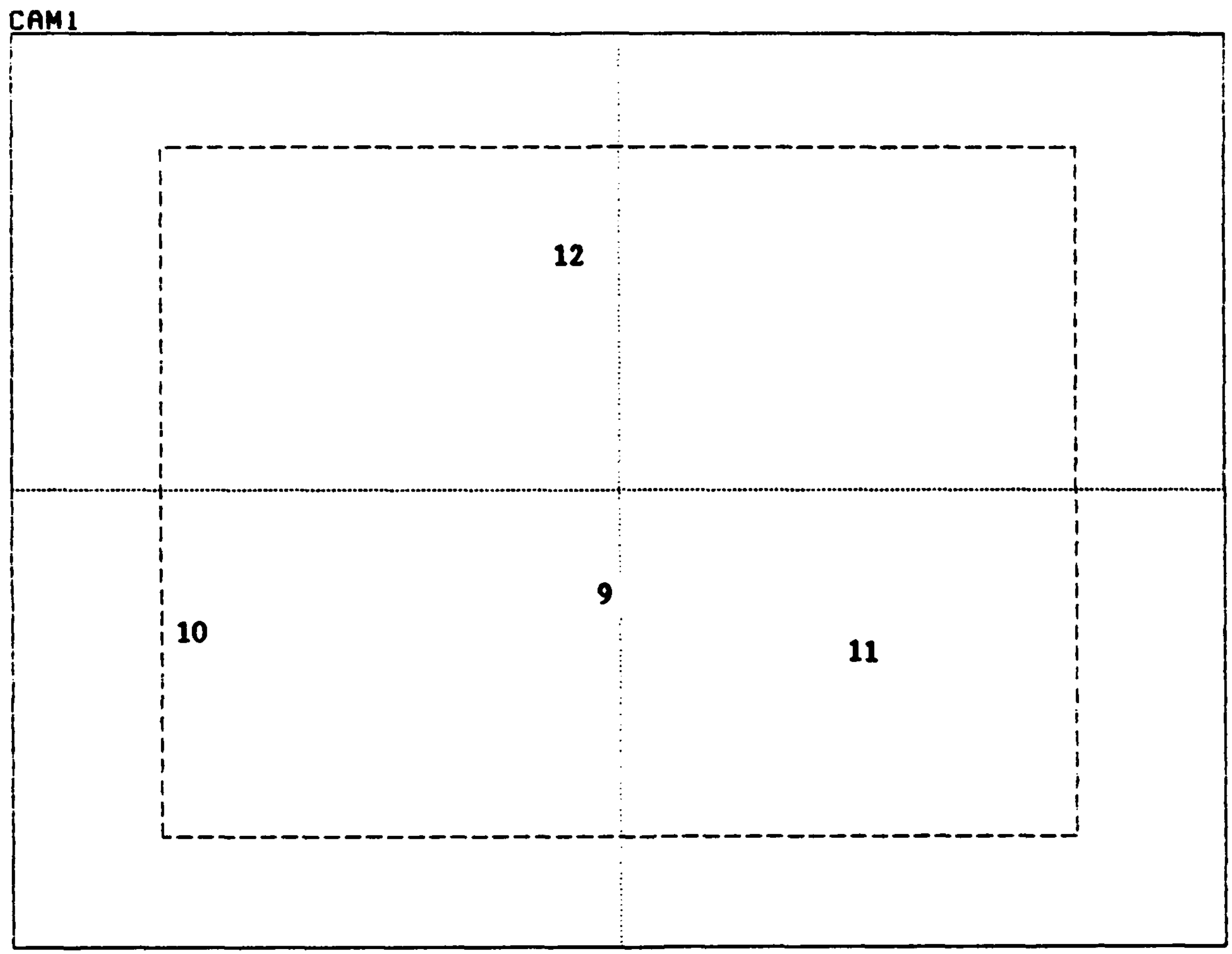


FIGURE 10: CAMERA DETECTOR PLATE

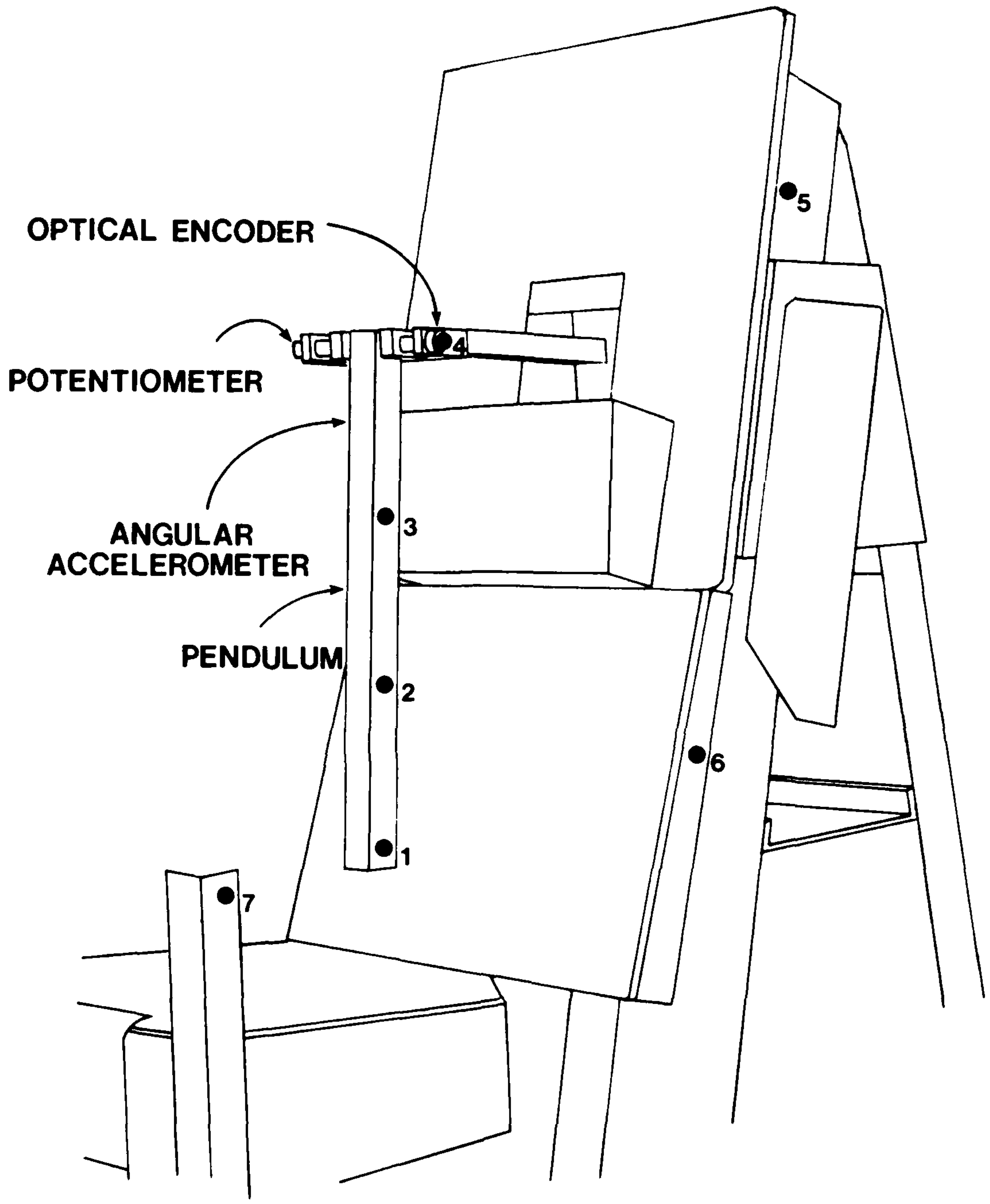


FIGURE 11: INSTRUMENTATION AND LED LOCATIONS

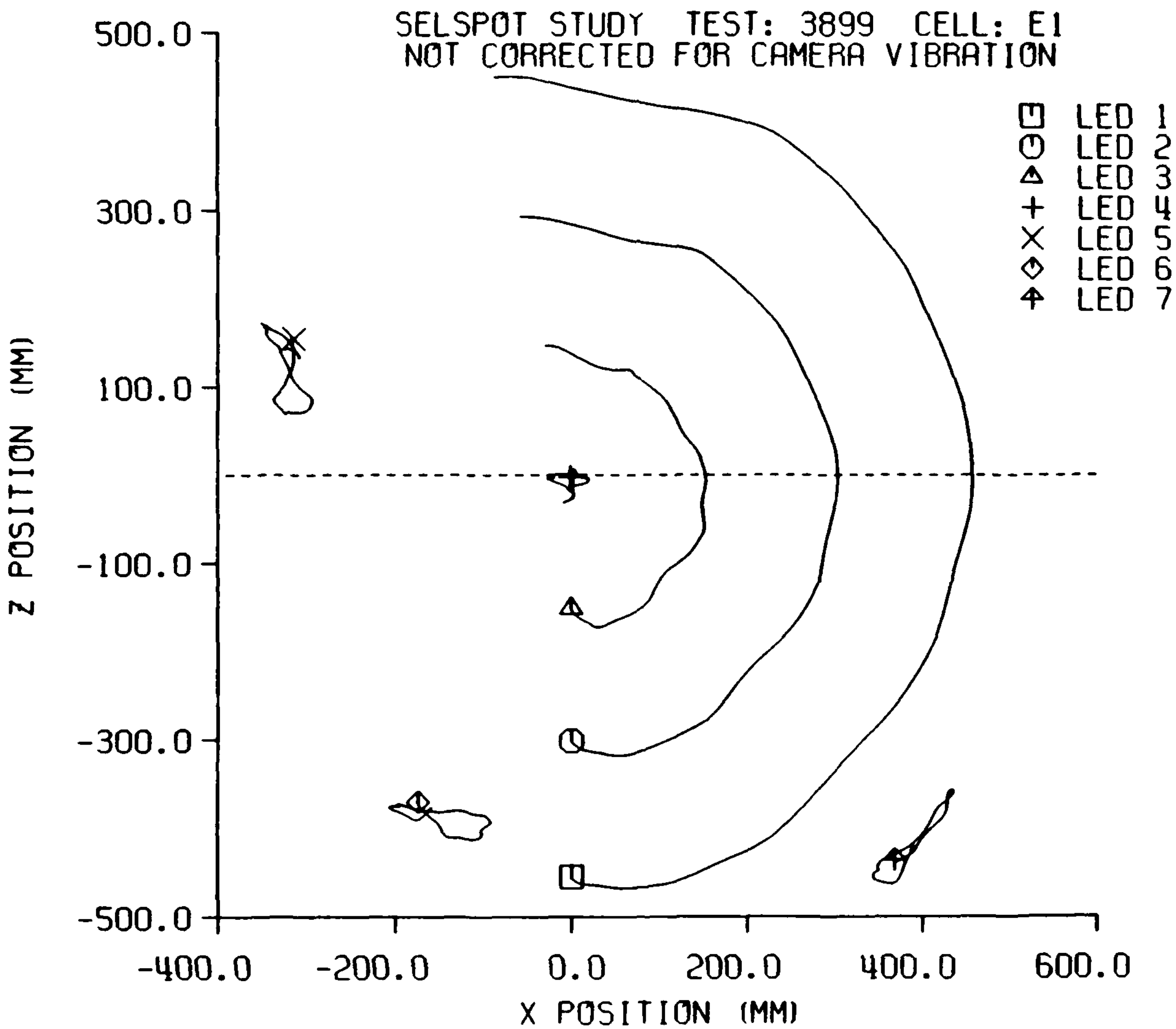


FIGURE 12: LED POSITIONS IN XZ PLANE

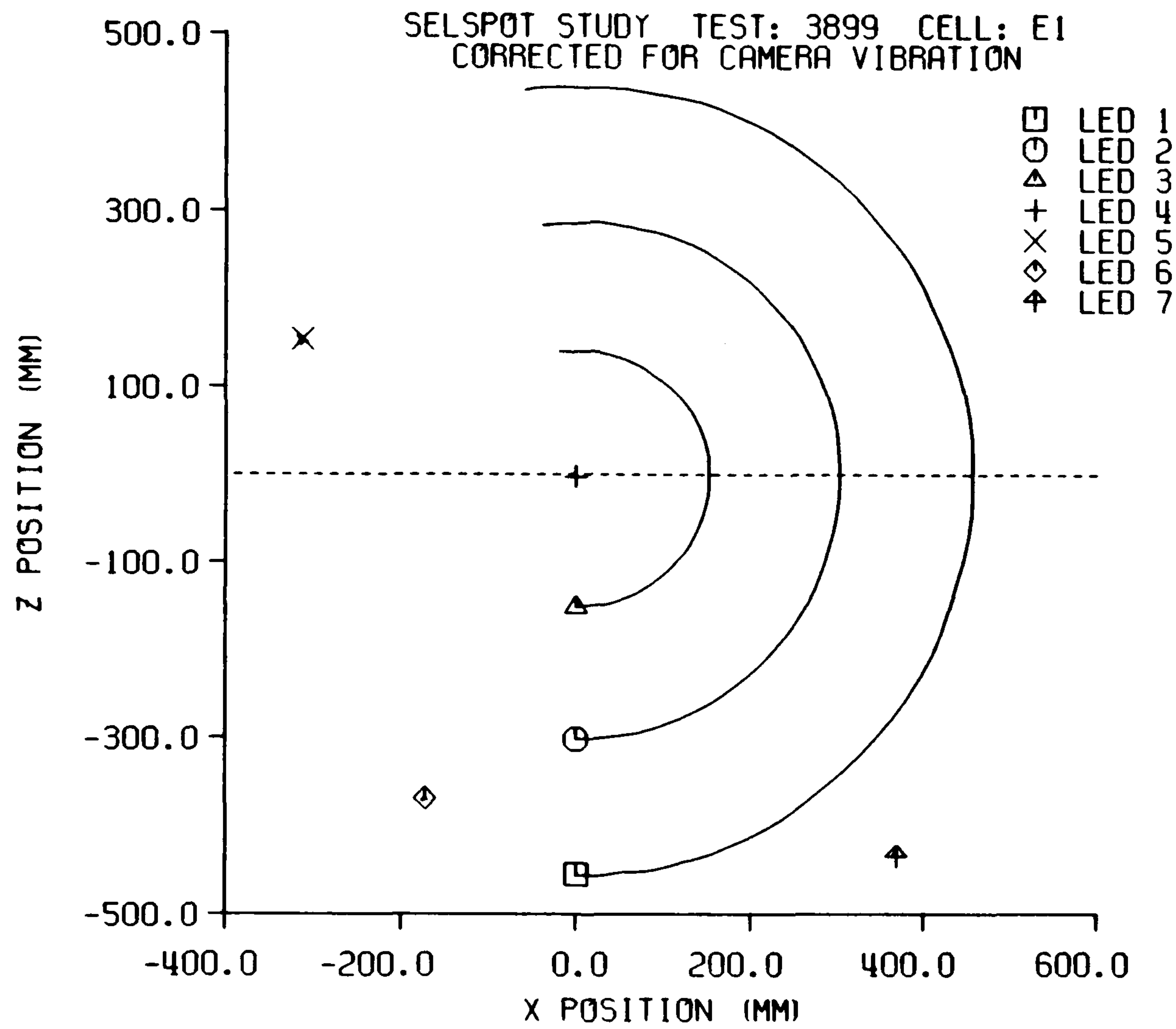


FIGURE 13: LED POSITIONS IN XZ PLANE WITH VIBRATION CORRECTION

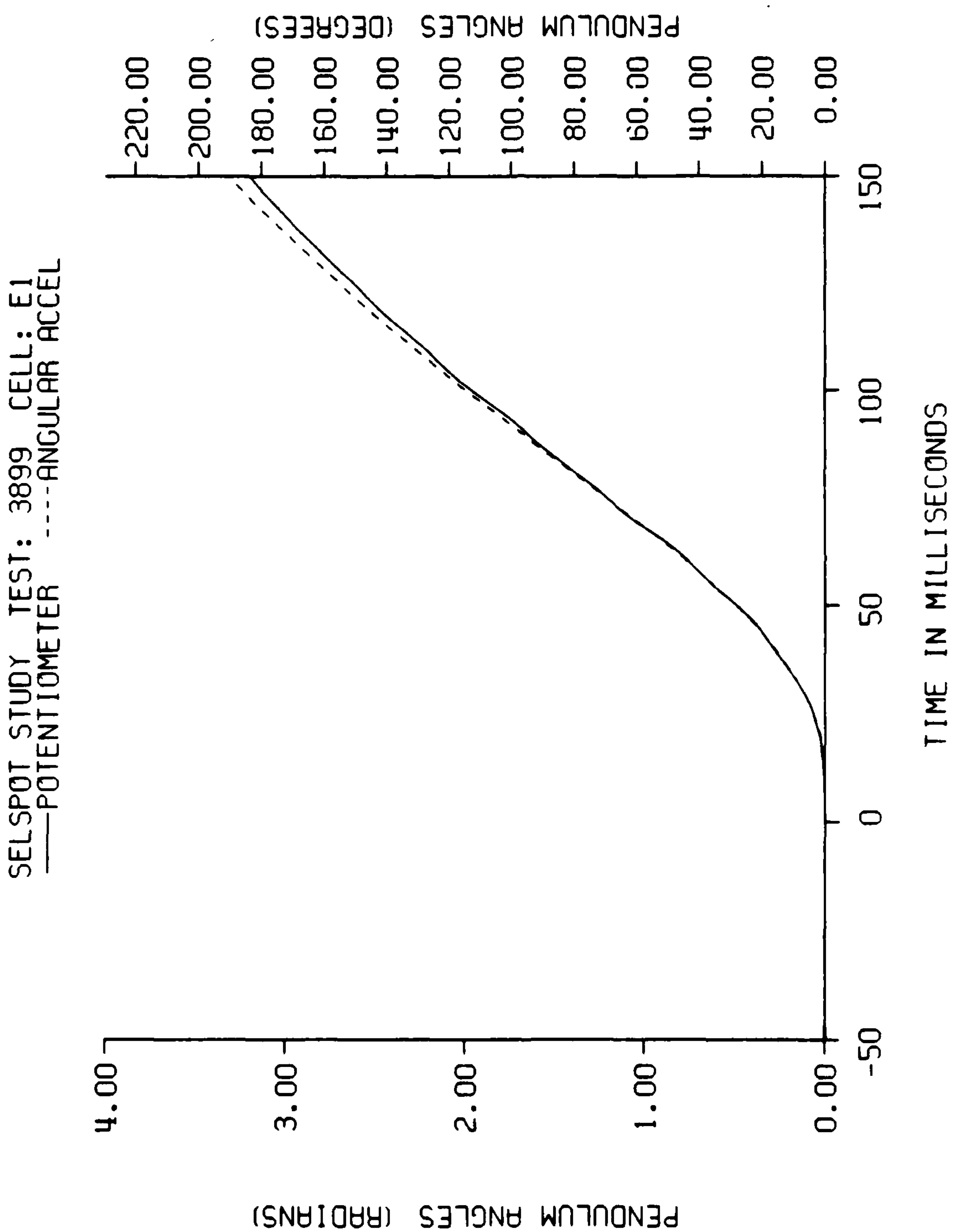
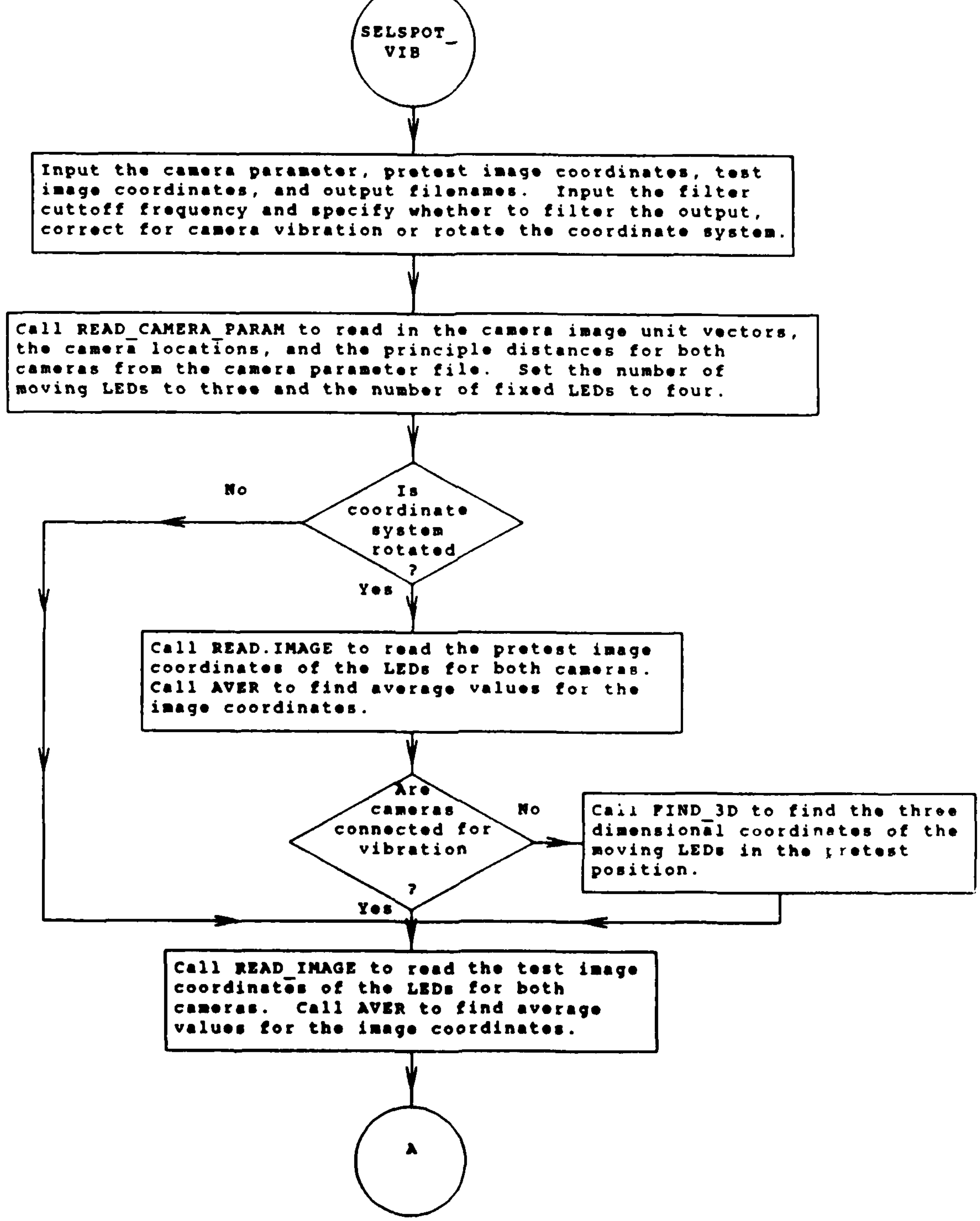
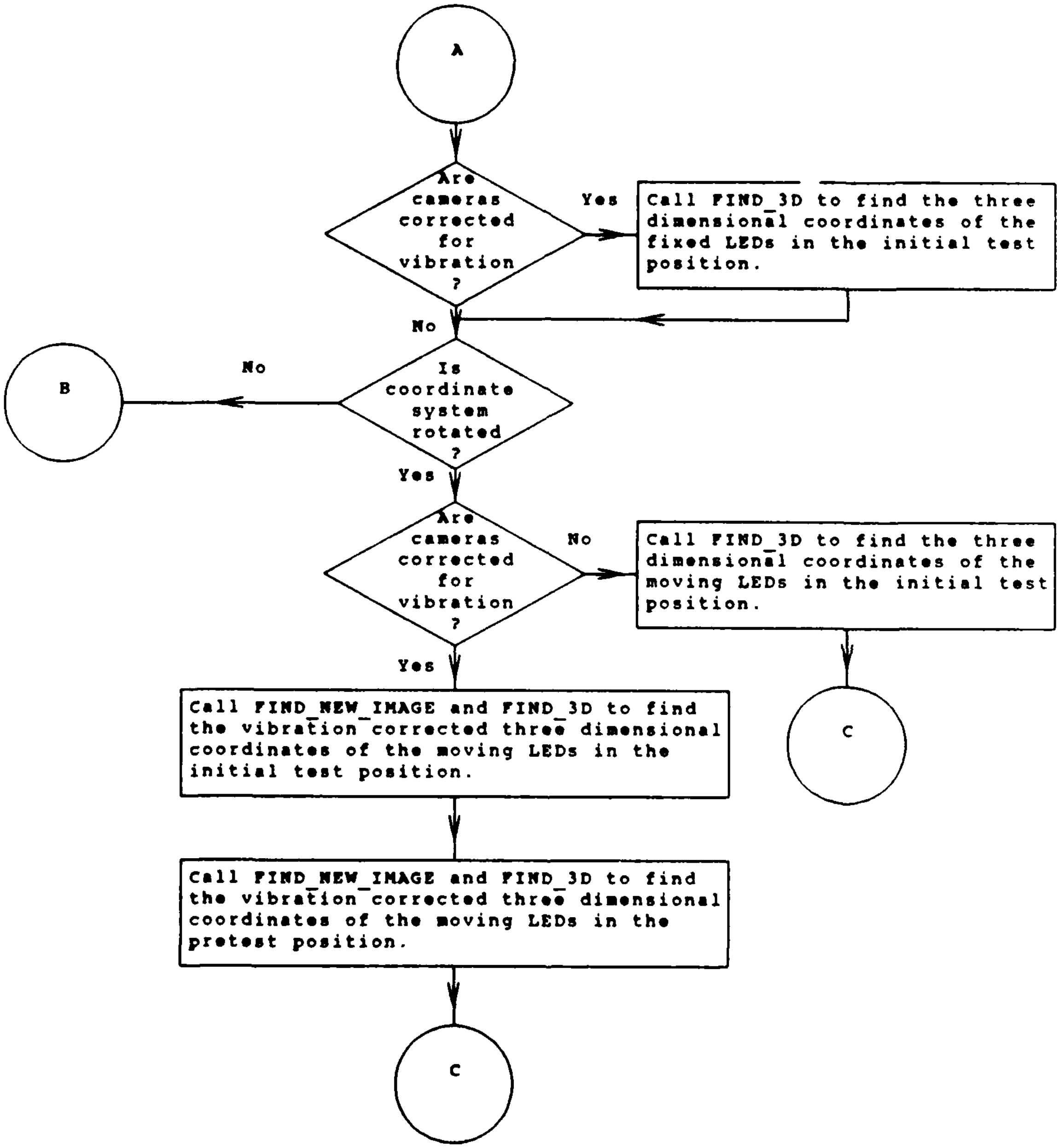
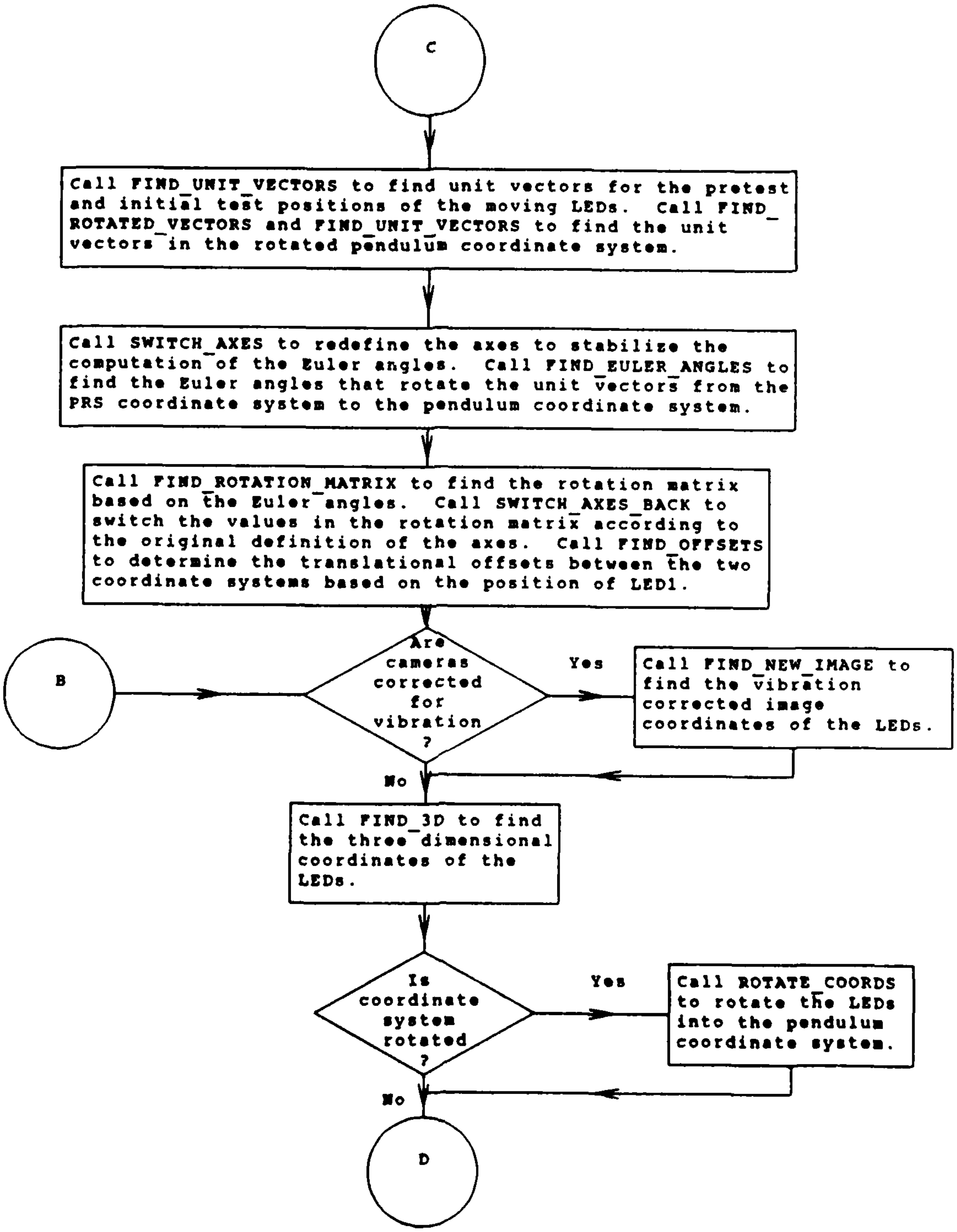
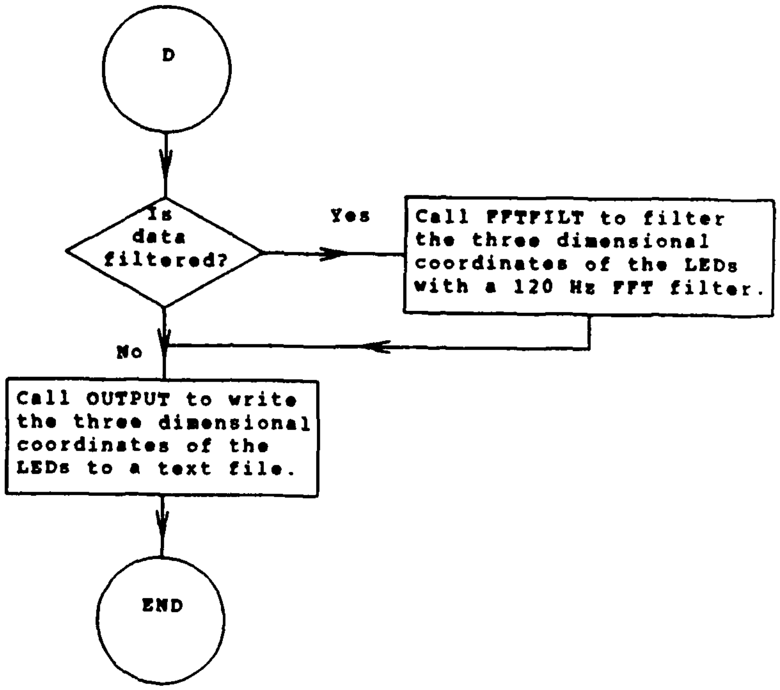


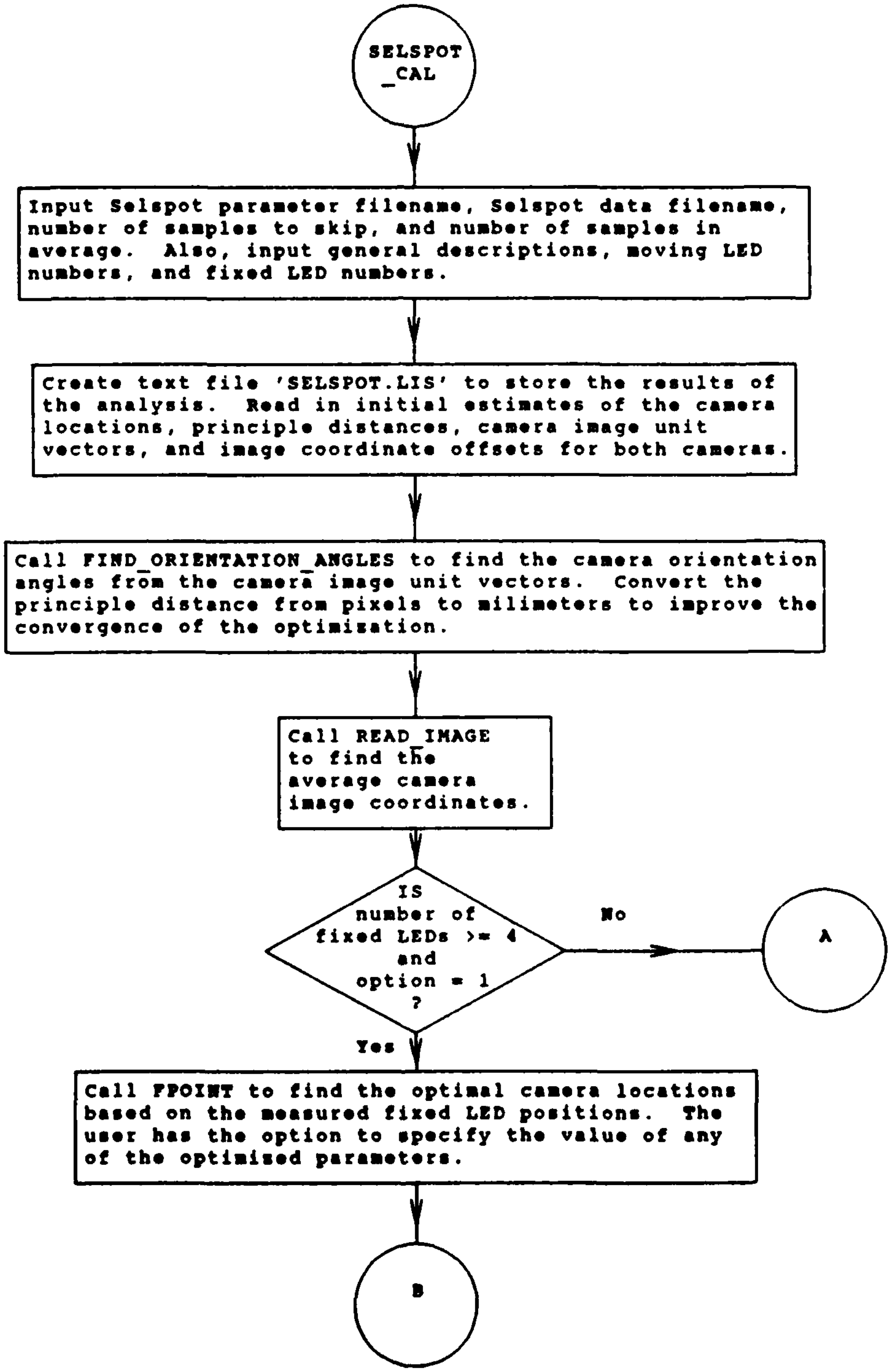
FIGURE 14: PENDULUM ANGLES

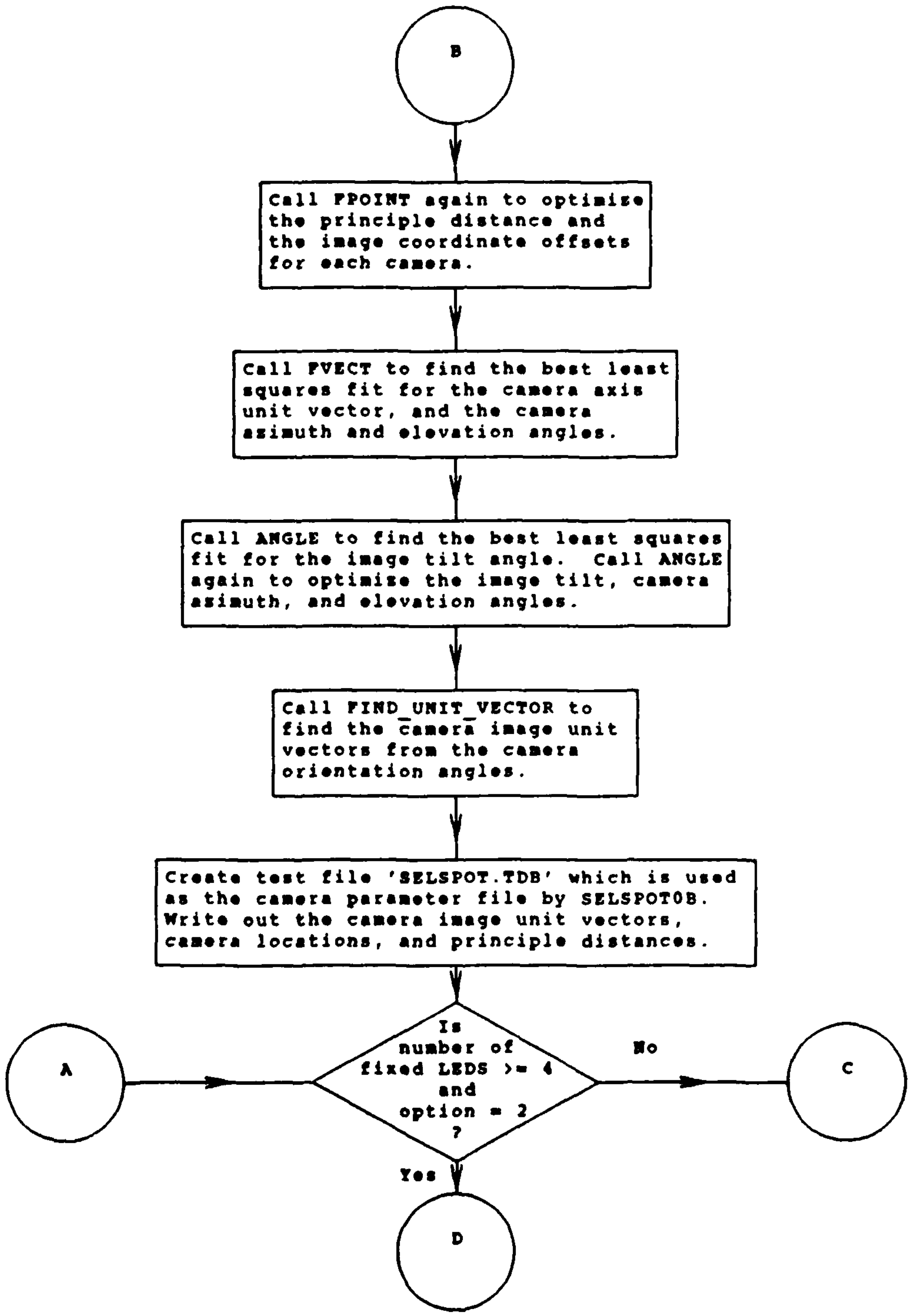

SELSPOT_VIB
Input the camera parameter, pretest image coordinates, test image coordinates, and output filenames. Input the filter cuttoff frequency and specify whether to filter the output, correct for camera vibration or rotate the coordinate system.
Call READ_CAMERA_PARAM to read in the camera image unit vectors, the camera locations, and the principle distances for both cameras from the camera parameter file. Set the number of moving LEDs to three and the number of fixed LEDs to four.
Is coordinate system rotated ?
No
Yes
Call READ.IMAGE to read the pretest image coordinates of the LEDs for both cameras. Call AVER to find average values for the image coordinates.
Are cameras connected for vibration ?
No
Yes
Call FIND_3D to find the three dimensional coordinates of the moving LEDs in the pretest position.
Call READ_IMAGE to read the test image coordinates of the LEDs for both cameras. Call AVER to find average values for the image coordinates.
A

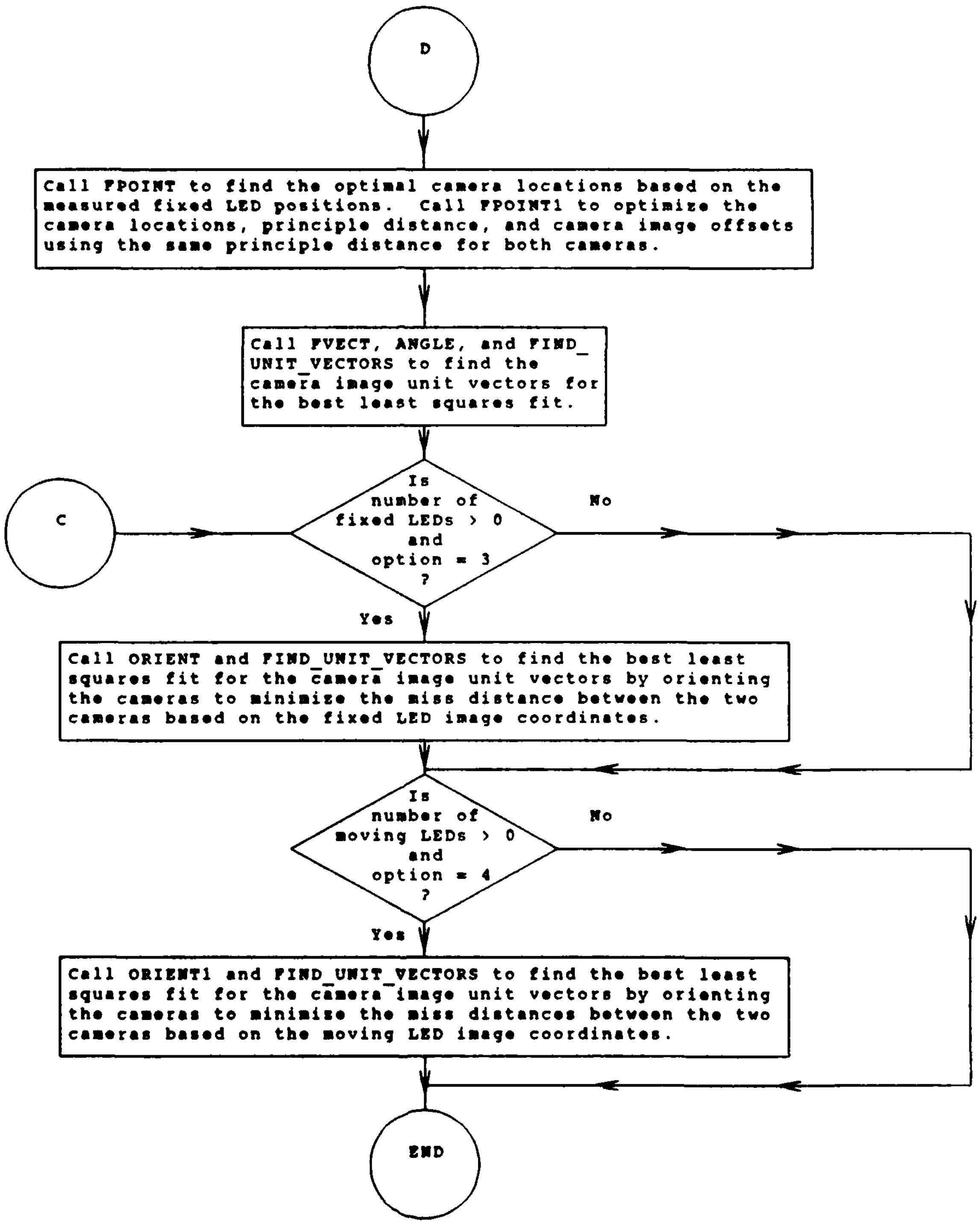

A
Are cameras corrected for vibration ?
Yes
Call FIND_3D to find the three dimensional coordinates of the fixed LEDs in the initial test position.
No
Is coordinate system rotated ?
No
B
Yes
Are cameras corrected for vibration ?
No
Call FIND_3D to find the three dimensional coordinates of the moving LEDs in the initial test position.
C
Yes
Call FIND_NEW_IMAGE and FIND_3D to find the vibration_corrected three_dimensional coordinates of the moving LEDs in the initial test position.
Call FIND_NEW_IMAGE and FIND_3D to find the vibration_corrected three_dimensional coordinates of the moving LEDs in the pretest position.
C

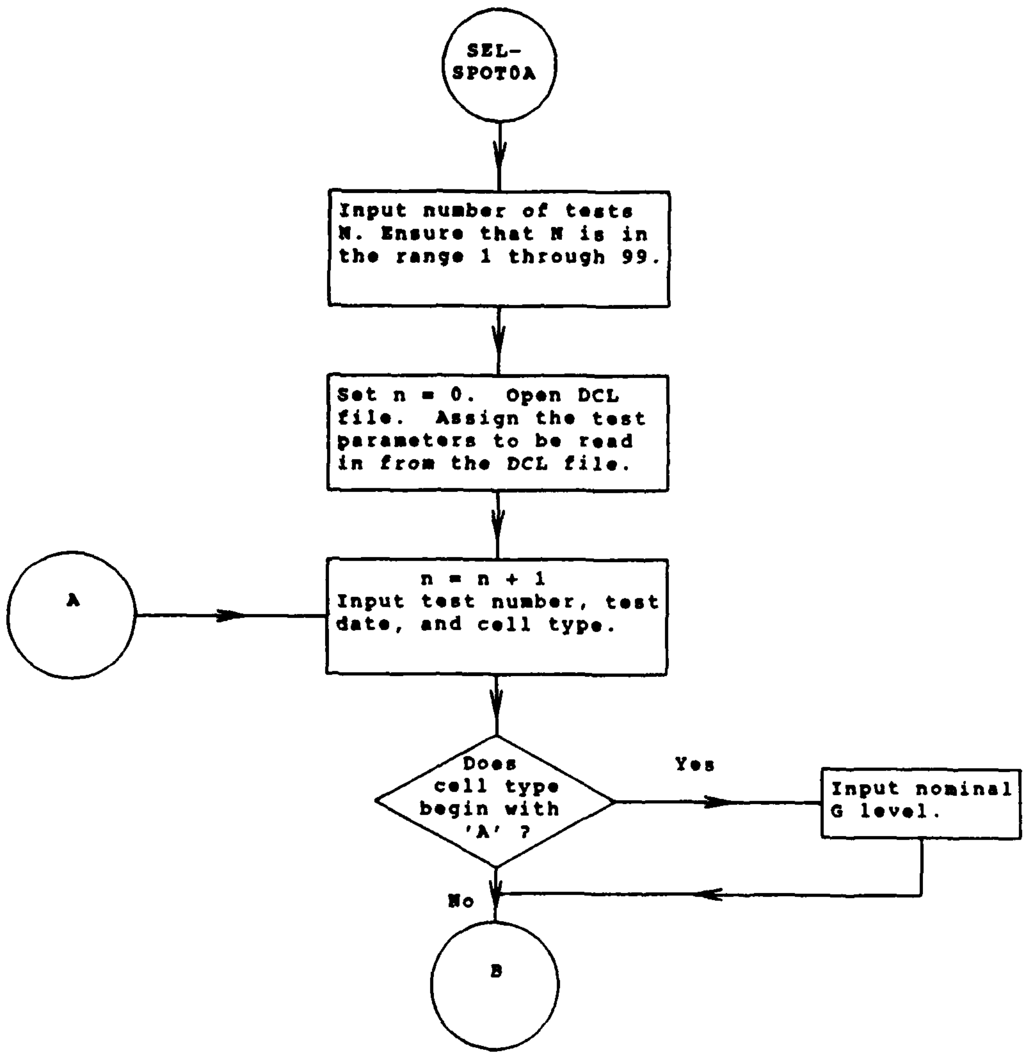

C
Call FIND_UNIT_VECTORS to find unit vectors for the pretest and initial test positions of the moving LEDs. Call FIND_ROTATED_VECTORS and FIND_UNIT_VECTORS to find the unit vectors in the rotated pendulum coordinate system.
Call SWITCH_AXES to redefine the axes to stabilize the computation of the Euler angles. Call FIND_EULER_ANGLES to find the Euler angles that rotate the unit vectors from the PRS coordinate system to the pendulum coordinate system.
Call FIND_ROTATION_MATRIX to find the rotation matrix based on the Euler angles. Call SWITCH_AXES_BACK to switch the values in the rotation matrix according to the original definition of the axes. Call FIND_OFFSETS to determine the translational offsets between the two coordinate systems based on the position of LED1.
B
Are cameras corrected for vibration ?
Yes
Call FIND_NEW_IMAGE to find the vibration corrected image coordinates of the LEDs.
No
Call FIND_3D to find the three dimensional coordinates of the LEDs.
Is coordinate system rotated ?
Yes
Call ROTATE_COORDS to rotate the LEDs into the pendulum coordinate system.
No
D

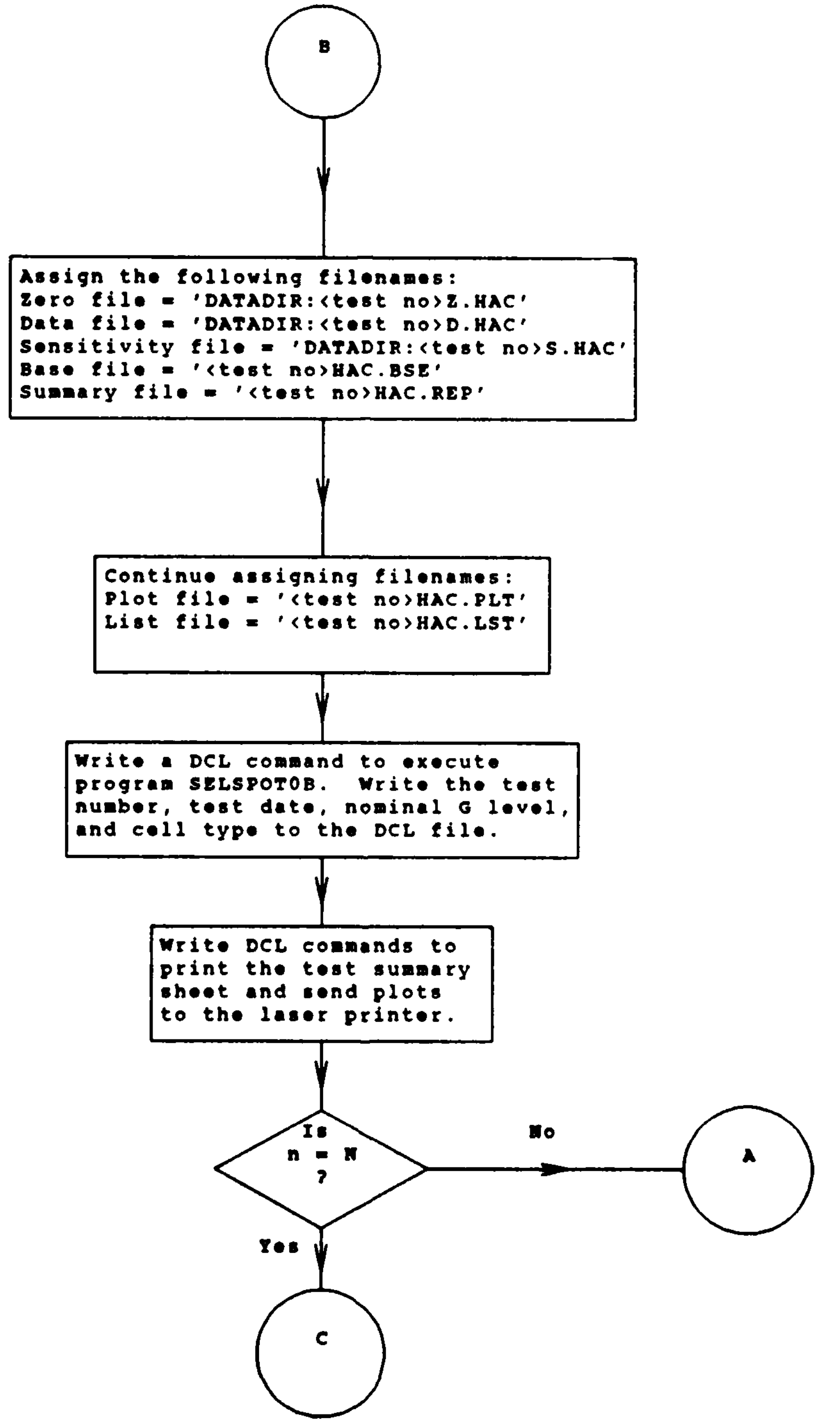

D
Is data filtered?
Yes
Call FFTFILT to filter the three dimensional coordinates of the LEDs with a 120 Hz FFT filter.
No
Call OUTPUT to write the three dimensional coordinates of the LEDs to a text file.
END

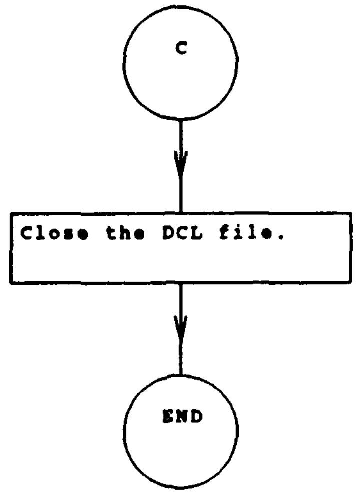

SELSPOT _CAL
Input Selspot parameter filename, Selspot data filename, number of samples to skip, and number of samples in average. Also, input general descriptions, moving LED numbers, and fixed LED numbers.
Create text file 'SELSPOT.LIS' to store the results of the analysis. Read in initial estimates of the camera locations, principle distances, camera image unit vectors, and image coordinate offsets for both cameras.
Call FIND_ORIENTATION_ANGLES to find the camera orientation angles from the camera image unit vectors. Convert the principle distance from pixels to milimeters to improve the convergence of the optimization.
Call READ_IMAGE to find the average camera image coordinates.
IS number of fixed LEDs >= 4 and option = 1 ?
No
A
Yes
Call FPOINT to find the optimal camera locations based on the measured fixed LED positions. The user has the option to specify the value of any of the optimized parameters.
B

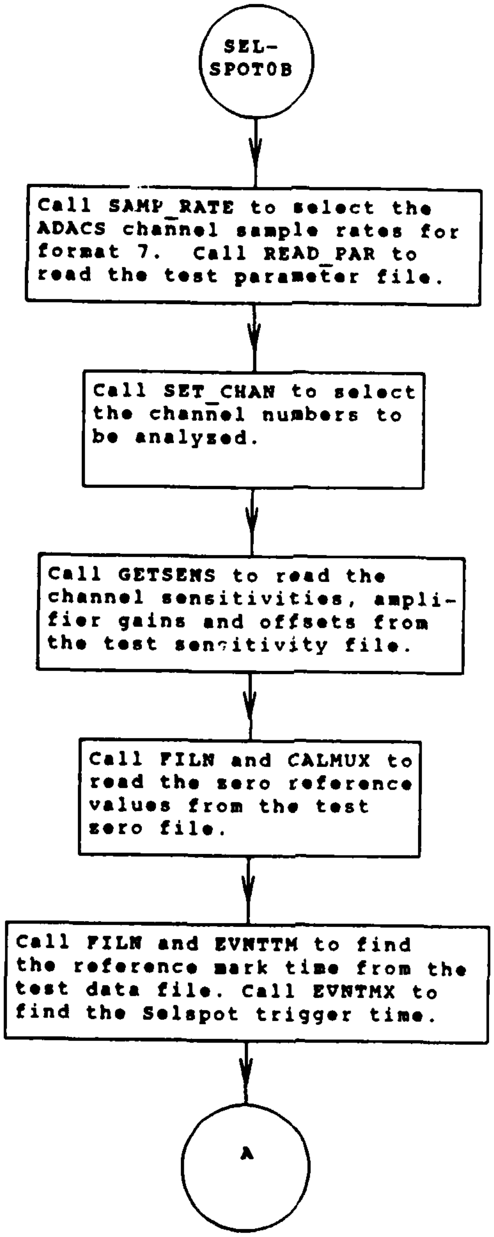

B
Call FPOINT again to optimize the principle distance and the image coordinate offsets for each camera.
Call FVECT to find the best least squares fit for the camera axis unit vector, and the camera azimuth and elevation angles.
Call ANGLE to find the best least squares fit for the image tilt angle. Call ANGLE again to optimize the image tilt, camera azimuth, and elevation angles.
Call FIND_UNIT_VECTOR to find the camera image unit vectors from the camera orientation angles.
Create test file 'SELSPOT.TDB' which is used as the camera parameter file by SELSPOTOB. Write out the camera image unit vectors, camera locations, and principle distances.
A
Is number of fixed LEDS >= 4 and option = 2 ?
No
C
Yes
D

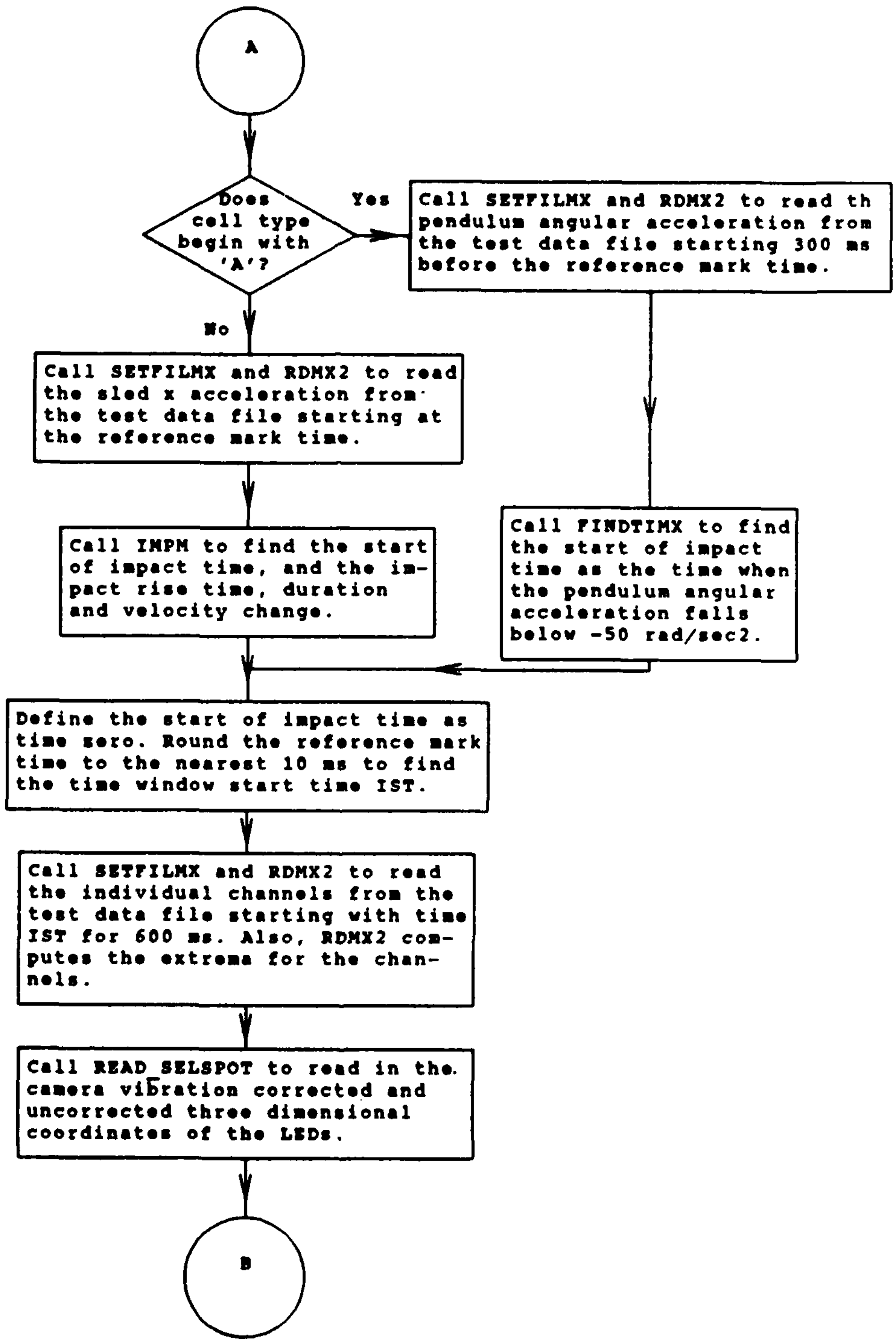

D
Call FPOINT to find the optimal camera locations based on the measured fixed LED positions. Call FPOINT1 to optimize the camera locations, principle distance, and camera image offsets using the same principle distance for both cameras.
Call FVECT, ANGLE, and FIND_UNIT_VECTORS to find the camera image unit vectors for the best least squares fit.
C
Is number of fixed LEDs > 0 and option = 3 ?
No
Yes
Call ORIENT and FIND_UNIT_VECTORS to find the best least squares fit for the camera image unit vectors by orienting the cameras to minimize the miss distance between the two cameras based on the fixed LED image coordinates.
Is number of moving LEDs > 0 and option = 4 ?
No
Yes
Call ORIENT1 and FIND_UNIT_VECTORS to find the best least squares fit for the camera image unit vectors by orienting the cameras to minimize the miss distances between the two cameras based on the moving LED image coordinates.
END

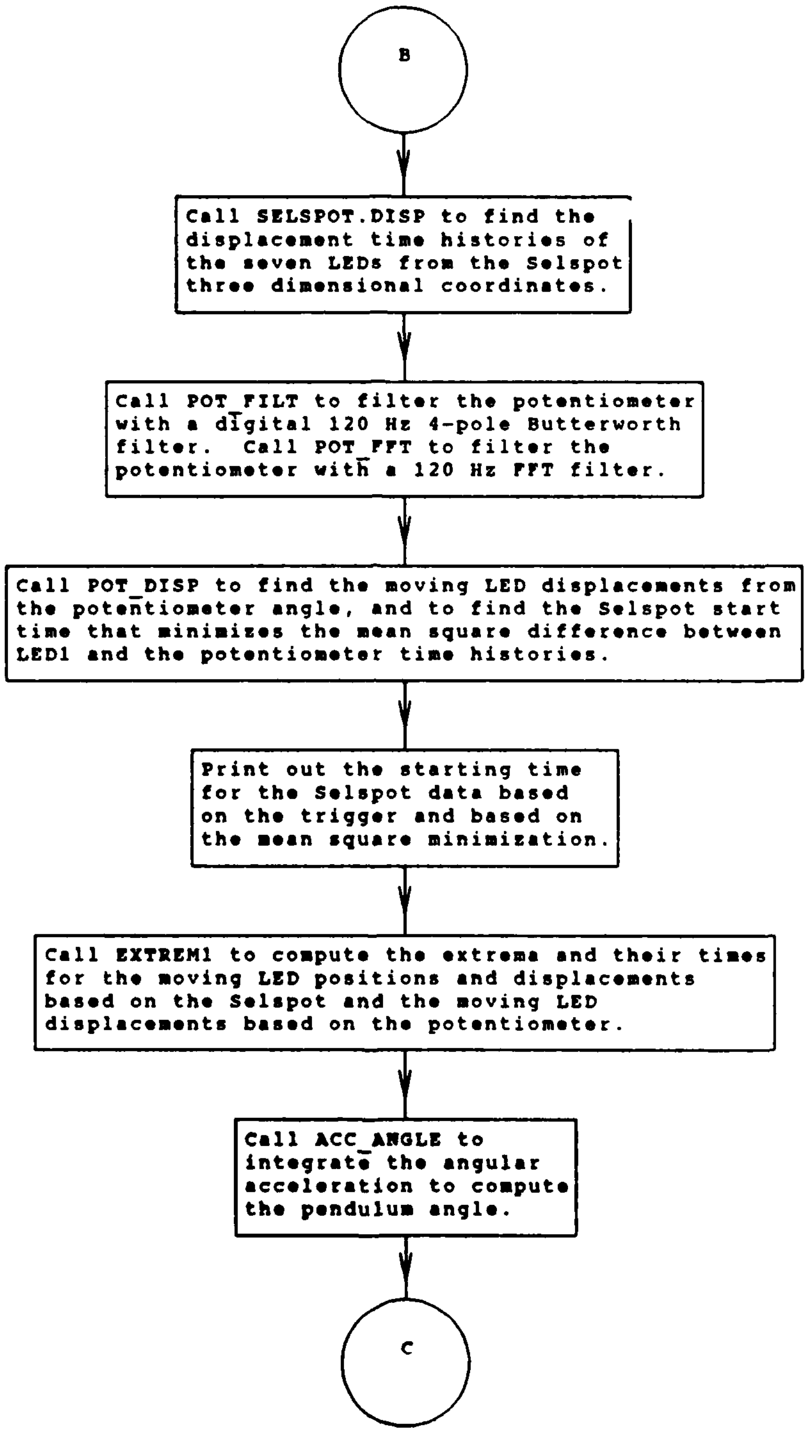

SEL-
SPOT0A
Input number of tests N. Ensure that N is in the range 1 through 99.
Set n = 0. Open DCL file. Assign the test parameters to be read in from the DCL file.
A
n = n + 1
Input test number, test date, and cell type.
Does cell type begin with 'A' ?
Yes
Input nominal G level.
No
B

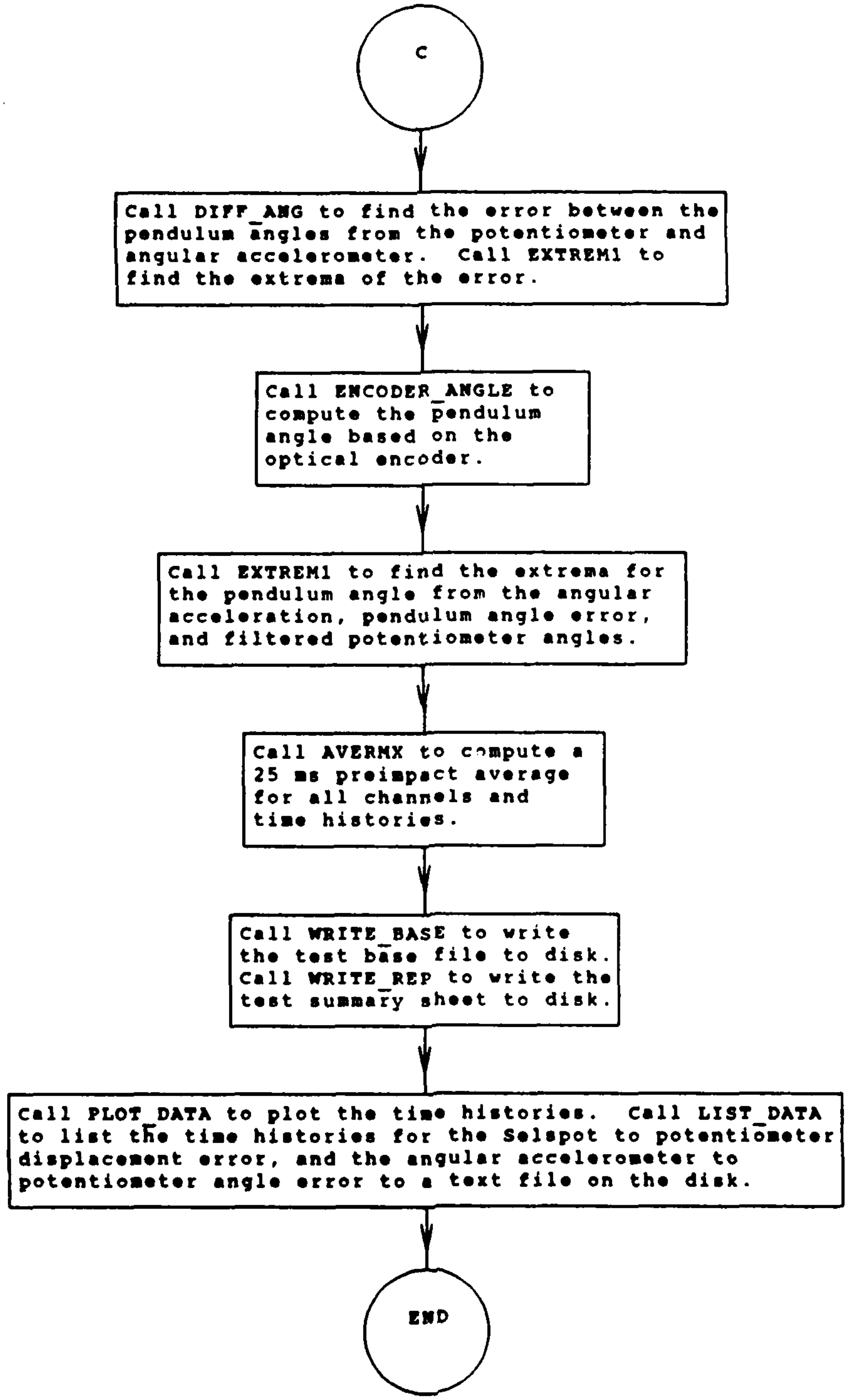

B
Assign the following filenames:
Zero file = 'DATADIR:<test no>Z.HAC'
Data file = 'DATADIR:<test no>D.HAC'
Sensitivity file = 'DATADIR:<test no>S.HAC'
Base file = '<test no>HAC.BSE'
Summary file = '<test no>HAC.REP'
Continue assigning filenames:
Plot file = '<test no>HAC.PLT'
List file = '<test no>HAC.LST'
Write a DCL command to execute program SELSPOTOB. Write the test number, test date, nominal G level, and cell type to the DCL file.
Write DCL commands to print the test summary sheet and send plots to the laser printer.
Is n = N ?
No
A
Yes
C

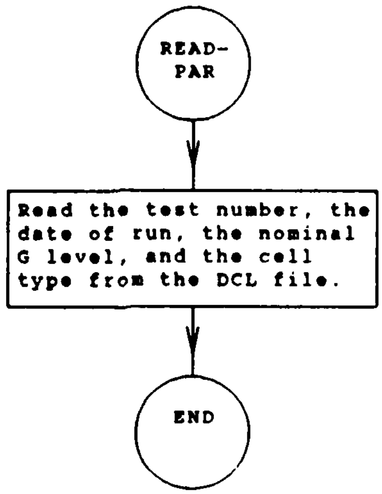

C
Close the DCL file.
END

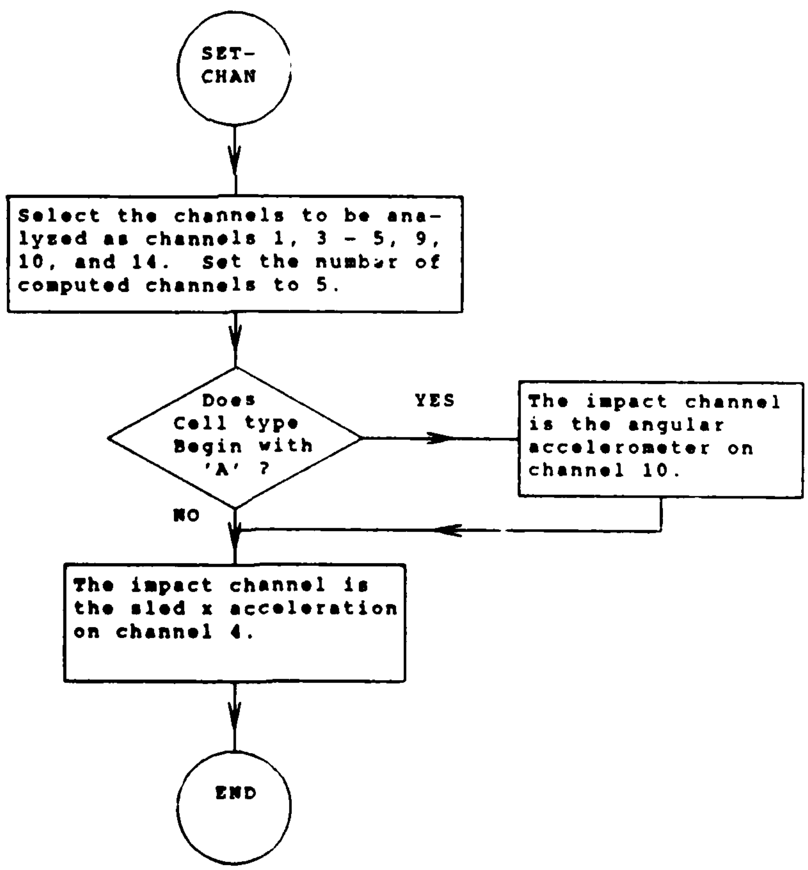

SEL-SPOTOB
Call SAMP_RATE to select the ADACS channel sample rates for format 7. Call READ_PAR to read the test parameter file.
Call SET_CHAN to select the channel numbers to be analyzed.
Call GETSENS to read the channel sensitivities, amplifier gains and offsets from the test sensitivity file.
Call FILN and CALMUX to read the zero reference values from the test zero file.
Call FILN and EVNTTM to find the reference mark time from the test data file. Call EVNTMX to find the Selspot trigger time.
A

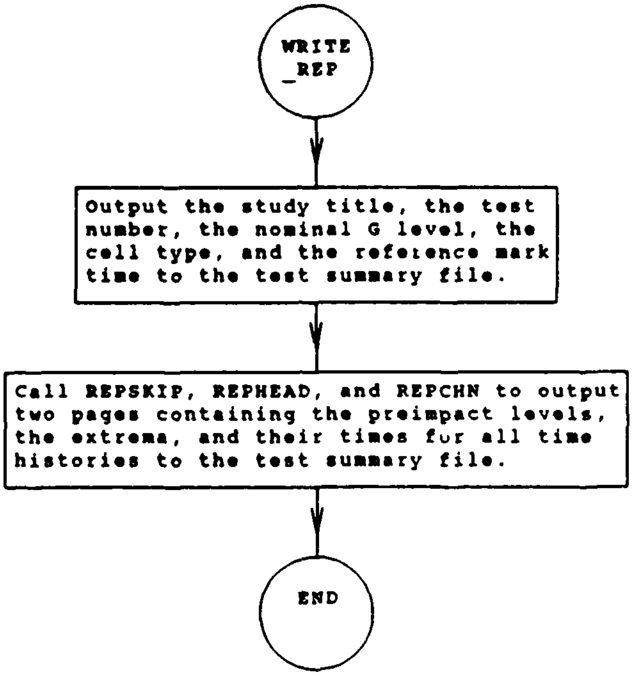

A
Does cell type begin with 'A'?
Yes
Call SETFILMX and RDMX2 to read th pendulum angular acceleration from the test data file starting 300 ms before the reference mark time.
No
Call SETFILMX and RDMX2 to read the sled x acceleration from the test data file starting at the reference mark time.
Call IMPM to find the start of impact time, and the impact rise time, duration and velocity change.
Call FINDTIMX to find the start of impact time as the time when the pendulum angular acceleration falls below -50 rad/sec2.
Define the start of impact time as time zero. Round the reference mark time to the nearest 10 ms to find the time window start time IST.
Call SETFILMX and RDMX2 to read the individual channels from the test data file starting with time IST for 600 ms. Also, RDMX2 computes the extrema for the channels.
Call READ_SELSPOT to read in the camera vibration corrected and uncorrected three dimensional coordinates of the LEDs.
B

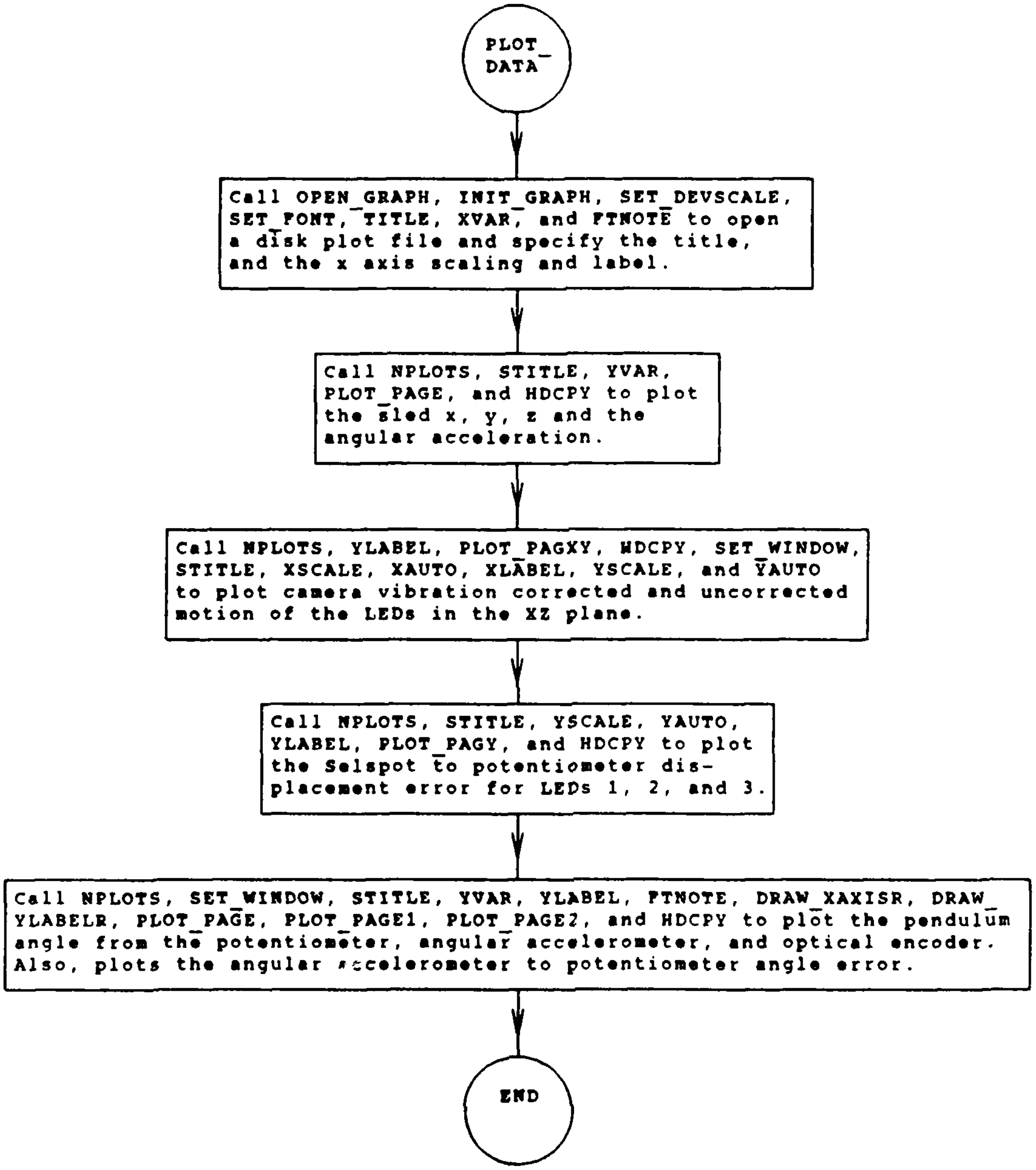

B
Call SELSPOT.DISP to find the displacement time histories of the seven LEDs from the Selspot three dimensional coordinates.
Call POT_FILT to filter the potentiometer with a digital 120 Hz 4-pole Butterworth filter. Call POT_FFT to filter the potentiometer with a 120 Hz FFT filter.
Call POT_DISP to find the moving LED displacements from the potentiometer angle, and to find the Selspot start time that minimizes the mean square difference between LED1 and the potentiometer time histories.
Print out the starting time for the Selspot data based on the trigger and based on the mean square minimization.
Call EXTREM1 to compute the extrema and their times for the moving LED positions and displacements based on the Selspot and the moving LED displacements based on the potentiometer.
Call ACC_ANGLE to integrate the angular acceleration to compute the pendulum angle.
C

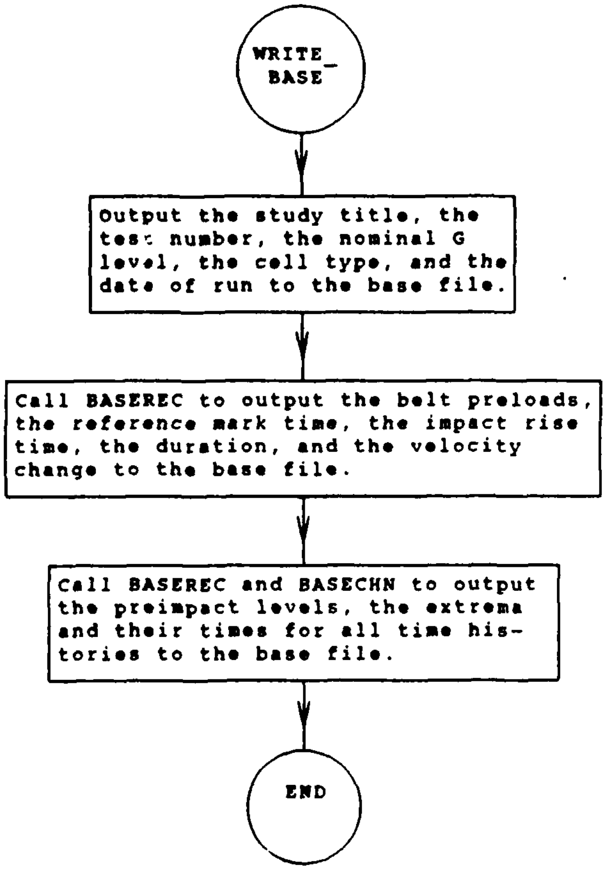

C
Call DIFF_ANG to find the error between the pendulum angles from the potentiometer and angular accelerometer. Call EXTREM1 to find the extrema of the error.
Call ENCODER_ANGLE to compute the pendulum angle based on the optical encoder.
Call EXTREM1 to find the extrema for the pendulum angle from the angular acceleration, pendulum angle error, and filtered potentiometer angles.
Call AVERMX to compute a 25 ms preimpact average for all channels and time histories.
Call WRITE_BASE to write the test base file to disk. Call WRITE_REP to write the test summary sheet to disk.
Call PLOT_DATA to plot the time histories. Call LIST_DATA to list the time histories for the Selspot to potentiometer displacement error, and the angular accelerometer to potentiometer angle error to a text file on the disk.
END


READ-PAR
Read the test number, the date of run, the nominal G level, and the cell type from the DCL file.
END


SET-CHAN
Select the channels to be analyzed as channels 1, 3 - 5, 9, 10, and 14. Set the number of computed channels to 5.
Does Cell type Begin with 'A' ?
YES
The impact channel is the angular accelerometer on channel 10.
NO
The impact channel is the sled x acceleration on channel 4.
END


WRITE
_REP
Output the study title, the test number, the nominal G level, the cell type, and the reference mark time to the test summary file.
Call REPSKIP, REPHEAD, and REPCHN to output two pages containing the preimpact levels, the extrema, and their times for all time histories to the test summary file.
END


PLOT_DATA
Call OPEN_GRAPH, INIT_GRAPH, SET_DEVSCALE, SET_FONT, TITLE, XVAR, and FTNOTE to open a disk plot file and specify the title, and the x axis scaling and label.
Call NPLOTS, STITLE, YVAR, PLOT_PAGE, and HDCPY to plot the sled x, y, z and the angular acceleration.
Call NPLOTS, YLABEL, PLOT_PAGXY, HDCPY, SET_WINDOW, STITLE, XSCALE, XAUTO, XLABEL, YSCALE, and YAUTO to plot camera vibration corrected and uncorrected motion of the LEDs in the XZ plane.
Call NPLOTS, STITLE, YSCALE, YAUTO, YLABEL, PLOT_PAGY, and HDCPY to plot the Selspot to potentiometer displacement error for LEDs 1, 2, and 3.
Call NPLOTS, SET_WINDOW, STITLE, YVAR, YLABEL, FTNOTE, DRAW_XAXISR, DRAW_YLABELR, PLOT_PAGE, PLOT_PAGE1, PLOT_PAGE2, and HDCPY to plot the pendulum angle from the potentiometer, angular accelerometer, and optical encoder. Also, plots the angular accelerometer to potentiometer angle error.
END


WRITE_ BASE
Output the study title, the test number, the nominal G level, the cell type, and the date of run to the base file.
Call BASEREC to output the belt preloads, the reference mark time, the impact rise time, the duration, and the velocity change to the base file.
Call BASEREC and BASECHN to output the preimpact levels, the extrema and their times for all time histories to the base file.
END

APPENDIX B

Representative Test Data

SELSPOT STUDY TEST: STATIC CELL: A1

DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
REFERENCE MARK TIME (MS)				-49.0	
SLED ACCELERATION (G)					
X AXIS	-0.01	0.11	-0.09	8.0	3.0
Y AXIS	0.00	0.06	-0.09	9.0	82.0
Z AXIS	1.00	1.05	0.94	6.0	13.0
SLED VELOCITY (M/SEC)	-0.02	0.12	-0.11	13.0	3.0
POTENTIOMETER ANGLE (RAD)	0.00	2.04	0.00	150.0	0.1
POTENTIOMETER DISP (MM)					
AT LED 1		777.60	-2.47	149.0	151.0
AT LED 2		518.04	-1.41	149.0	151.0
AT LED 3		258.84	0.00	149.0	151.0
ANGULAR ACCEL (RAD/SEC2)	-5.72	53.67	-815.94	89.0	4.0
ANG ACCEL ANGLE (RAD)	0.00	2.04	0.00	150.0	1.0
LED 1 POSITION (MM)					
X AXIS		454.05	3.90	117.0	1.0
Y AXIS		0.39	-22.41	3.0	67.0
Z AXIS		216.81	-457.90	151.0	7.0
LED 1 DISPLACEMENT (MM)		783.57	4.00	151.0	1.0
LED 1 DISP ERROR (MM)		8.38	0.00	19.0	151.0
LED 2 POSITION (MM)					
X AXIS		300.65	2.56	113.0	1.0
Y AXIS		-3.94	-16.74	3.0	59.0
Z AXIS		141.64	-303.57	151.0	5.0
LED 2 DISPLACEMENT (MM)		517.44	3.04	151.0	1.0
LED 2 DISP ERROR (MM)		6.97	0.00	19.0	151.0
LED 3 POSITION (MM)					
X AXIS		149.60	1.64	111.0	1.0
Y AXIS		0.75	-7.37	5.0	67.0
Z AXIS		69.19	-152.57	151.0	5.0
LED 3 DISPLACEMENT (MM)		257.22	1.59	151.0	1.0
LED 3 DISP ERROR (MM)		3.99	0.00	141.0	151.0
LED 4 POSITION (MM)					
X AXIS		1.82	1.01	101.0	5.0
Y AXIS		68.24	65.87	117.0	123.0
Z AXIS		-3.41	-4.43	59.0	65.0

Page 1 of 2

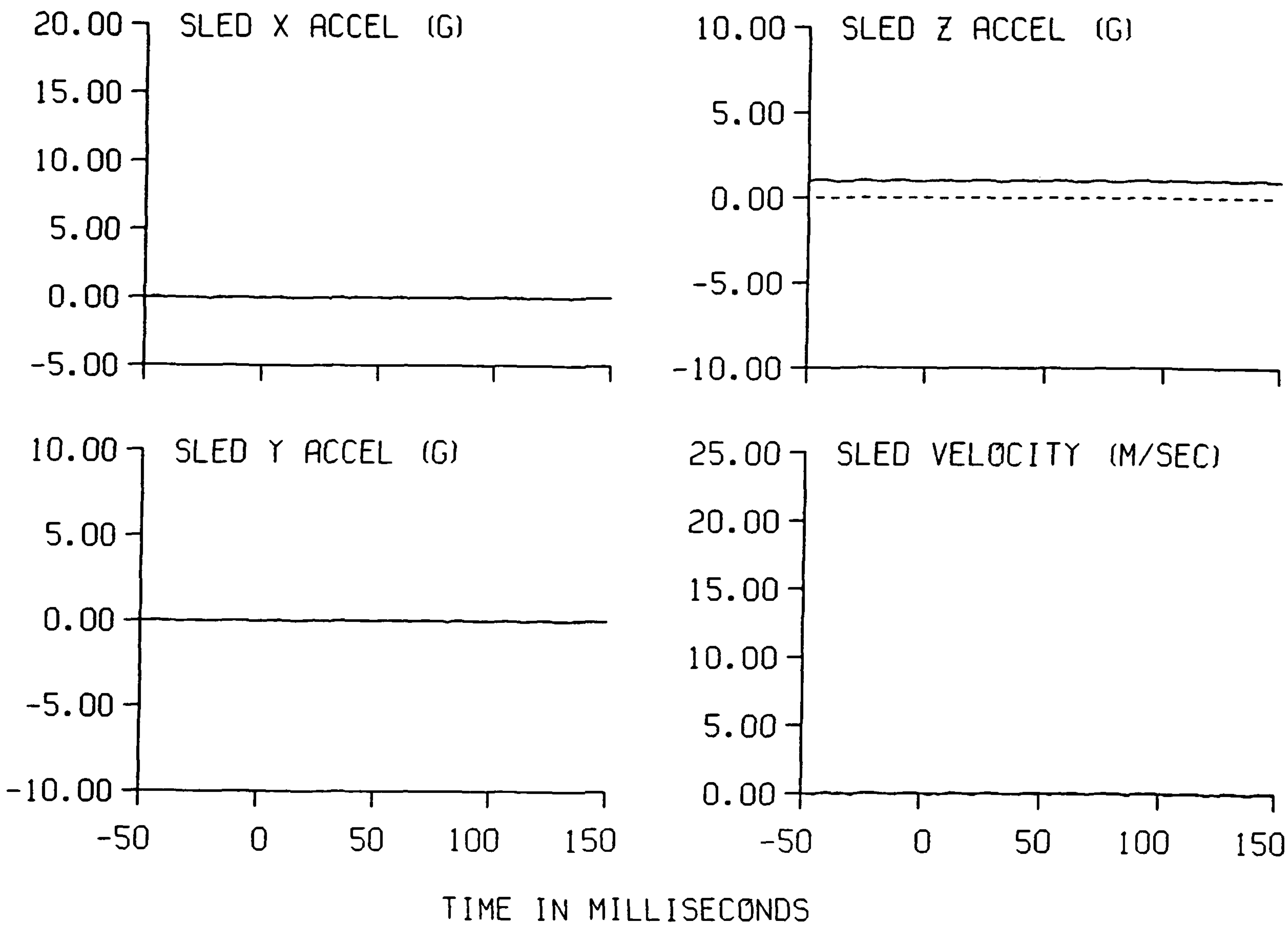
SELSPOT STUDY TEST: STATIC CELL: A1

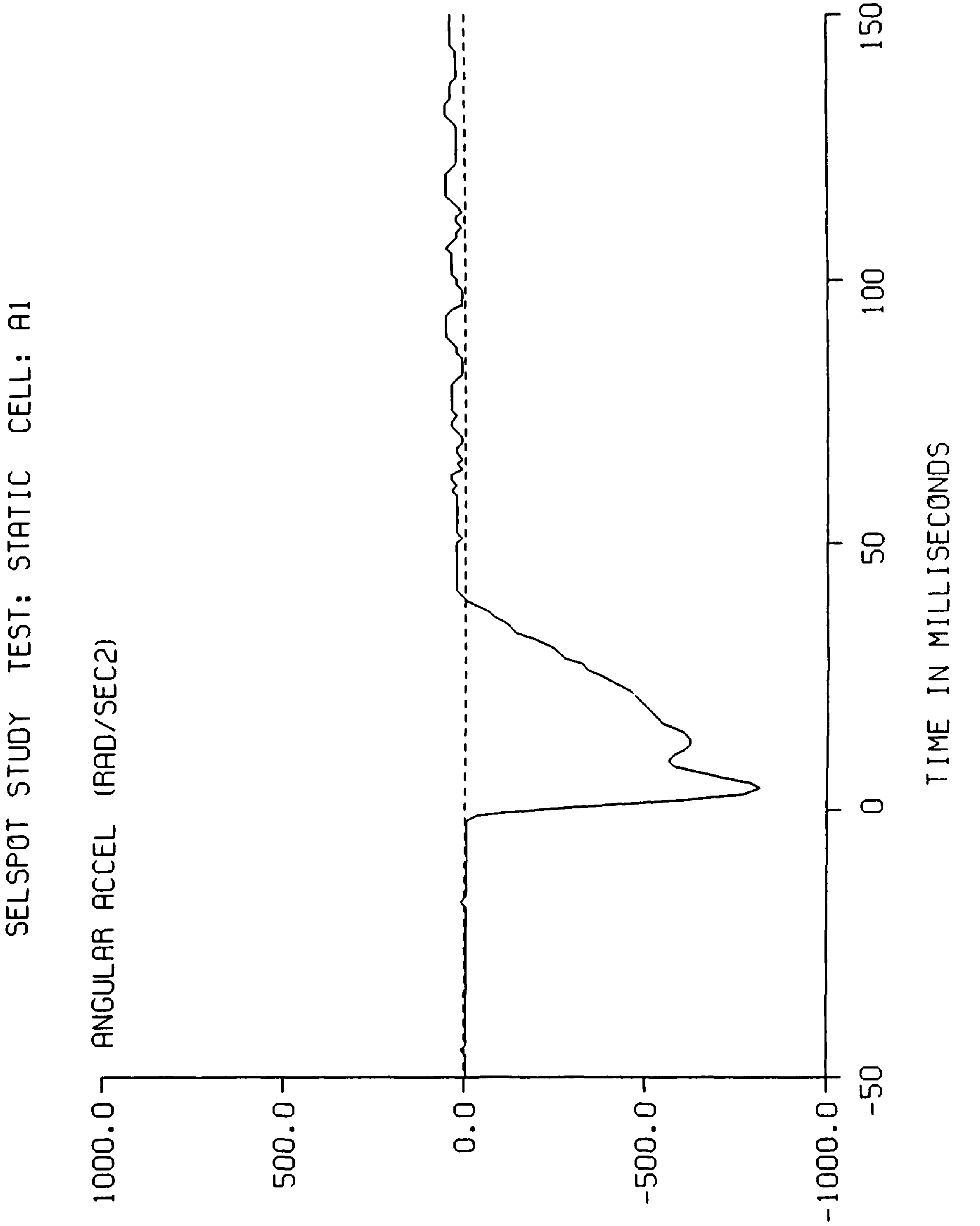
DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
LED 5 POSITION (MM)					
X AXIS		-304.79	-306.47	131.0	103.0
Y AXIS		207.33	203.83	85.0	117.0
Z AXIS		155.99	154.59	103.0	123.0
LED 6 POSITION (MM)					
X AXIS		-169.07	-170.34	31.0	73.0
Y AXIS		223.79	221.20	95.0	151.0
Z AXIS		-368.53	-369.68	7.0	151.0
LED 7 POSITION (MM)					
X AXIS		370.12	368.81	53.0	31.0
Y AXIS		189.19	186.78	9.0	85.0
Z AXIS		-440.48	-441.59	73.0	93.0
ANGLE ERROR (RADIANS)		0.04	0.00	125.0	8.0

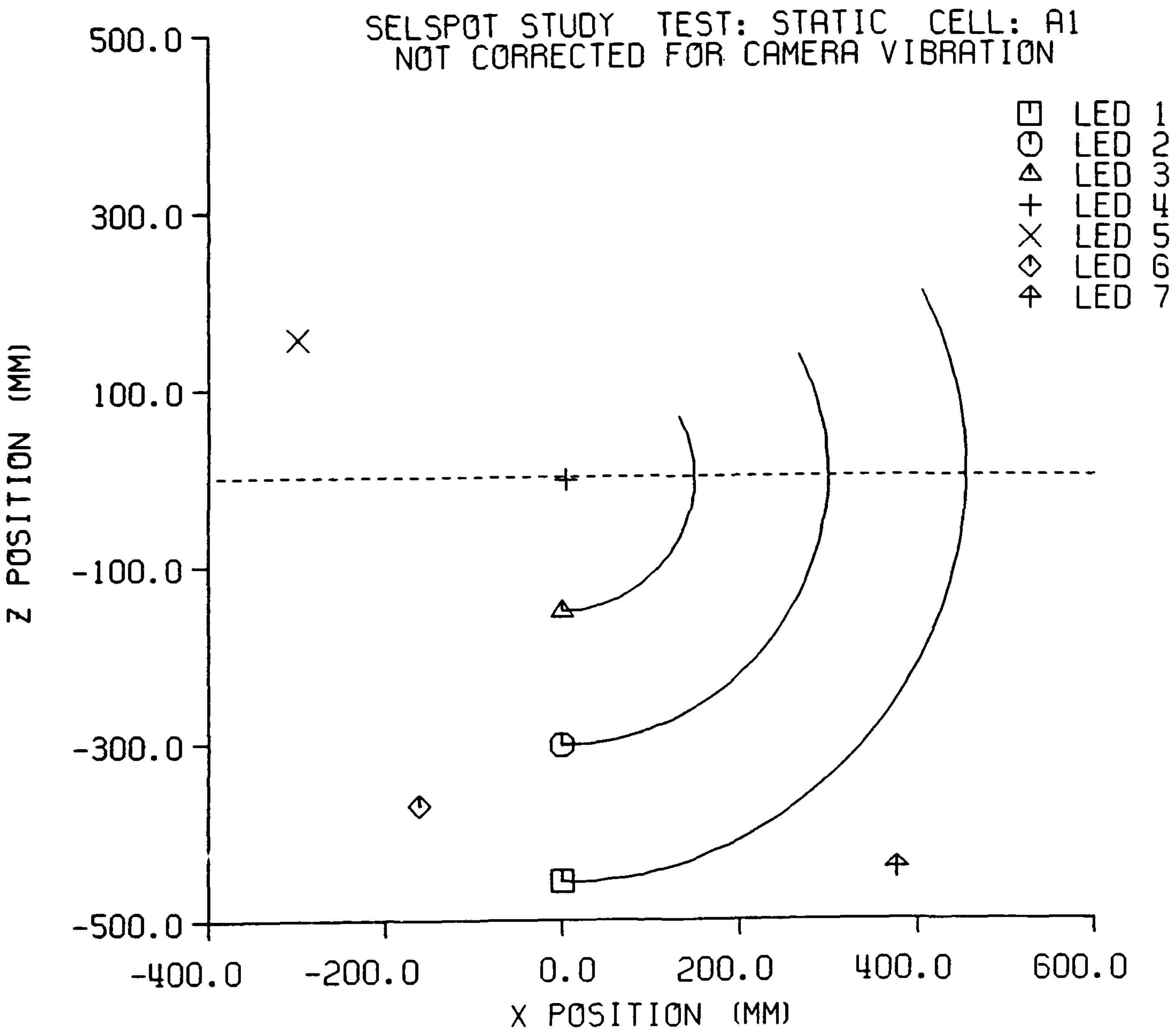
Page 2 of 2

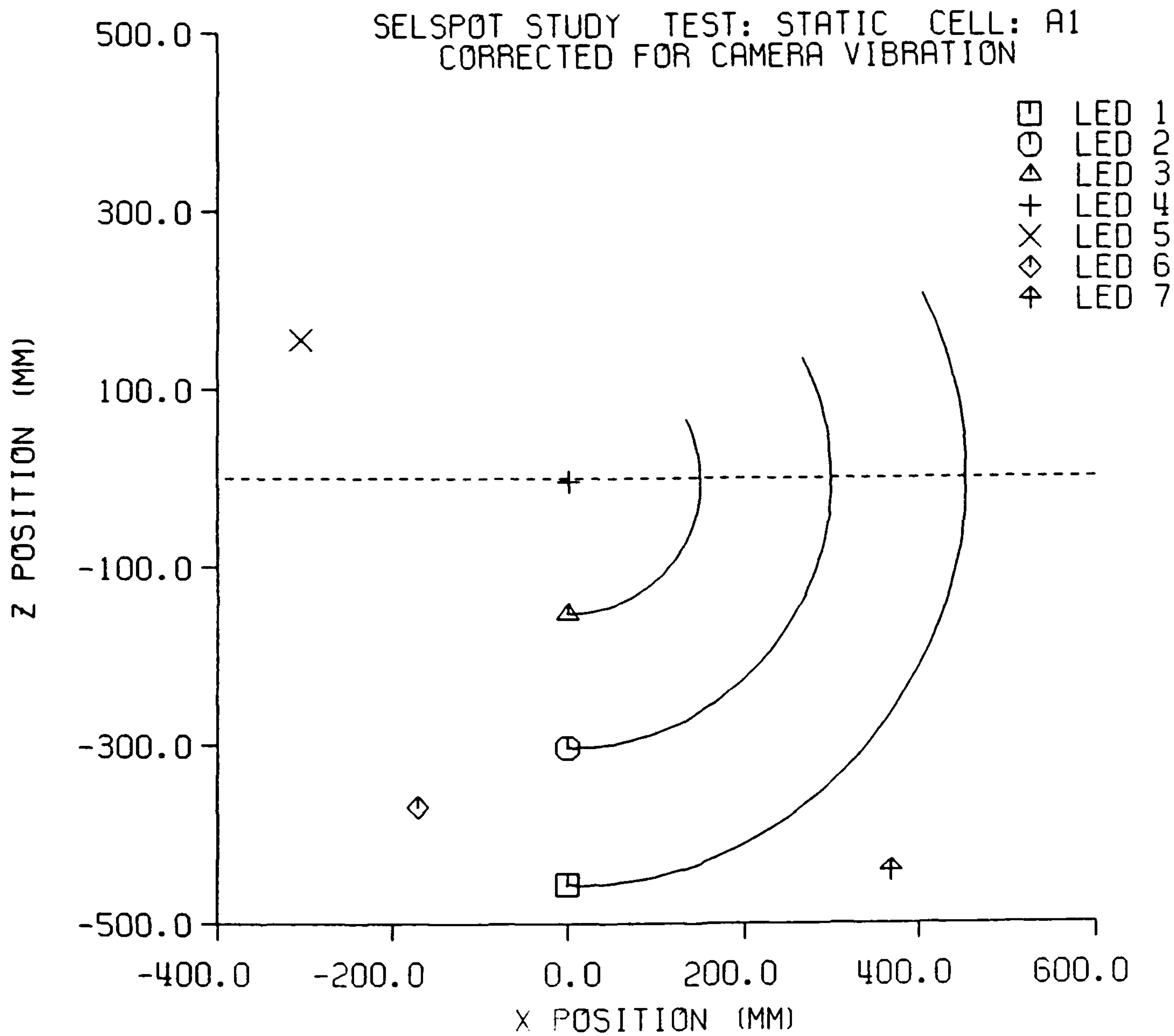
TIME (MS)	DISPLACEMENT ERROR LED 1-POT (MM)	LED 2-POT (MM)	LED 3-POT (MM)	ANGLE ERROR TIME (MS)	ANG ACC-POT (RADIANS)
1.00	3.2744	2.6138	1.3913	0.00	0.0008
3.00	4.3333	3.5054	1.8429	2.00	0.0013
5.00	3.0768	2.5455	1.5926	4.00	0.0004
7.00	1.9214	1.7286	1.1481	6.00	0.0002
9.00	2.2598	2.2137	1.1878	8.00	0.0001
11.00	2.9181	2.6958	1.5096	10.00	0.0034
13.00	3.3651	2.7045	1.8132	12.00	0.0074
15.00	4.9437	3.6405	2.4717	14.00	0.0082
17.00	7.5568	5.7948	3.4922	16.00	0.0062
19.00	8.3773	6.9684	3.9629	18.00	0.0039
21.00	6.3798	5.8380	3.3999	20.00	0.0010
23.00	4.6700	4.4440	2.7649	22.00	0.0013
25.00	5.6089	4.9692	3.0674	24.00	0.0007
27.00	6.6716	6.0023	3.6539	26.00	0.0022
29.00	4.5591	4.9273	3.2332	28.00	0.0029
31.00	1.0405	2.4879	2.0333	30.00	0.0001
33.00	0.4740	1.8123	1.5443	32.00	0.0012
35.00	2.8525	3.3244	2.1683	34.00	0.0033
37.00	3.8695	4.1136	2.6739	36.00	0.0066
39.00	1.7885	2.7083	2.1621	38.00	0.0033
41.00	0.2230	1.2345	1.3469	40.00	0.0026
43.00	0.4457	1.6471	1.2521	42.00	0.0044
45.00	1.9631	2.6552	1.6826	44.00	0.0001
47.00	1.5311	2.1618	1.7680	46.00	0.0011
49.00	0.3459	0.5343	1.2628	48.00	0.0026
51.00	1.4442	0.4465	0.6252	50.00	0.7093
53.00	1.5341	0.5598	0.1841	52.00	0.7109
55.00	2.0031	0.9194	0.0872	54.00	0.7126
57.00	3.0375	1.7180	0.2667	56.00	0.7142
59.00	3.3491	1.9882	0.3759	58.00	0.7159
61.00	2.3319	1.3415	0.4232	60.00	0.7176
63.00	0.9957	0.6075	0.3906	62.00	0.7193
65.00	0.8752	0.7935	0.3664	64.00	0.7210
67.00	2.5959	2.1084	0.6936	66.00	0.7227
69.00	5.1503	3.8401	1.5225	68.00	0.7244
71.00	6.4392	4.8261	2.2589	70.00	0.7261
73.00	5.4430	4.4539	2.2397	72.00	0.7278
75.00	3.8191	3.5426	1.7412	74.00	0.7296
77.00	4.0253	3.5410	1.7485	76.00	0.7313
79.00	5.7898	4.5078	2.4426	78.00	0.7331
81.00	6.3481	4.9727	2.8396	80.00	0.7348
83.00	4.6769	4.2192	2.3739	82.00	0.7366
85.00	3.0346	3.4300	1.8268	84.00	0.7383
87.00	3.2779	3.7256	2.0395	86.00	0.7400
89.00	4.1138	4.3514	2.5616	88.00	0.7418
91.00	3.8308	4.2207	2.6122	90.00	0.7435
93.00	3.2718	3.8836	2.4333	92.00	0.7453
95.00	3.6039	4.2128	2.6295	94.00	0.7470
97.00	3.2997	4.2464	2.7496	96.00	0.7488
99.00	0.5424	2.5993	2.0028	98.00	0.7505
AVERAGE	3.3857	3.1665	1.8772		0.0017
STANDARD DEV	1.9846	1.5863	0.9630		0.0038

SELSPOT STUDY TEST: STATIC CELL: A1

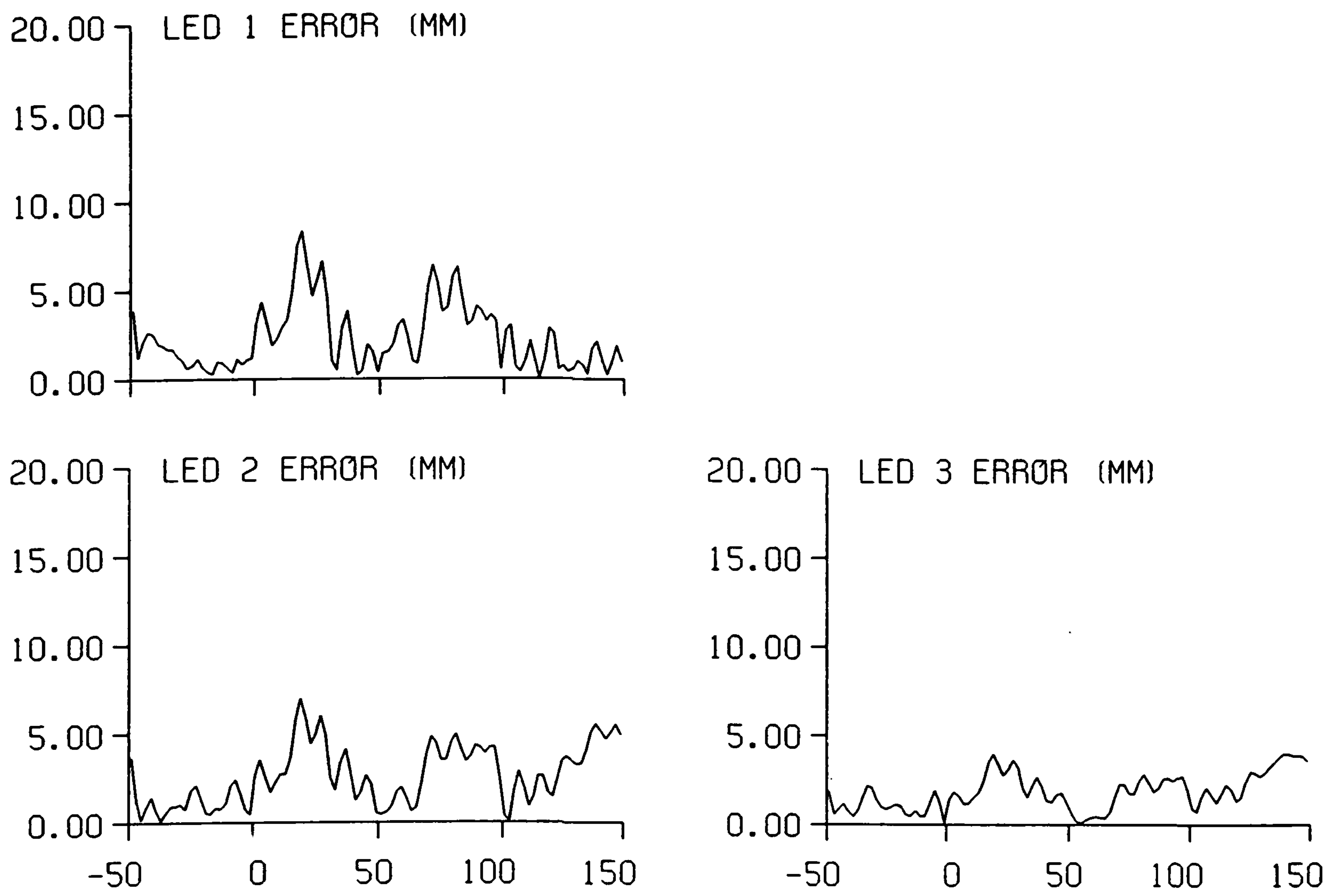


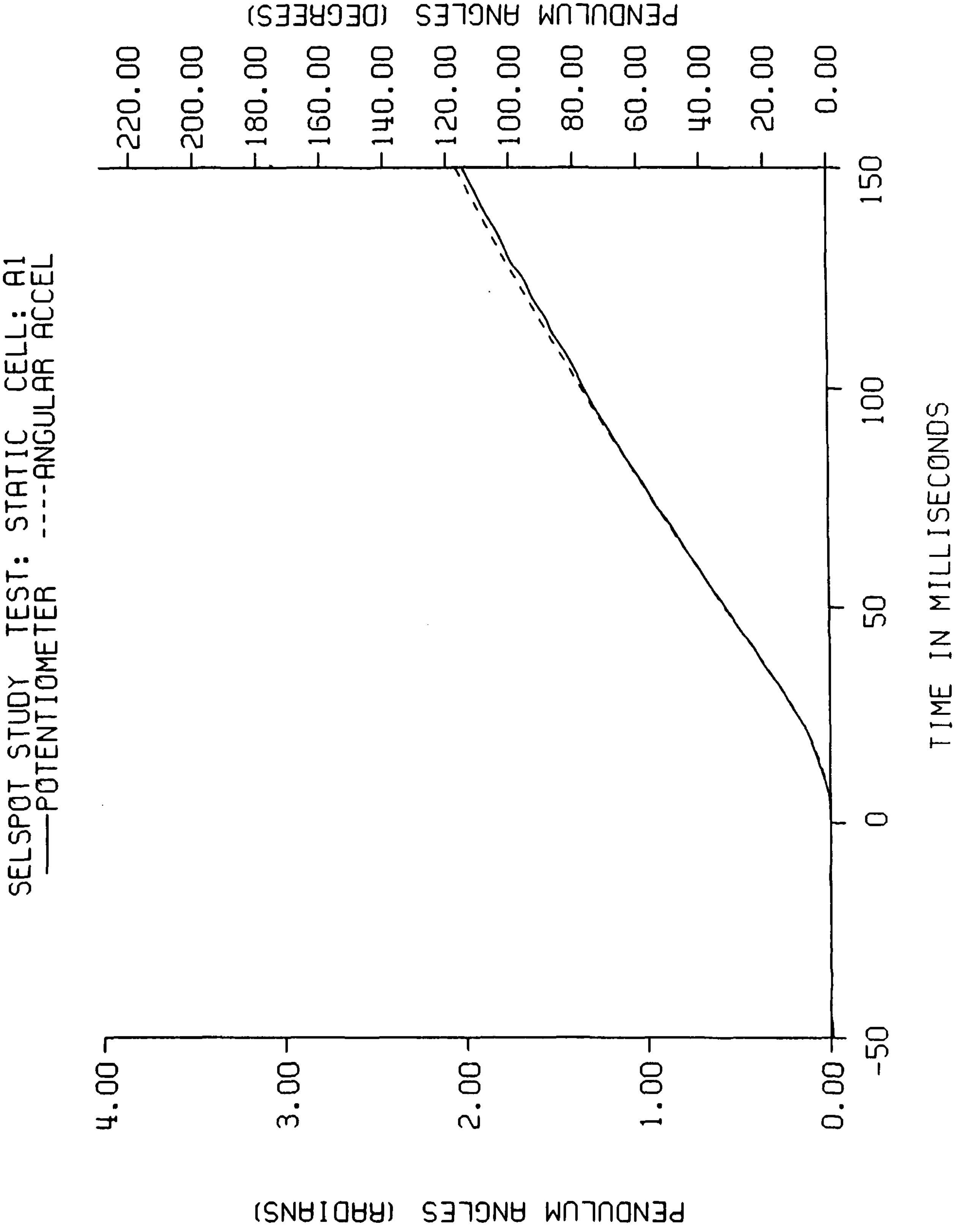

SELSPØT STUDY TEST: STATIC CELL: A1
ANGULAR ACCEL (RAD/SEC2)
1000.0
500.0
0.0
-500.0
-1000.0
-50
0
50
100
150
TIME IN MILLISECØNDS

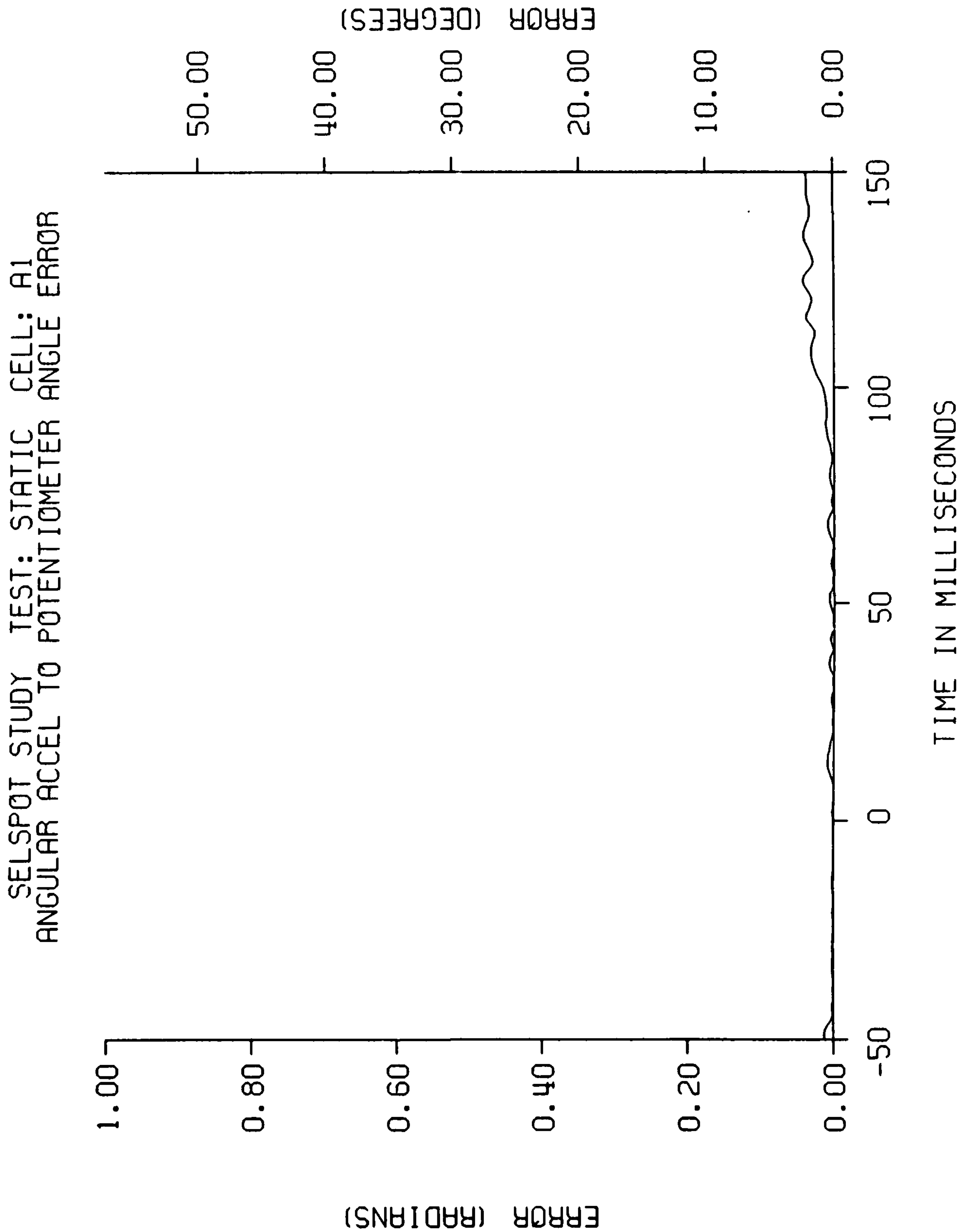

SELSPOT STUDY TEST: STATIC CELL: A1
NOT CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
500.0
300.0
100.0
-100.0
-300.0
-500.0
Z POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0
X POSITION (MM)

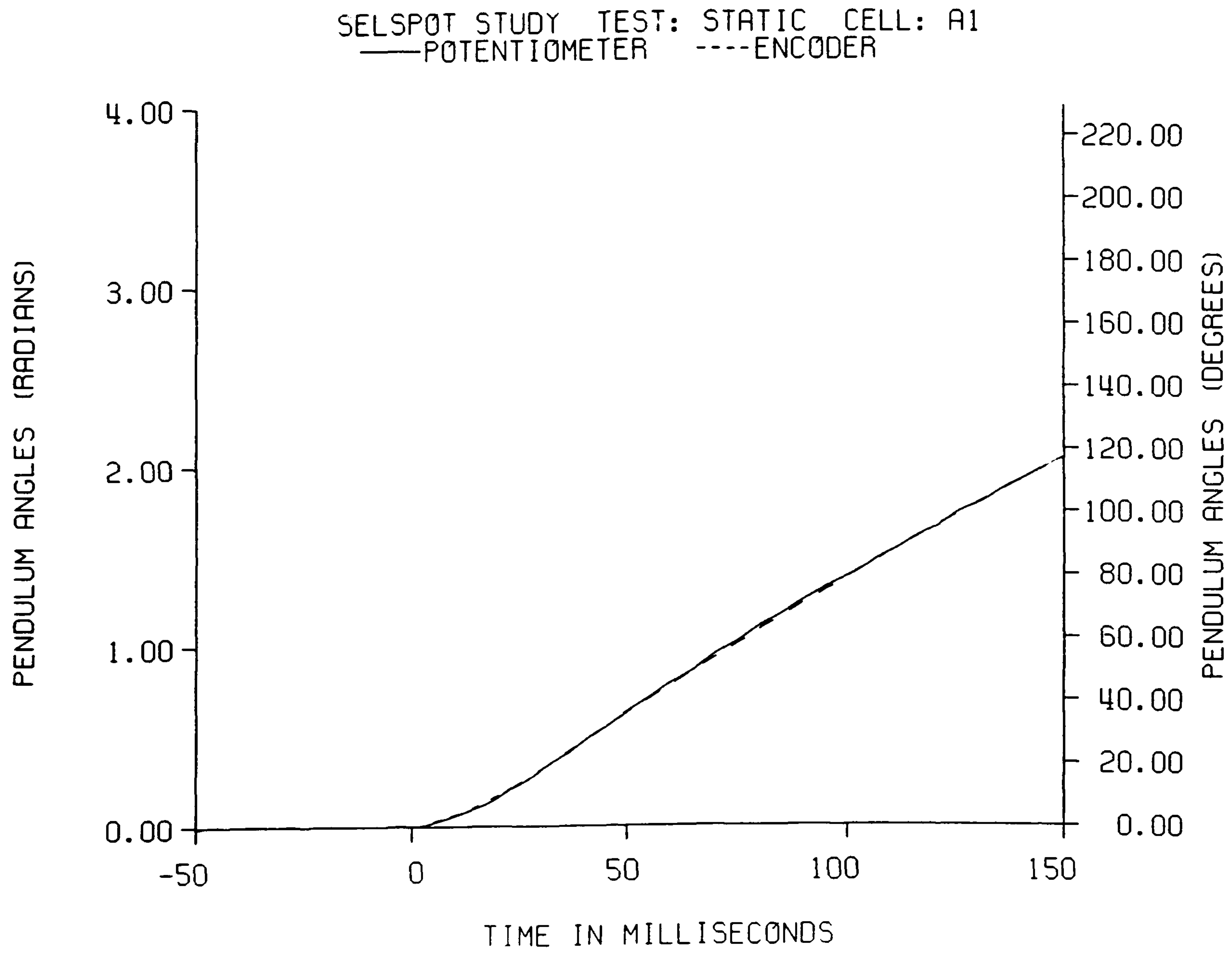

SELSPOT STUDY TEST: STATIC CELL: A1
CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
500.0
300.0
100.0
-100.0
-300.0
-500.0
Z POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0
X POSITION (MM)

SELSPOT STUDY TEST: STATIC CELL: A1
SELSPOT TO POTENTIOMETER DISPLACEMENT ERROR




SELSPOT STUDY TEST: STATIC CELL: A1
——POTENTIOMETER ----ANGULAR ACCEL
PENDULUM ANGLES (DEGREES)
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
PENDULUM ANGLES (RADIANS)
4.00
3.00
2.00
1.00
0.00
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY TEST: STATIC CELL: A1
ANGULAR ACCEL TO POTENTIOMETER ANGLE ERROR
ERROR (RADIANS)
1.00
0.80
0.60
0.40
0.20
0.00
ERROR (DEGREES)
50.00
40.00
30.00
20.00
10.00
0.00
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY TEST: STATIC CELL: A1
——POTENTIOMETER ----ENCODER
4.00
3.00
2.00
1.00
0.00
PENDULUM ANGLES (RADIANS)
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
PENDULUM ANGLES (DEGREES)
-50
0
50
100
150
TIME IN MILLISECONDS

SELSPOT STUDY TEST: 3890 NOM G: 6.0 CELL: B1

DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
REFERENCE MARK TIME (MS)				-209.0	
SLED ACCELERATION (G)					
X AXIS	0.01	5.50	0.11	49.0	0.0
Y AXIS	0.00	1.22	-0.39	57.0	42.0
Z AXIS	1.01	1.82	0.69	69.0	86.0
SLED VELOCITY (M/SEC)	0.00	5.76	-0.03	150.0	8.0
POTENTIOMETER ANGLE (RAD)	0.00	1.32	0.00	150.0	12.9
POTENTIOMETER DISP (MM)					
AT LED 1		560.82	-0.43	149.7	3.7
AT LED 2		373.39	-0.29	149.7	13.7
AT LED 3		186.43	-0.15	149.7	13.7
ANGULAR ACCEL (RAD/SEC2)	-8.07	29.99	-239.89	124.0	70.0
ANG ACCEL ANGLE (RAD)	0.00	1.32	0.00	150.0	1.0
LED 1 POSITION (MM)					
X AXIS		440.21	-0.10	149.7	5.7
Y AXIS		1.46	-26.52	1.7	115.7
Z AXIS		-112.13	-457.91	149.7	35.7
LED 1 DISPLACEMENT (MM)		558.85	0.65	149.7	11.7
LED 1 DISP ERROR (MM)		6.42	0.04	85.7	91.7
LED 2 POSITION (MM)					
X AXIS		291.39	0.15	149.7	1.7
Y AXIS		-4.27	-19.59	5.7	115.7
Z AXIS		-74.71	-303.42	149.7	9.7
LED 2 DISPLACEMENT (MM)		370.37	0.83	149.7	9.7
LED 2 DISP ERROR (MM)		5.53	0.02	85.7	117.7
LED 3 POSITION (MM)					
X AXIS		145.48	0.37	149.7	7.7
Y AXIS		2.41	-7.90	3.7	141.7
Z AXIS		-38.46	-152.54	149.7	27.7
LED 3 DISPLACEMENT (MM)		184.29	0.31	149.7	1.7
LED 3 DISP ERROR (MM)		3.62	0.04	85.7	107.7
LED 4 POSITION (MM)					
X AXIS		2.23	1.25	11.7	121.7
Y AXIS		69.28	66.65	105.7	141.7
Z AXIS		-3.59	-4.38	109.7	93.7

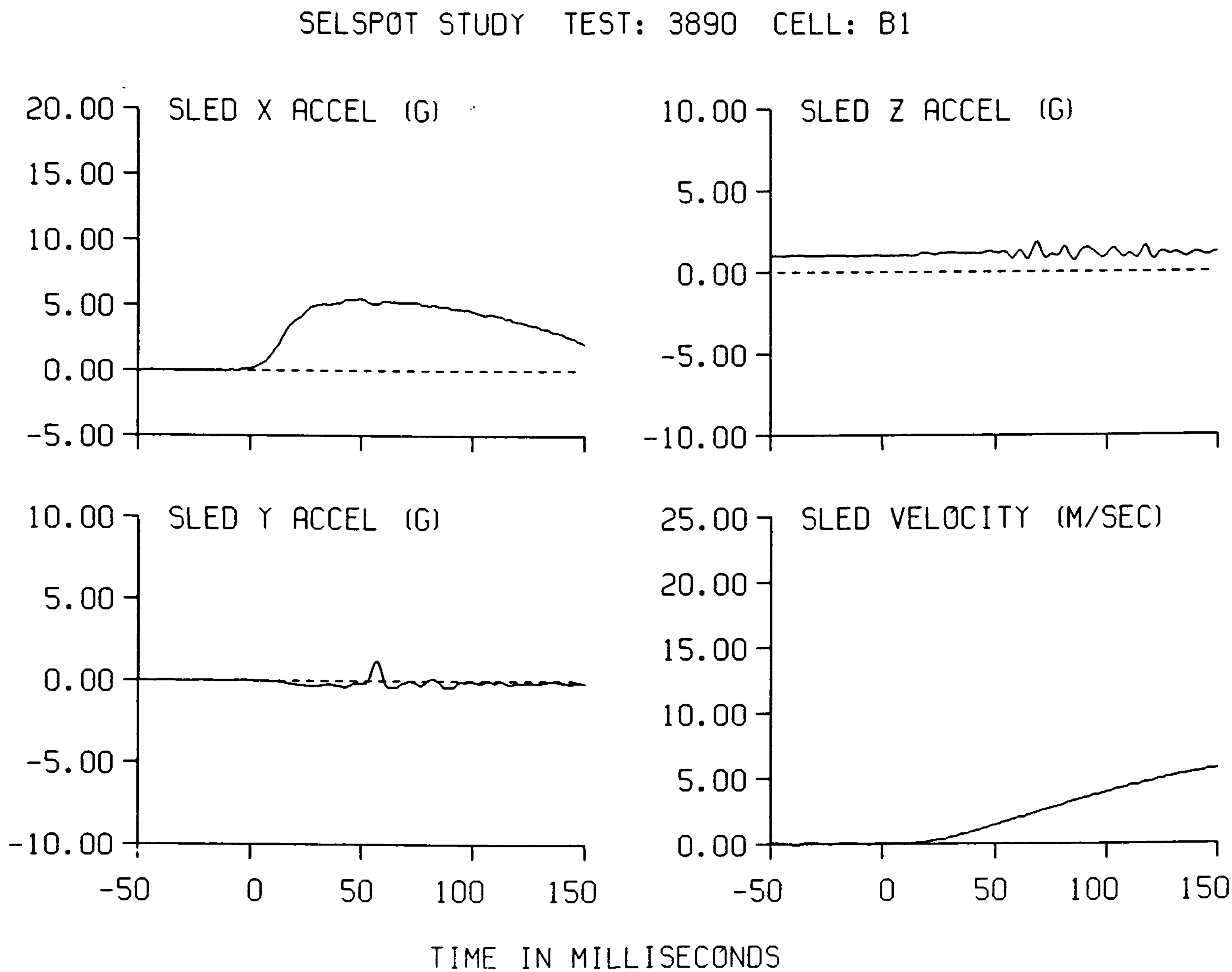
Page 1 of 2

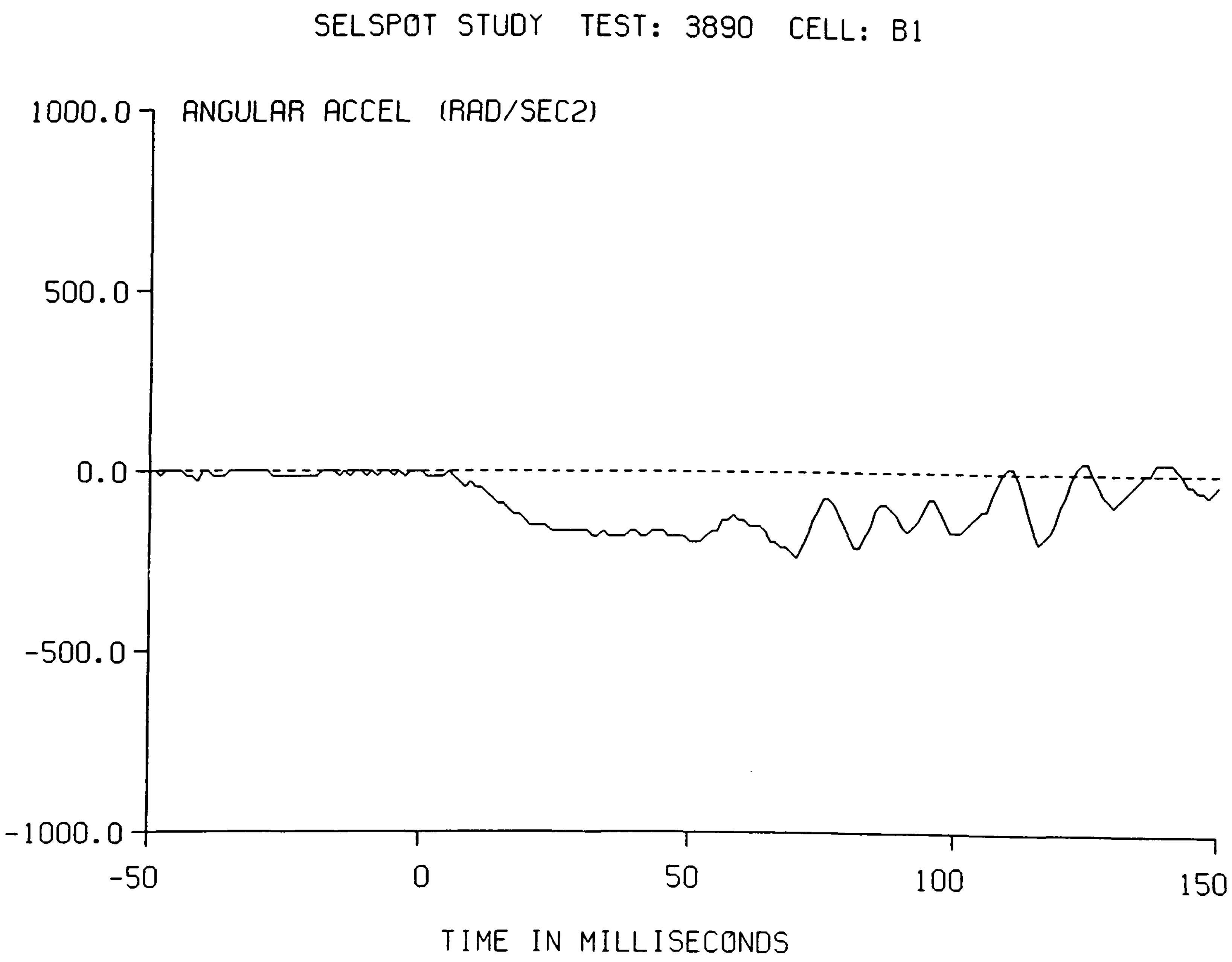
SELSPOT STUDY TEST: 3890 NOM G: 6.0 CELL: B1

DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
LED 5 POSITION (MM)					
X AXIS		-307.23	-309.75	141.7	103.7
Y AXIS		208.66	202.91	7.7	47.7
Z AXIS		149.26	145.38	103.7	67.7
LED 6 POSITION (MM)					
X AXIS		-161.87	-163.49	25.7	65.7
Y AXIS		221.54	214.72	9.7	55.7
Z AXIS		-373.62	-374.92	7.7	41.7
LED 7 POSITION (MM)					
X AXIS		378.93	378.04	101.7	49.7
Y AXIS		188.17	184.72	107.7	23.7
Z AXIS		-433.64	-435.06	121.7	9.7
ANGLE ERROR (RADIANS)		0.05	0.00	148.0	1.0

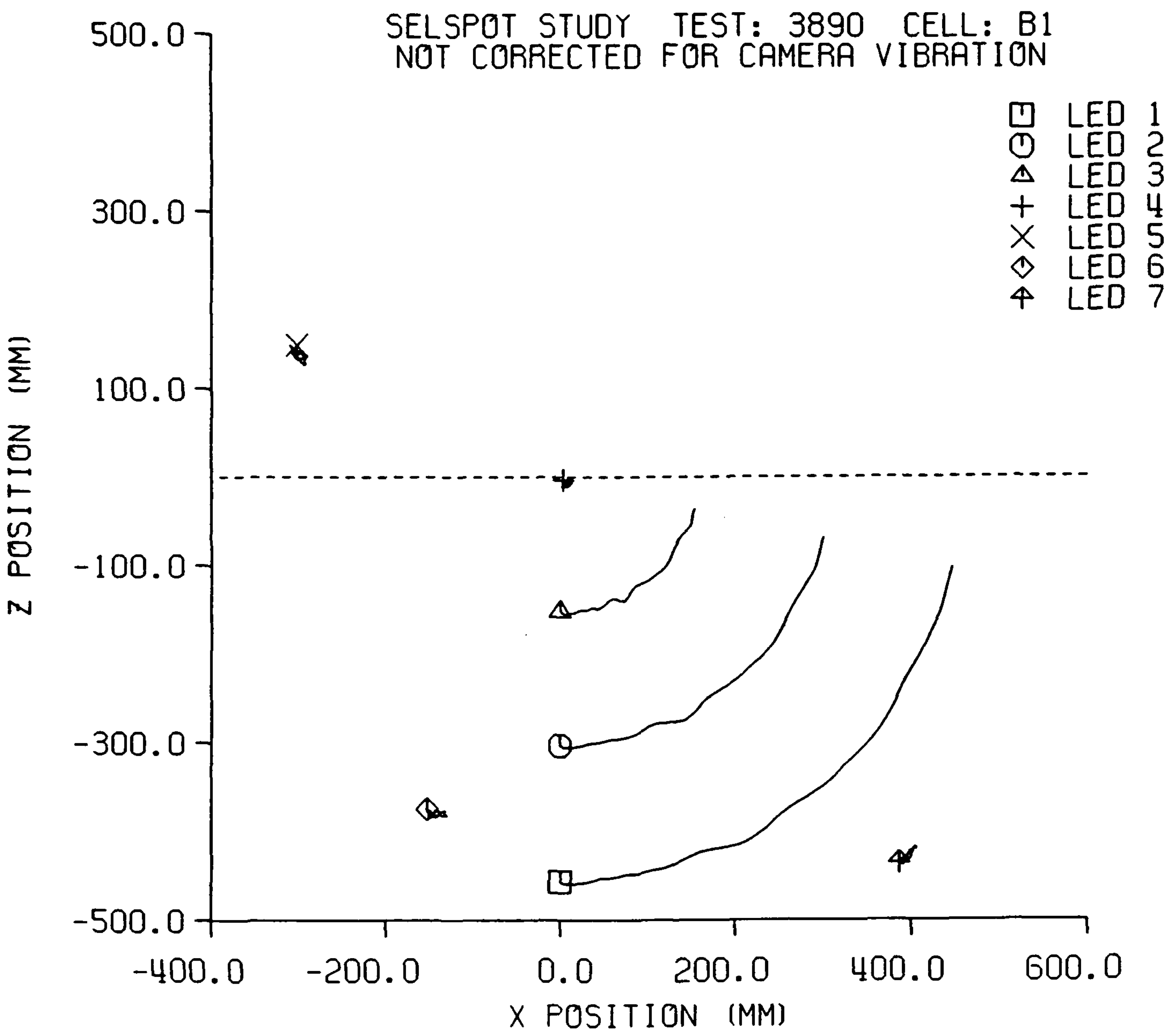
Page 2 of 2

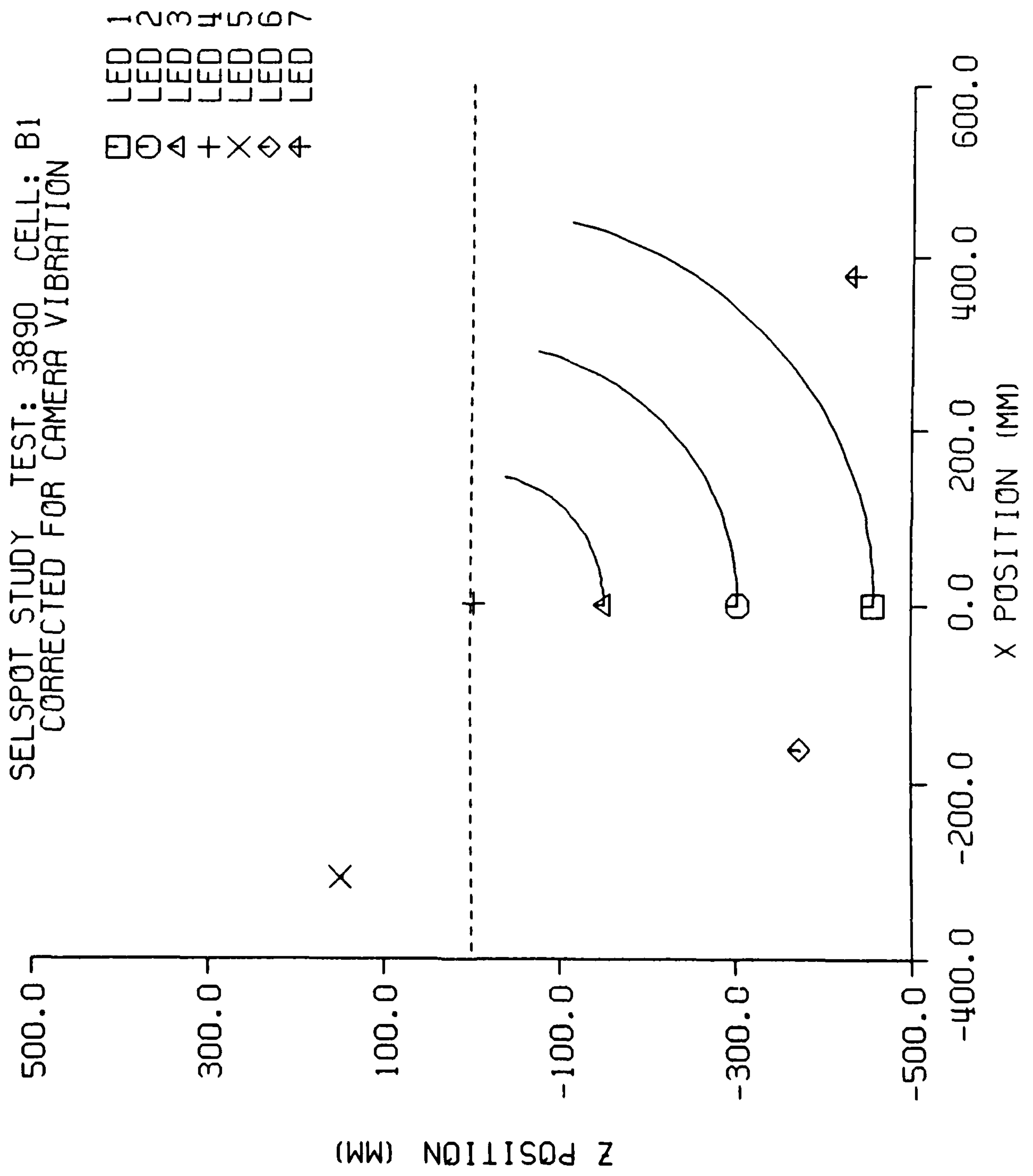
	DISPLACEMENT ERROR			ANGLE ERROR	
TIME (MS)	LED 1-POT (MM)	LED 2-POT (MM)	LED 3-POT (MM)	TIME (MS)	ANG ACC-POT (RADIANS)
1.70	1.0091	1.2885	0.3586	0.00	0.0005
3.70	1.9609	1.7513	1.6283	2.00	0.0007
5.70	2.8314	2.4109	1.3544	4.00	0.0010
7.70	2.1754	1.8133	0.5145	6.00	0.0013
9.70	0.9232	0.9867	1.3554	8.00	0.0019
11.70	1.0578	1.4601	1.0305	10.00	0.0021
13.70	1.3027	2.6340	1.3449	12.00	0.0021
15.70	2.2374	2.6734	1.3561	14.00	0.0028
17.70	2.8912	1.6579	1.2246	16.00	0.0035
19.70	2.4640	1.6747	1.3315	18.00	0.0043
21.70	1.7425	1.5006	1.2336	20.00	0.0053
23.70	1.7738	1.9970	1.2525	22.00	0.0041
25.70	2.2055	2.0875	1.3355	24.00	0.0030
27.70	2.1507	1.6765	1.3959	26.00	0.0041
29.70	1.7565	1.4961	1.6281	28.00	0.0046
31.70	1.8765	1.8465	2.4020	30.00	0.0042
33.70	2.1762	1.9625	2.8043	32.00	0.0037
35.70	1.5960	1.3621	1.7892	34.00	0.0035
37.70	0.4616	0.6640	0.7638	36.00	0.0039
39.70	0.3014	0.9731	0.9076	38.00	0.0039
41.70	1.3897	2.1172	1.8022	40.00	0.0030
43.70	2.4637	2.8909	2.5840	42.00	0.0024
45.70	2.4412	2.5800	2.0914	44.00	0.0028
47.70	2.1016	1.9033	1.3867	46.00	0.0036
49.70	2.5594	2.3929	1.6396	48.00	0.0044
51.70	3.2776	3.2222	2.3484	50.00	0.1478
53.70	3.3782	3.3300	2.6538	52.00	0.1485
55.70	3.1383	3.1753	2.5365	54.00	0.1492
57.70	3.2236	3.2420	2.6101	56.00	0.1499
59.70	3.2081	3.2832	2.7583	58.00	0.1506
61.70	2.4939	2.8445	2.5201	60.00	0.1513
63.70	1.7195	2.4459	2.0419	62.00	0.1519
65.70	1.8689	2.8988	1.9446	64.00	0.1526
67.70	2.6269	3.7416	2.1067	66.00	0.1533
69.70	2.9135	3.7733	2.1231	68.00	0.1540
71.70	2.7877	3.1342	2.0666	70.00	0.1547
73.70	3.1110	2.9794	2.3754	72.00	0.1554
75.70	3.6719	3.4598	2.9534	74.00	0.1561
77.70	3.4762	3.6587	2.9995	76.00	0.1568
79.70	2.8098	3.3338	2.5067	78.00	0.1575
81.70	3.2257	3.4723	2.3339	80.00	0.1581
83.70	5.0478	4.5641	2.9351	82.00	0.1588
85.70	6.4171	5.5280	3.6189	84.00	0.1595
87.70	5.5199	5.1039	3.4645	86.00	0.1602
89.70	2.7200	3.4002	2.5162	88.00	0.1609
91.70	0.0409	1.5145	1.5358	90.00	0.1616
93.70	1.0723	0.4382	1.0703	92.00	0.1623
95.70	0.0753	0.7178	1.2383	94.00	0.1630
97.70	2.2344	2.1291	1.9602	96.00	0.1637
99.70	2.9430	3.1672	2.5694	98.00	0.1644
AVERAGE	2.3770	2.4872	1.9261		0.0018
STANDARD DEV	1.2322	1.1030	0.7477		0.0029

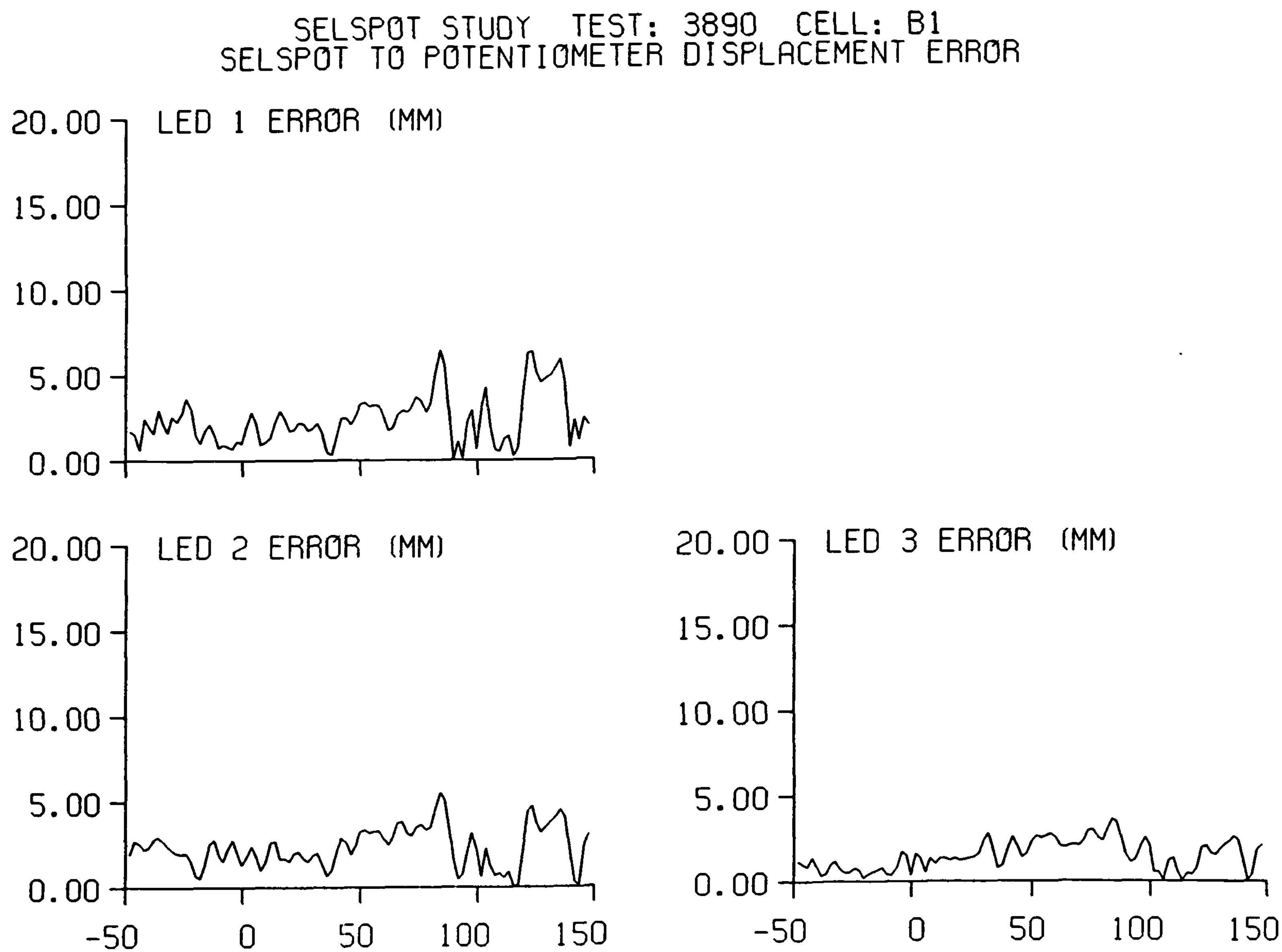

SELSPOT STUDY TEST: 3890 CELL: B1
SLED X ACCEL (G)
20.00
15.00
10.00
5.00
0.00
-5.00
SLED Z ACCEL (G)
10.00
5.00
0.00
-5.00
-10.00
SLED Y ACCEL (G)
10.00
5.00
0.00
-5.00
-10.00
SLED VELOCITY (M/SEC)
25.00
20.00
15.00
10.00
5.00
0.00
-50
0
50
100
150
TIME IN MILLISECONDS

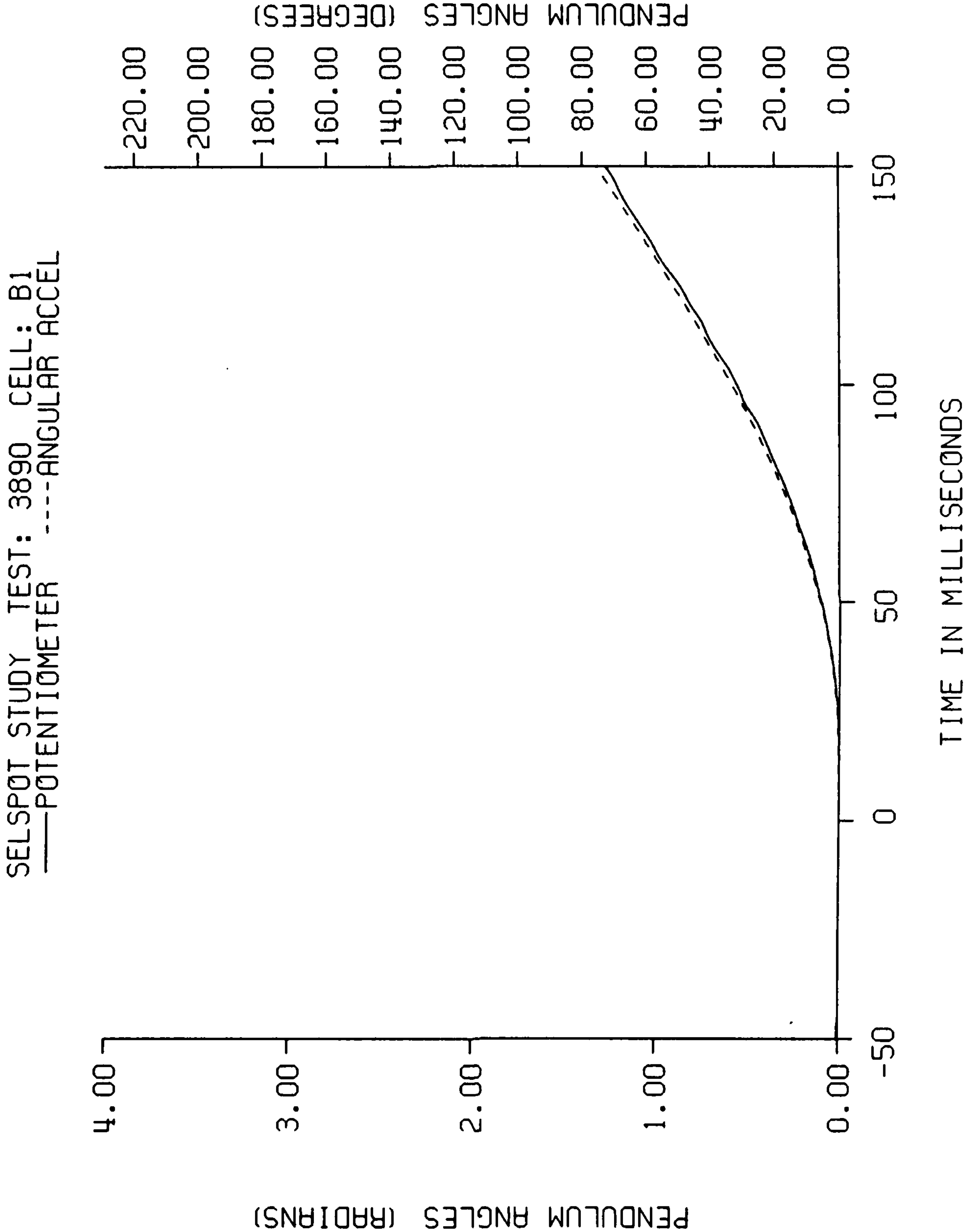


SELSPOT STUDY TEST: 3890 CELL: B1
ANGULAR ACCEL (RAD/SEC2)
1000.0
500.0
0.0
-500.0
-1000.0
-50
0
50
100
150
TIME IN MILLISECONDS

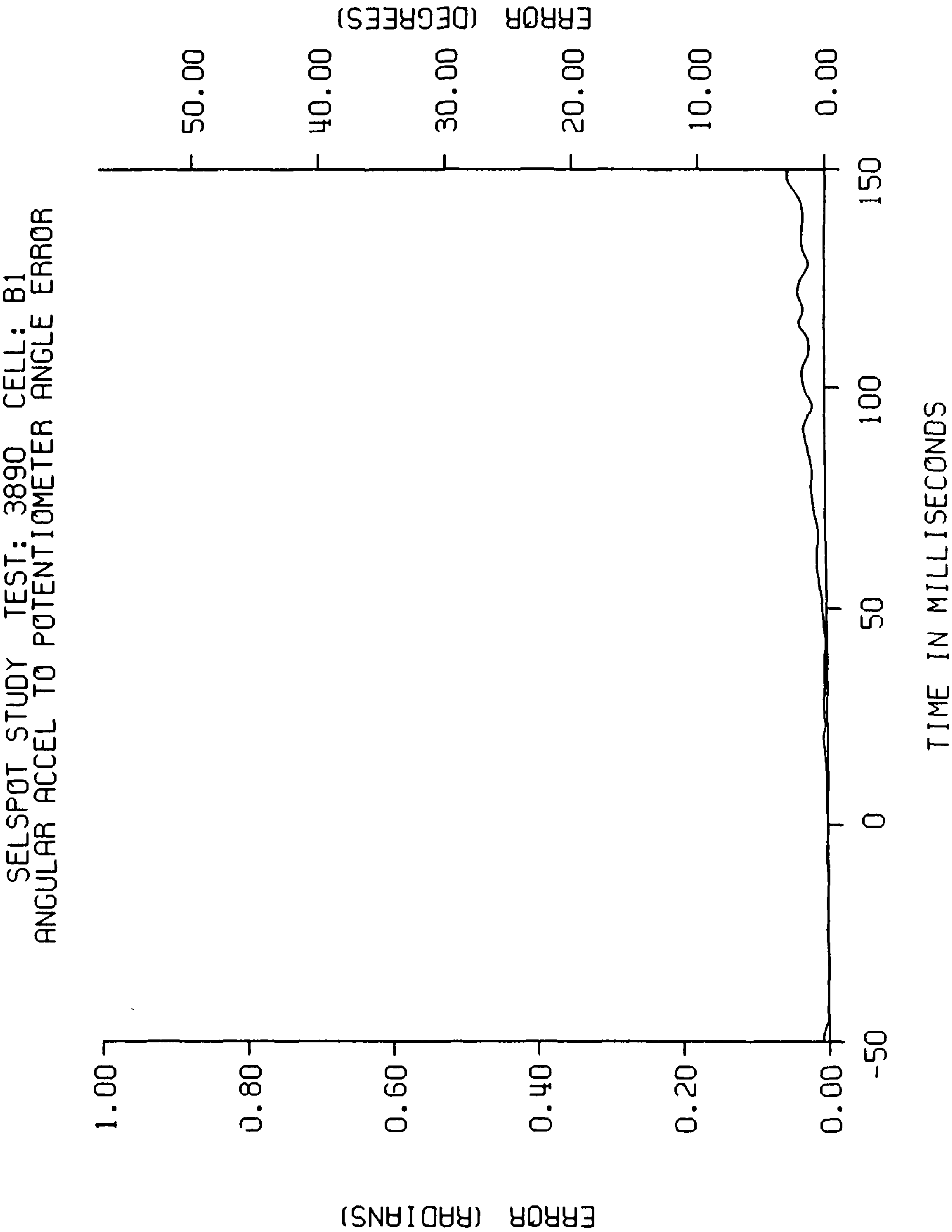

SELSPOT STUDY TEST: 3890 CELL: B1
NOT CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
500.0
300.0
100.0
-100.0
-300.0
-500.0
Z POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0
X POSITION (MM)

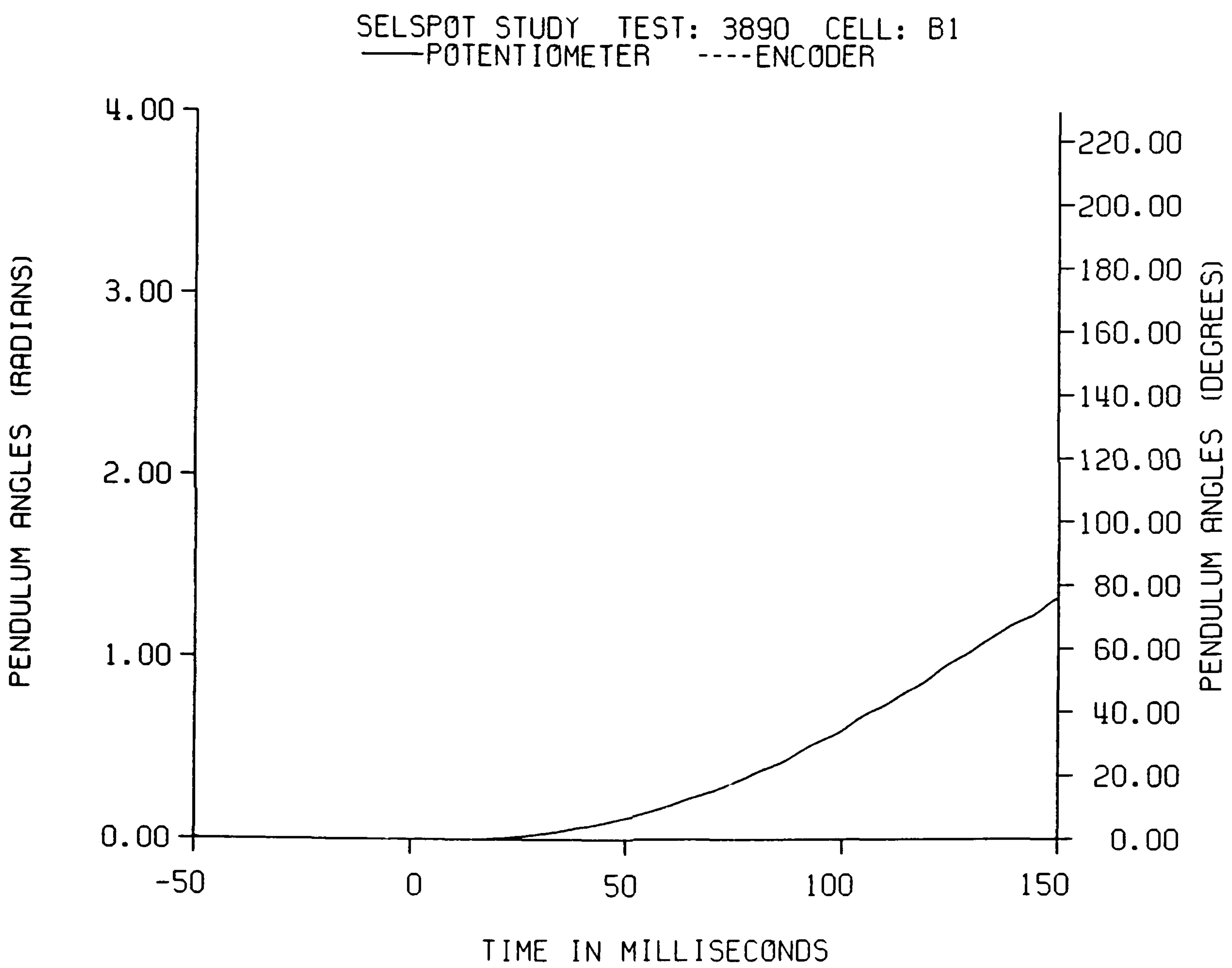

SELSPOT STUDY TEST: 3890 CELL: B1
CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
-400.0
-200.0
0.0
200.0
400.0
600.0
X POSITION (MM)
500.0
300.0
100.0
-100.0
-300.0
-500.0
Z POSITION (MM)


SELSPOT STUDY TEST: 3890 CELL: B1
SELSPOT TO POTENTIOMETER DISPLACEMENT ERROR
LED 1 ERROR (MM)
LED 2 ERROR (MM)
LED 3 ERROR (MM)
20.00
15.00
10.00
5.00
0.00
-50
0
50
100
150



SELSPOT STUDY TEST: 3890 CELL: B1
——POTENTIOMETER ----ANGULAR ACCEL
PENDULUM ANGLES (DEGREES)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
PENDULUM ANGLES (RADIANS)
0.00
1.00
2.00
3.00
4.00
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY TEST: 3890 CELL: B1
ANGULAR ACCEL TO POTENTIOMETER ANGLE ERROR
ERROR (DEGREES)
50.00
40.00
30.00
20.00
10.00
0.00
ERROR (RADIANS)
1.00
0.80
0.60
0.40
0.20
0.00
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY TEST: 3890 CELL: B1
——POTENTIOMETER ----ENCODER
PENDULUM ANGLES (RADIANS)
4.00
3.00
2.00
1.00
0.00
-50
0
50
100
150
TIME IN MILLISECONDS
PENDULUM ANGLES (DEGREES)
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00

SELSPOT STUDY TEST: 3893 NOM G: 10.0 CELL: C1

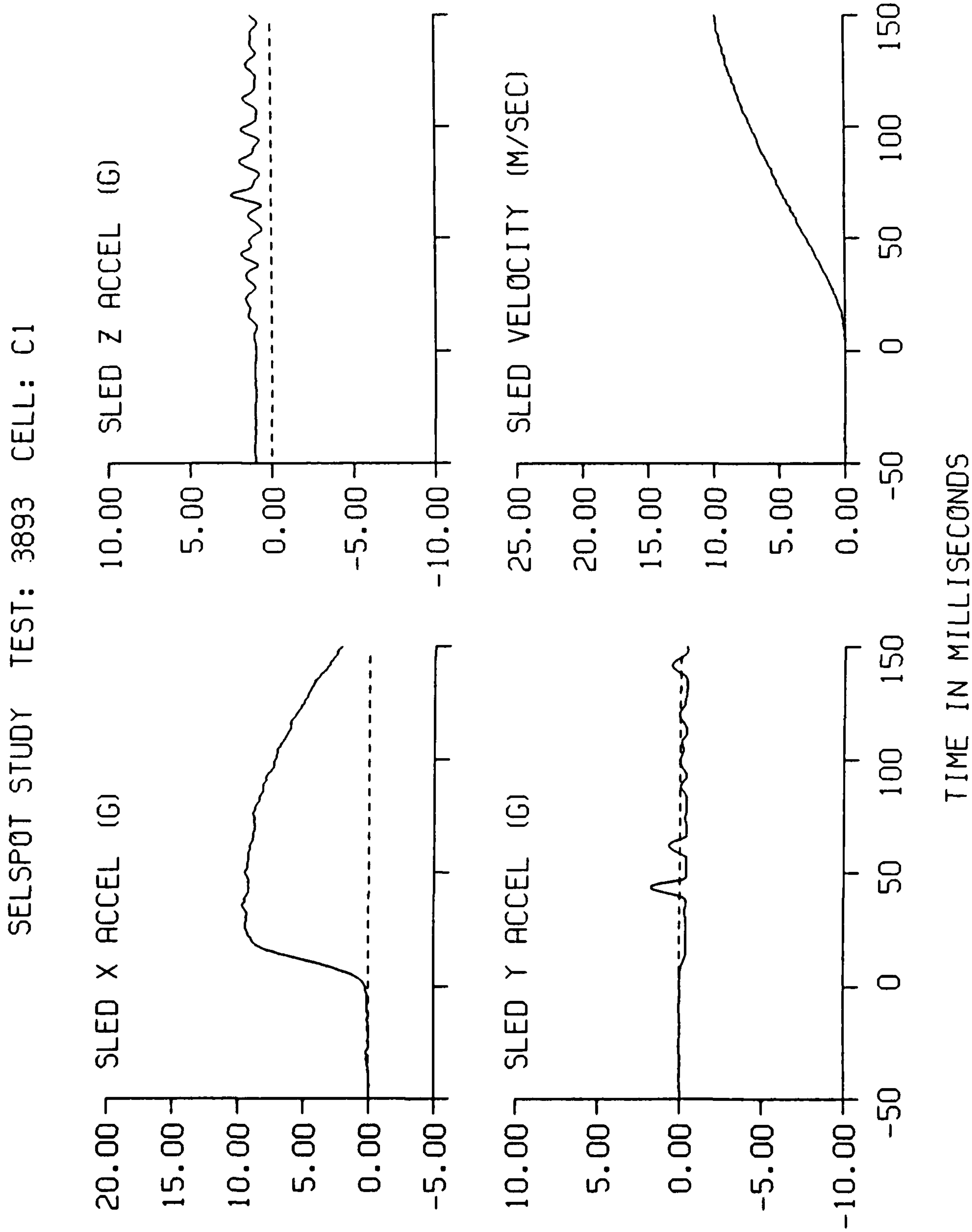
DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
REFERENCE MARK TIME (MS)				-129.0	
SLED ACCELERATION (G)					
X AXIS	0.06	9.59	0.20	35.0	0.0
Y AXIS	-0.02	1.73	-0.41	43.0	14.0
Z AXIS	1.01	2.49	0.57	69.0	54.0
SLED VELOCITY (M/SEC)	0.00	9.91	-0.07	151.0	5.0
POTENTIOMETER ANGLE (RAD)	0.00	2.14	0.00	150.0	2.9
POTENTIOMETER DISP (MM)					
AT LED 1		800.57	-0.45	149.4	3.4
AT LED 2		533.29	-0.31	149.4	3.4
AT LED 3		266.43	-0.16	149.4	3.4
ANGULAR ACCEL (RAD/SEC2)	-3.58	371.82	-377.84	134.0	56.0
ANG ACCEL ANGLE (RAD)	0.00	2.15	0.00	150.0	1.0
LED 1 POSITION (MM)					
X AXIS		454.26	0.06	119.4	3.4
Y AXIS		5.40	-15.11	145.4	45.4
Z AXIS		247.45	-457.58	149.4	23.4
LED 1 DISPLACEMENT (MM)		800.52	0.54	149.4	1.4
LED 1 DISP ERROR (MM)		5.44	0.01	69.4	23.4
LED 2 POSITION (MM)					
X AXIS		300.02	0.05	119.4	5.4
Y AXIS		5.27	-14.77	149.4	67.4
Z AXIS		161.90	-303.06	149.4	21.4
LED 2 DISPLACEMENT (MM)		529.10	1.59	149.4	9.4
LED 2 DISP ERROR (MM)		5.46	0.04	69.4	125.4
LED 3 POSITION (MM)					
X AXIS		149.49	0.07	117.4	1.4
Y AXIS		2.57	-6.75	149.4	69.4
Z AXIS		79.33	-152.24	149.4	1.4
LED 3 DISPLACEMENT (MM)		263.26	0.96	149.4	1.4
LED 3 DISP ERROR (MM)		4.45	0.19	69.4	111.4
LED 4 POSITION (MM)					
X AXIS		-0.09	-1.68	95.4	137.4
Y AXIS		67.69	63.82	105.4	31.4
Z AXIS		-2.75	-4.15	93.4	43.4

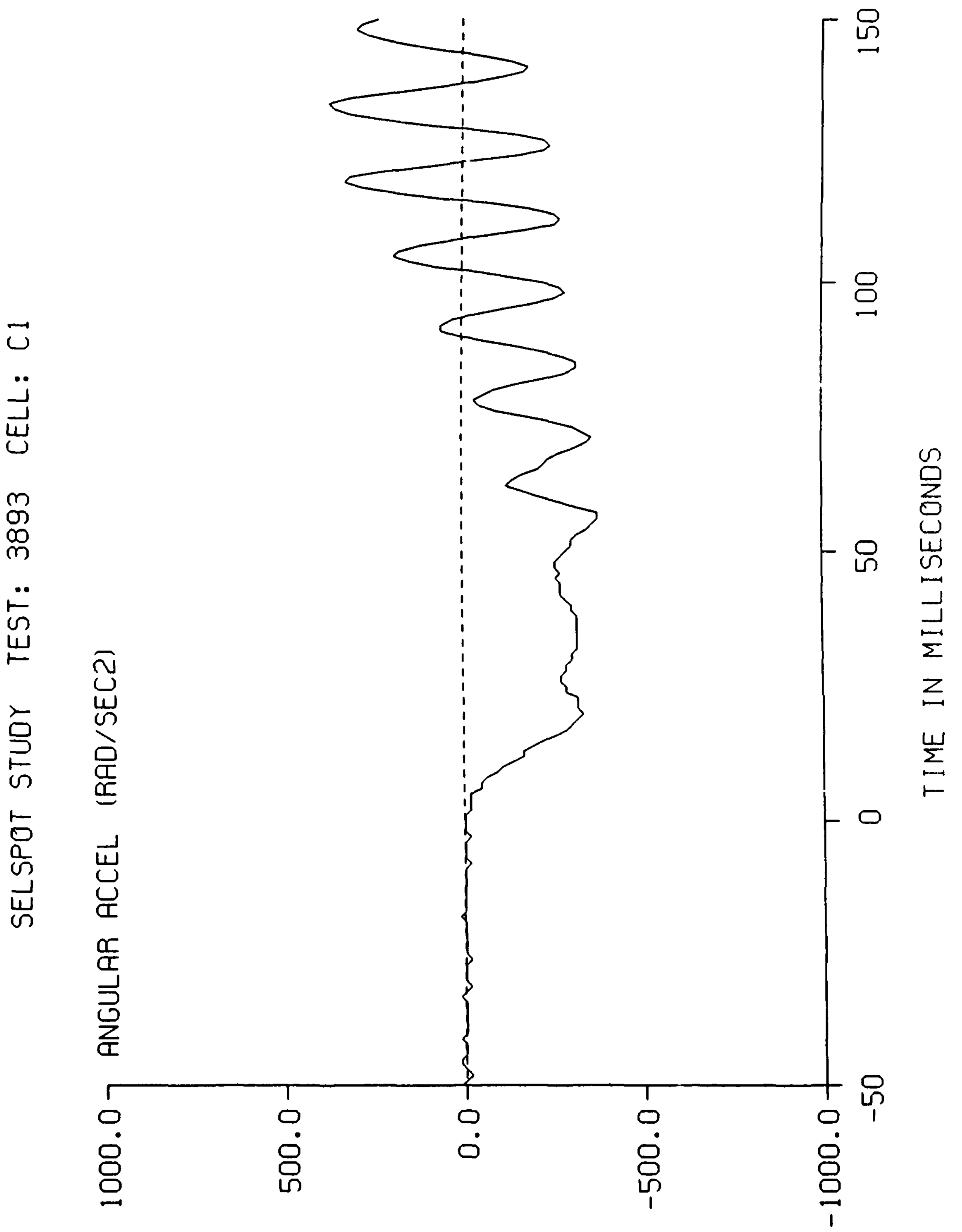
SELSPOT STUDY TEST: 3893 NOM G: 10.0 CELL: C1

DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
LED 5 POSITION (MM)					
X AXIS		-309.77	-314.25	131.4	95.4
Y AXIS		195.51	185.11	9.4	47.4
Z AXIS		157.92	154.03	103.4	51.4
LED 6 POSITION (MM)					
X AXIS		-178.47	-180.89	9.4	51.4
Y AXIS		216.90	206.31	7.4	53.4
Z AXIS		-367.11	-369.32	5.4	91.4
LED 7 POSITION (MM)					
X AXIS		362.31	360.64	101.4	135.4
Y AXIS		204.42	196.91	57.4	131.4
Z AXIS		-439.80	-441.70	39.4	9.4
ANGLE ERROR (RADIANS)		0.07	0.00	150.0	2.0

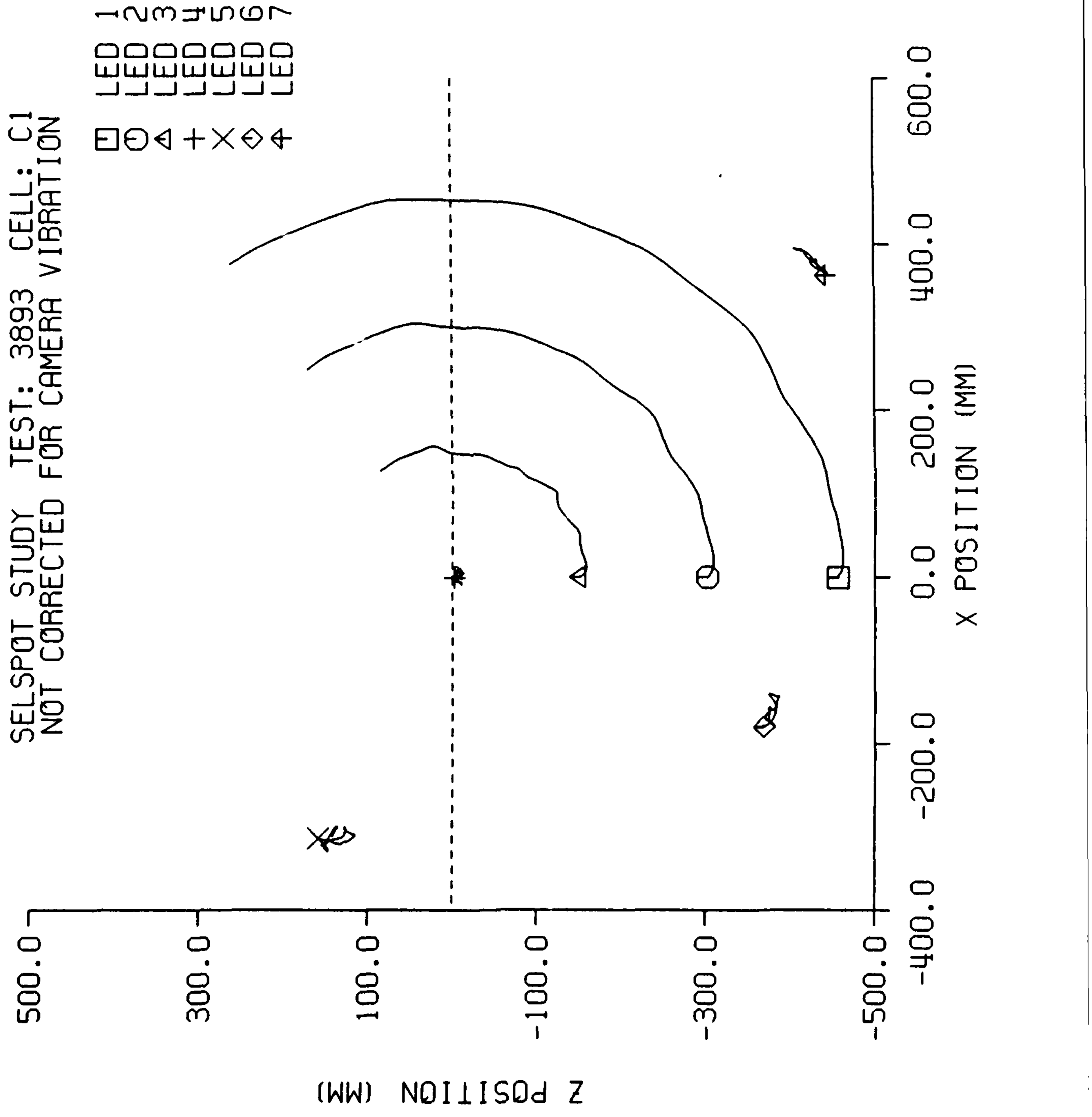
Page 2 of 2

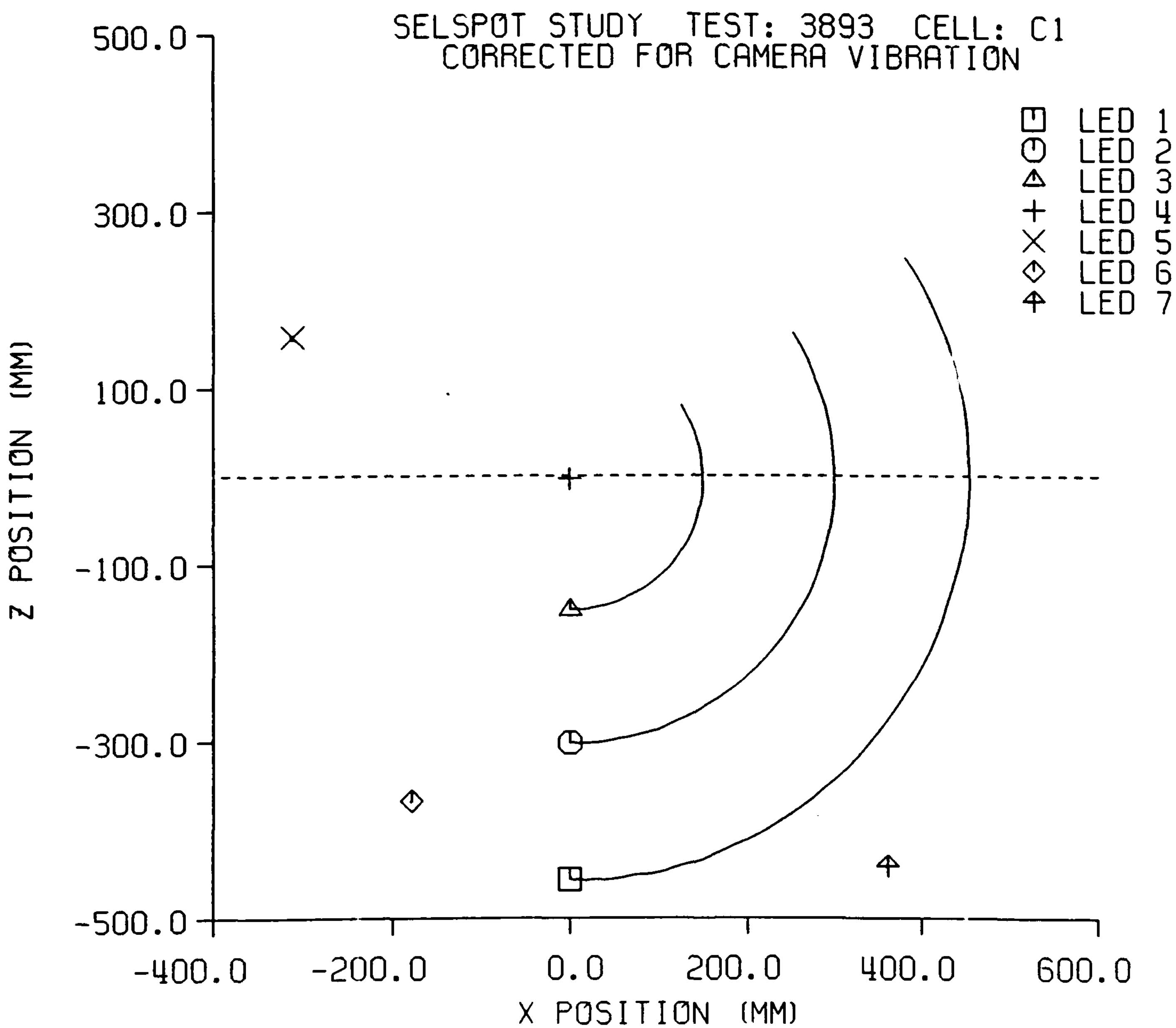
	DISPLACEMENT ERROR			ANGLE ERROR	
TIME (MS)	LED 1-POT (MM)	LED 2-POT (MM)	LED 3-POT (MM)	TIME (MS)	ANG ACC-POT (RADIANS)
1.40	0.8099	2.2509	1.0187	0.00	0.0007
3.40	1.2153	2.1788	2.0272	2.00	0.0001
5.40	1.3692	1.9647	2.1145	4.00	0.0007
7.40	0.8174	1.6494	1.4834	6.00	0.0003
9.40	1.4302	1.5114	1.2224	8.00	0.0012
11.40	1.5820	1.3843	1.4476	10.00	0.0011
13.40	1.4749	0.9092	1.4132	12.00	0.0013
15.40	1.3151	0.4187	0.9391	14.00	0.0011
17.40	1.5907	0.7674	1.4780	16.00	0.0004
19.40	1.6212	1.2698	1.8862	18.00	0.0011
21.40	0.7239	0.9425	1.7766	20.00	0.0020
23.40	0.0127	0.8097	1.7226	22.00	0.0023
25.40	0.3319	1.2475	1.7024	24.00	0.0023
27.40	0.6588	1.7116	1.6797	26.00	0.0026
29.40	0.0478	1.3579	1.5826	28.00	0.0032
31.40	0.8748	0.7469	1.6625	30.00	0.0044
33.40	0.5512	0.9767	2.0258	32.00	0.0053
35.40	0.5158	1.8645	2.3093	34.00	0.0046
37.40	1.0278	2.5468	2.3156	36.00	0.0050
39.40	1.2136	2.8244	2.6533	38.00	0.0054
41.40	1.7727	3.0780	3.3342	40.00	0.0032
43.40	2.2638	3.1326	3.7998	42.00	0.0003
45.40	2.0060	2.7793	3.5793	44.00	0.0017
47.40	1.1460	2.4241	3.0270	46.00	0.0009
49.40	1.3388	3.0439	3.2022	48.00	0.0006
51.40	2.6531	4.2327	3.9247	50.00	0.3188
53.40	2.8930	4.4238	4.1407	52.00	0.3202
55.40	1.8263	3.5378	3.6110	54.00	0.3217
57.40	1.4303	2.8694	3.1066	56.00	0.3231
59.40	2.4738	3.0512	3.2172	58.00	0.3246
61.40	3.3[illegible]85	3.4296	3.6107	60.00	0.3261
63.40	3.2718	3.6433	3.7992	62.00	0.3275
65.40	3.3680	4.2390	3.9146	64.00	0.3290
67.40	4.5471	5.2193	4.2248	66.00	0.3305
69.40	5.4393	5.4558	4.4515	68.00	0.3319
71.40	4.5786	4.3901	4.1716	70.00	0.3334
73.40	2.7454	3.0770	3.5222	72.00	0.3349
75.40	1.3908	2.4579	2.9084	74.00	0.3364
77.40	0.2241	1.8829	2.3839	76.00	0.3379
79.40	1.5168	0.6443	1.8593	78.00	0.3393
81.40	2.7593	0.2947	1.5540	80.00	0.3408
83.40	2.1270	0.1513	1.6399	82.00	0.3423
85.40	0.8641	0.9062	1.7140	84.00	0.3438
87.40	1.4076	0.1685	1.3226	86.00	0.3453
89.40	3.4985	1.5515	0.7452	88.00	0.3468
91.40	4.4812	2.0615	0.6049	90.00	0.3482
93.40	3.4843	0.9409	0.8713	92.00	0.3497
95.40	2.6067	0.2279	0.8698	94.00	0.3512
97.40	3.3880	1.2140	0.2800	96.00	0.3526
99.40	4.6625	2.6596	0.4811	98.00	0.3541
AVERAGE	1.9750	2.1304	2.2866		0.0016
STANDARD DEV	1.3286	1.3533	1.1546		0.0037


SELSPØT STUDY TEST: 3893 CELL: C1
SLED X ACCEL (G)
SLED Z ACCEL (G)
SLED Y ACCEL (G)
SLED VELØCITY (M/SEC)
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
25.00
-50
0
50
100
150
TIME IN MILLISECØNDS

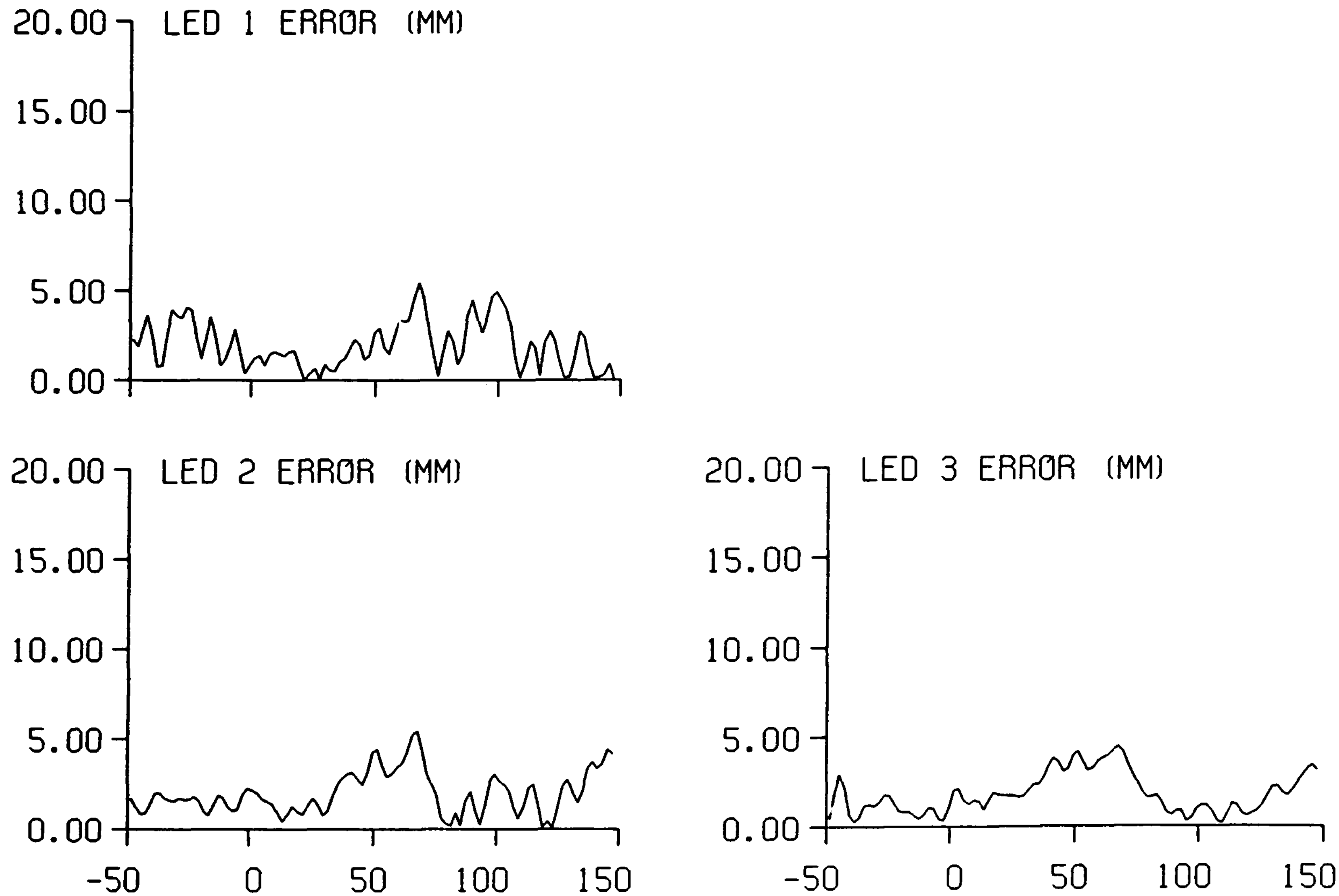


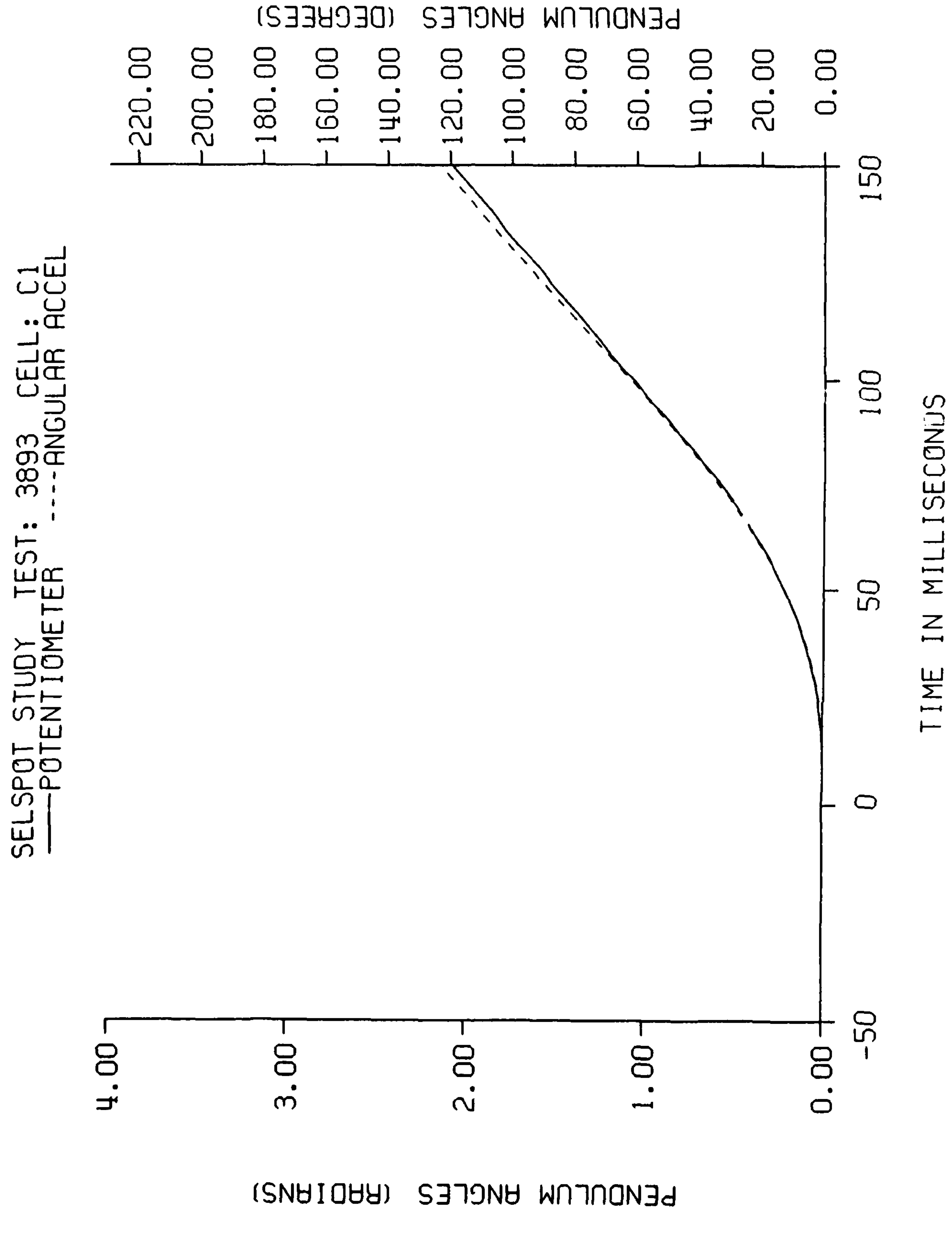
SELSPØT STUDY TEST: 3893 CELL: C1
ANGULAR ACCEL (RAD/SEC2)
1000.0
500.0
0.0
-500.0
-1000.0
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY   TEST: 3893   CELL: C1
NOT CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
X POSITION (MM)
Z POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0
500.0
300.0
100.0
-100.0
-300.0
-500.0

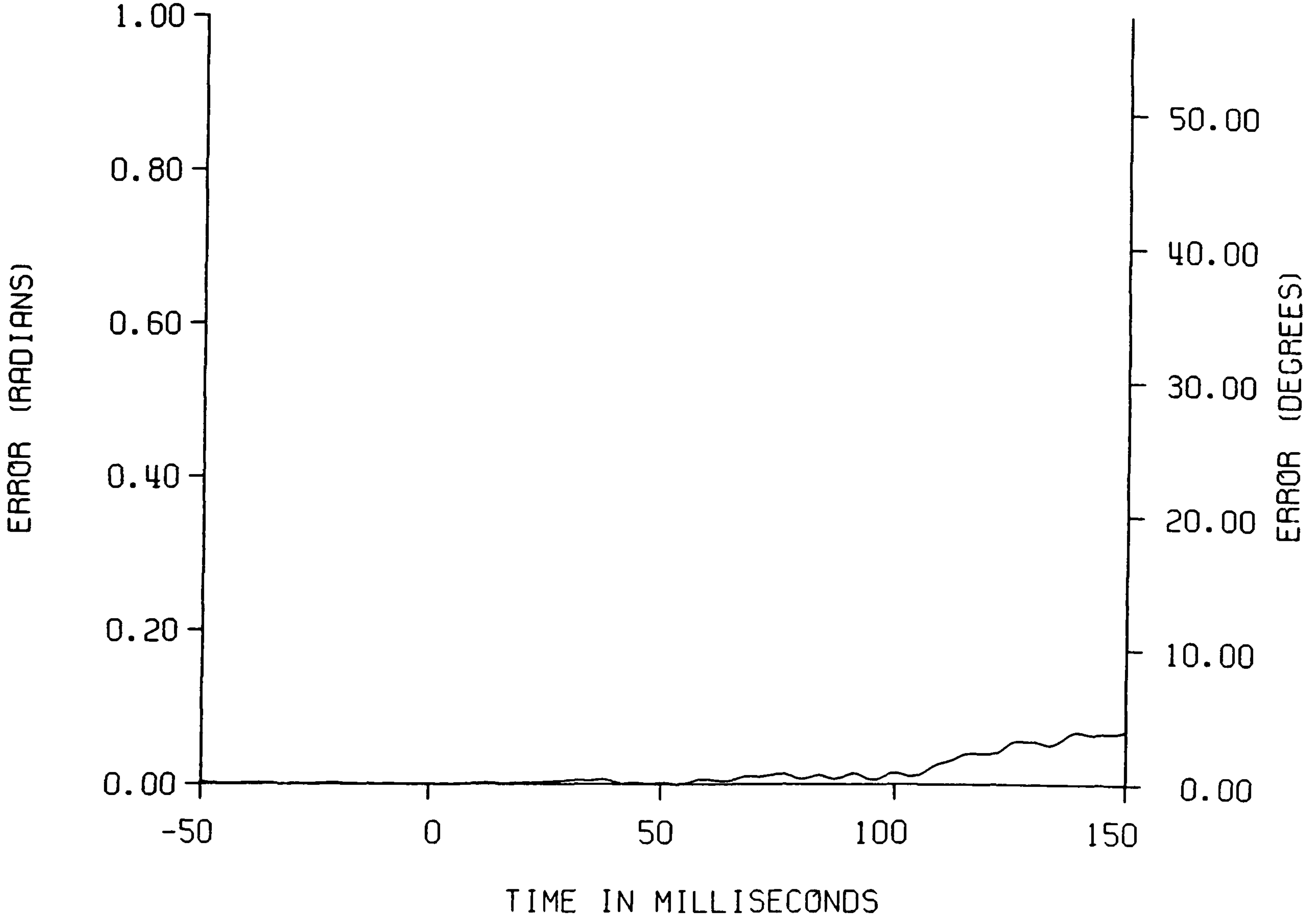

SELSPOT STUDY TEST: 3893 CELL: C1
CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
500.0
300.0
100.0
-100.0
-300.0
-500.0
Z POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0
X POSITION (MM)

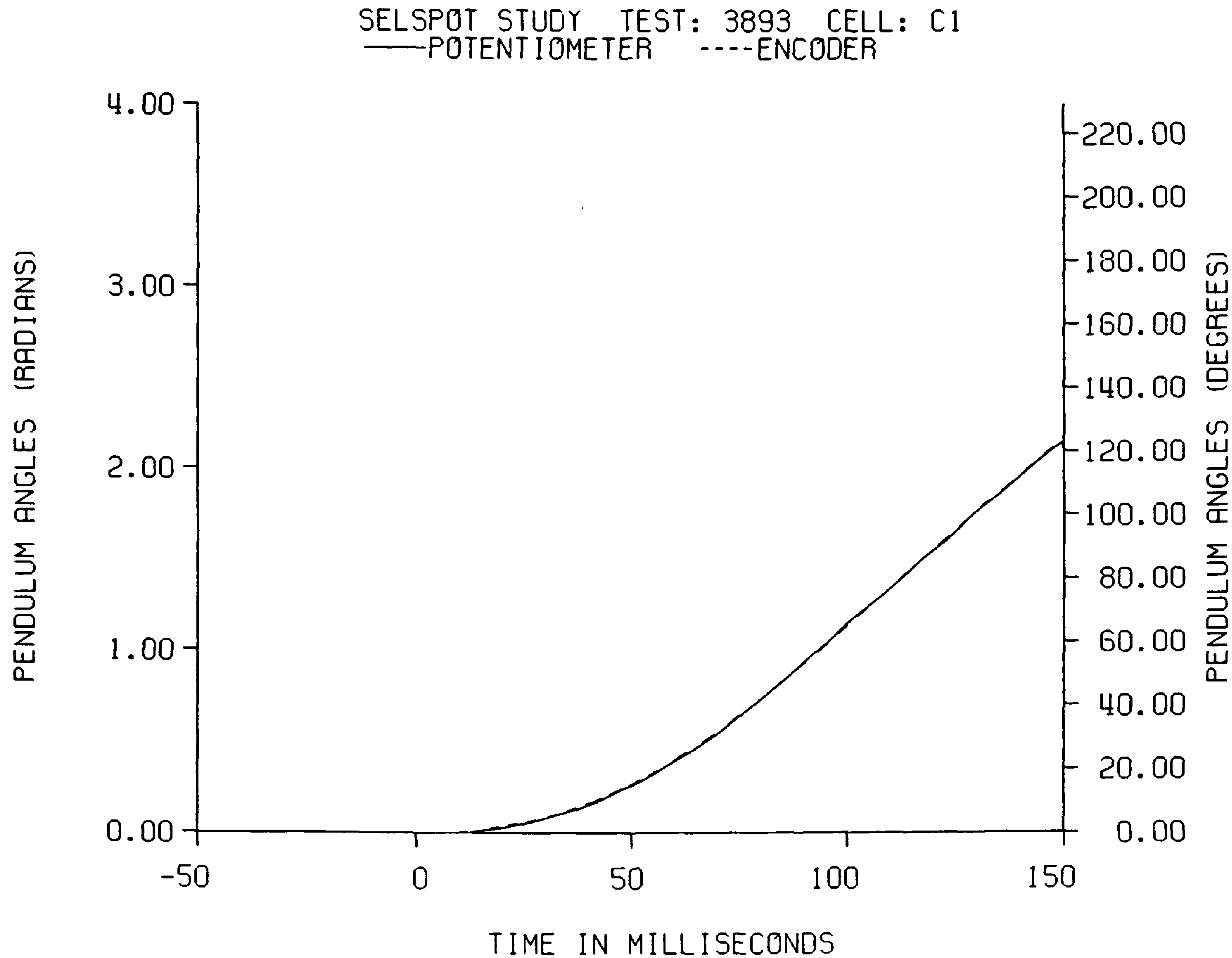
SELSPOT STUDY TEST: 3893 CELL: C1
SELSPOT TO POTENTIOMETER DISPLACEMENT ERROR




SELSPOT STUDY TEST: 3893 CELL: C1
——POTENTIOMETER ----ANGULAR ACCEL
PENDULUM ANGLES (DEGREES)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
PENDULUM ANGLES (RADIANS)
0.00
1.00
2.00
3.00
4.00
-50
0
50
100
150
TIME IN MILLISECONDS

SELSPOT STUDY TEST: 3893 CELL: C1
ANGULAR ACCEL TO POTENTIOMETER ANGLE ERROR




SELSPOT STUDY TEST: 3893 CELL: C1
——POTENTIOMETER ----ENCODER
PENDULUM ANGLES (RADIANS)
4.00
3.00
2.00
1.00
0.00
PENDULUM ANGLES (DEGREES)
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-50
0
50
100
150
TIME IN MILLISECONDS

SELSPOT STUDY TEST: 3896 NOM G: 15.0 CELL: D1

DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
REFERENCE MARK TIME (MS)				-116.0	
SLED ACCELERATION (G)					
X AXIS	0.03	14.99	0.20	22.0	0.0
Y AXIS	0.02	2.19	-0.36	38.0	11.0
Z AXIS	1.00	2.35	0.18	38.0	88.0
SLED VELOCITY (M/SEC)	-0.01	13.32	-0.08	151.0	4.0
POTENTIOMETER ANGLE (RAD)	0.00	2.80	0.00	150.0	8.2
POTENTIOMETER DISP (MM)					
AT LED 1		900.00	-0.02	149.1	9.1
AT LED 2		599.80	-0.04	149.1	9.1
AT LED 3		299.79	-0.03	149.1	9.1
ANGULAR ACCEL (RAD/SEC2)	-1.52	282.77	-751.77	117.0	49.0
ANG ACCEL ANGLE (RAD)	0.00	2.81	0.00	150.0	7.0
LED 1 POSITION (MM)					
X AXIS		455.49	0.17	97.1	1.1
Y AXIS		12.12	-11.86	105.1	65.1
Z AXIS		426.56	-457.10	149.1	7.1
LED 1 DISPLACEMENT (MM)		895.80	0.82	149.1	9.1
LED 1 DISP ERROR (MM)		7.14	0.03	1.1	107.1
LED 2 POSITION (MM)					
X AXIS		302.51	0.12	97.1	3.1
Y AXIS		8.73	-12.15	101.1	61.1
Z AXIS		279.78	-301.95	149.1	7.1
LED 2 DISPLACEMENT (MM)		589.87	0.97	149.1	5.1
LED 2 DISP ERROR (MM)		9.93	0.02	149.1	89.1
LED 3 POSITION (MM)					
X AXIS		151.96	-0.04	95.1	1.1
Y AXIS		5.11	-5.11	145.1	59.1
Z AXIS		137.97	-150.10	149.1	1.1
LED 3 DISPLACEMENT (MM)		291.88	0.76	149.1	11.1
LED 3 DISP ERROR (MM)		7.97	0.05	147.1	15.1
LED 4 POSITION (MM)					
X AXIS		1.05	-1.05	93.1	137.1
Y AXIS		68.76	64.82	79.1	135.1
Z AXIS		0.48	-1.35	91.1	53.1

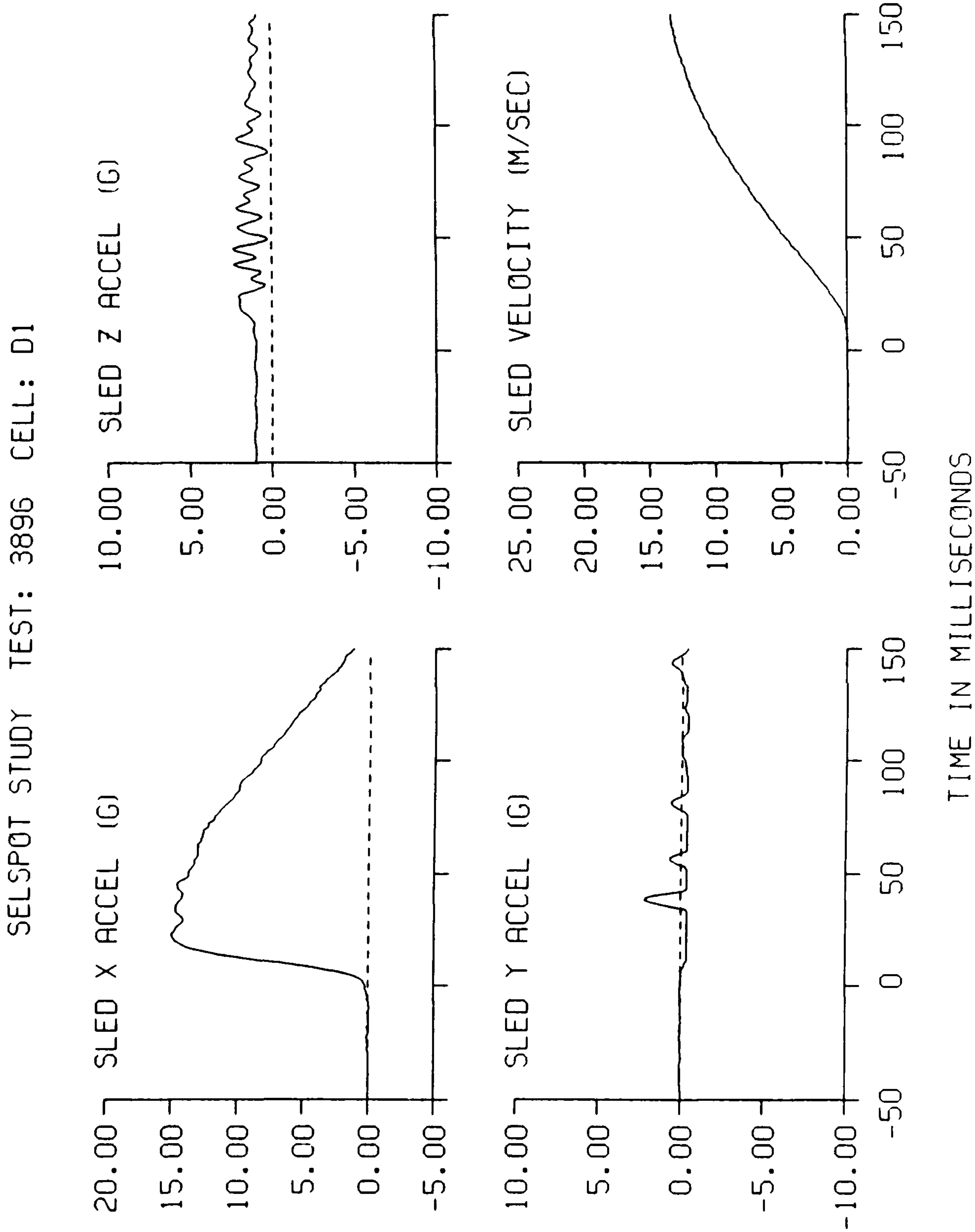
Page 1 of 2

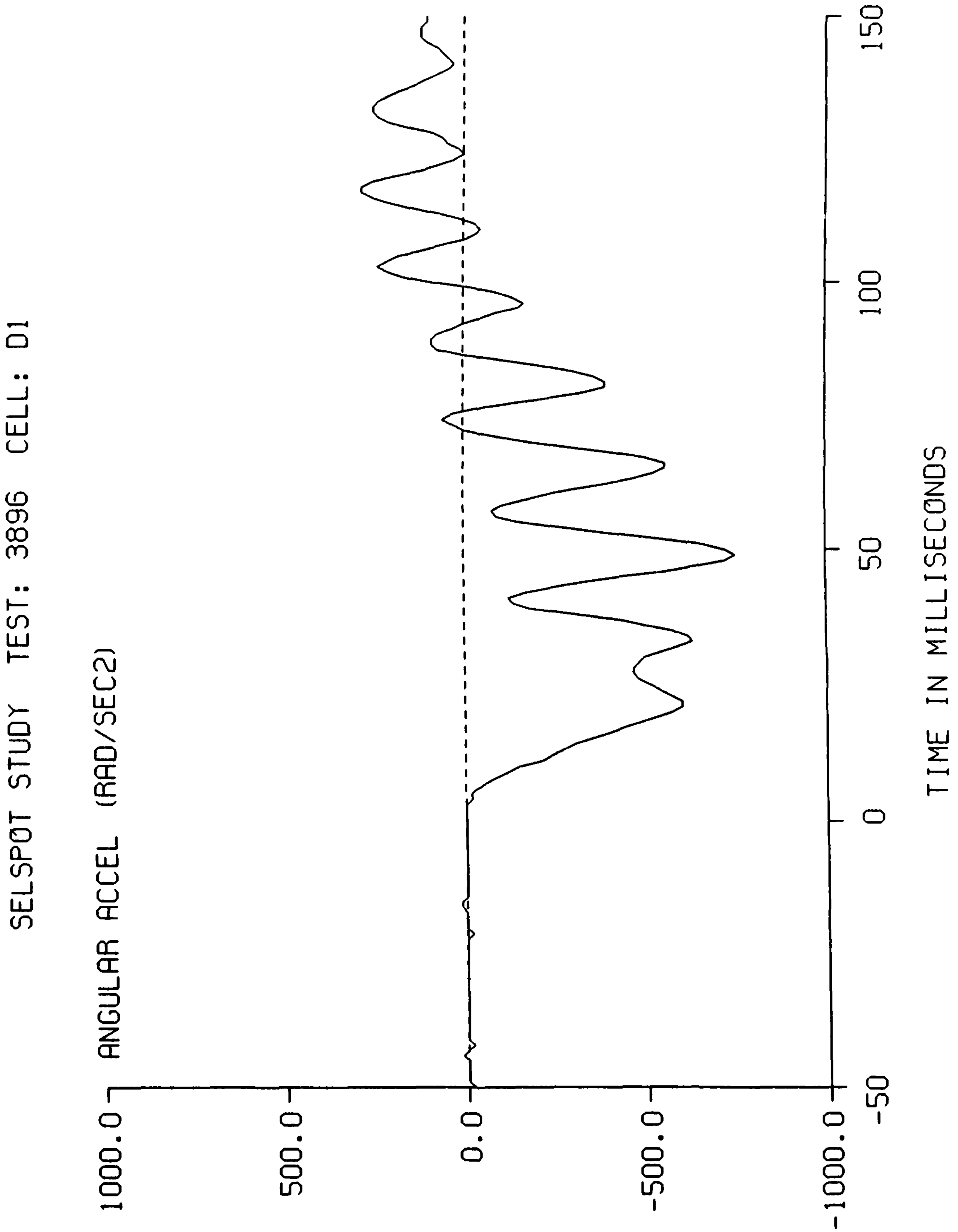
SELSPOT STUDY TEST: 3896 NOM G: 15.0 CELL: D1

DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
LED 5 POSITION (MM)					
X AXIS		-312.04	-319.09	135.1	101.1
Y AXIS		196.88	182.20	133.1	47.1
Z AXIS		154.77	148.44	99.1	53.1
LED 6 POSITION (MM)					
X AXIS		-166.22	-169.25	119.1	47.1
Y AXIS		221.14	207.44	13.1	53.1
Z AXIS		-368.80	-371.76	135.1	107.1
LED 7 POSITION (MM)					
X AXIS		377.93	374.73	105.1	61.1
Y AXIS		213.49	197.96	53.1	7.1
Z AXIS		-424.25	-427.62	53.1	79.1
ANGLE ERROR (RADIANS)		0.08	0.00	150.0	61.0

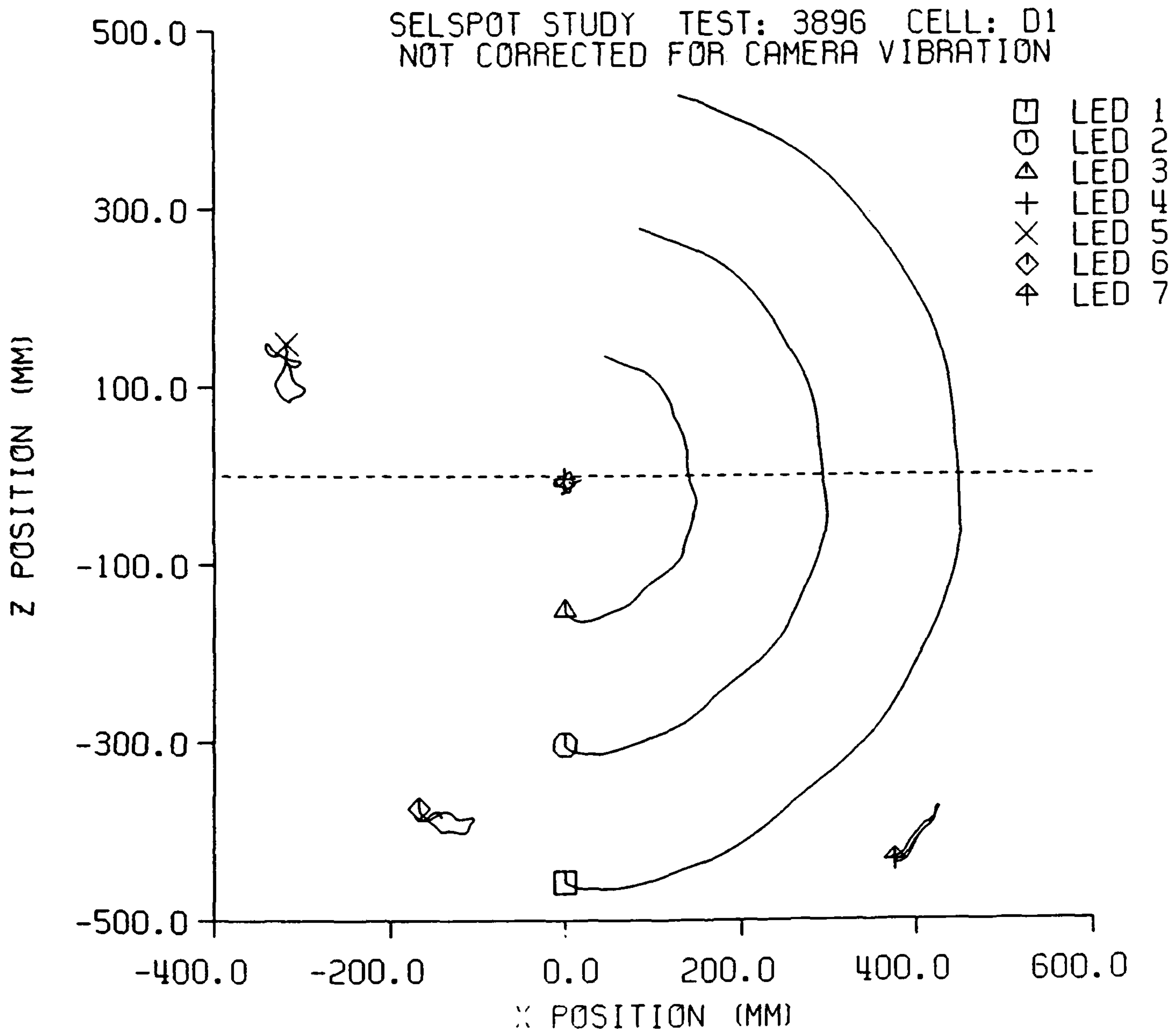
Page 2 of 2

	DISPLACEMENT ERROR			ANGLE ERROR	
TIME (MS)	LED 1-POT (MM)	LED 2-POT (MM)	LED 3-POT (MM)	TIME (MS)	ANG ACC-POT (RADIANS)
1.10	7.1439	3.3841	1.3536	0.00	0.0009
3.10	5.5318	2.8166	0.7173	2.00	0.0010
5.10	1.5201	0.8219	0.7022	4.00	0.0008
7.10	1.3206	1.3418	1.6631	6.00	0.0006
9.10	0.8362	1.1672	1.2047	8.00	0.0013
11.10	3.0145	1.9670	0.5197	10.00	0.0003
13.10	3.0598	3.0627	0.2194	12.00	0.0011
15.10	1.2217	1.7712	0.0486	14.00	0.0004
17.10	0.5516	0.5026	0.7325	16.00	0.0008
19.10	0.7355	0.6216	1.0312	18.00	0.0012
21.10	0.5112	0.7900	0.9163	20.00	0.0021
23.10	0.1287	1.1903	0.8521	22.00	0.0034
25.10	0.5619	1.9012	1.3026	24.00	0.0042
27.10	1.2215	2.5155	2.0746	26.00	0.0032
29.10	0.8706	2.4490	2.3393	28.00	0.0022
31.10	0.4046	1.7237	2.0230	30.00	0.0021
33.10	1.3536	1.0523	1.7586	32.00	0.0022
35.10	1.4066	0.8538	1.7772	34.00	0.0020
37.10	1.2564	0.9297	1.9384	36.00	0.0038
39.10	1.2573	1.2008	2.2828	38.00	0.0058
41.10	0.6473	1.9927	3.0391	40.00	0.0049
43.10	0.9155	3.2146	3.9855	42.00	0.0026
45.10	2.2080	4.0091	4.3469	44.00	0.0013
47.10	2.1002	3.7909	3.8315	46.00	0.0014
49.10	1.3651	3.0990	3.1815	48.00	0.0000
51.10	1.2988	2.6904	3.1024	50.00	0.5029
53.10	1.4984	2.4505	3.2011	52.00	0.5051
55.10	0.8356	1.8739	2.8379	54.00	0.5073
57.10	0.1016	1.4117	2.3638	56.00	0.5096
59.10	1.5258	2.3204	2.7576	58.00	0.5118
61.10	5.0083	4.5305	4.0520	60.00	0.5140
63.10	7.0133	5.9246	4.8770	62.00	0.5162
65.10	4.9459	4.8305	4.1926	64.00	0.5185
67.10	0.9141	2.3230	2.6913	66.00	0.5207
69.10	1.1574	0.7385	1.7386	68.00	0.5229
71.10	0.8137	0.5885	1.5460	70.00	0.5251
73.10	0.7601	0.4389	1.3096	72.00	0.5274
75.10	2.0255	0.4423	0.7427	74.00	0.5296
77.10	2.7199	1.1248	0.3831	76.00	0.5318
79.10	1.9757	1.0214	0.4237	78.00	0.5340
81.10	1.7918	1.1108	0.3208	80.00	0.5362
83.10	3.4362	2.1859	0.2708	82.00	0.5384
85.10	4.7471	3.1240	0.8266	84.00	0.5406
87.10	3.1065	2.2852	0.6081	86.00	0.5427
89.10	0.5719	0.0164	0.3188	88.00	0.5449
91.10	2.9797	1.6239	1.1646	90.00	0.5470
93.10	2.6863	1.4427	1.3052	92.00	0.5492
95.10	1.1876	0.2115	0.7108	94.00	0.5513
97.10	0.0796	0.8565	0.3252	96.00	0.5534
99.10	0.6197	1.5009	1.3874	98.00	0.5555
AVERAGE	1.8989	1.9047	1.7460		0.0012
STANDARD DEV	1.6856	1.2707	1.2681		0.0036

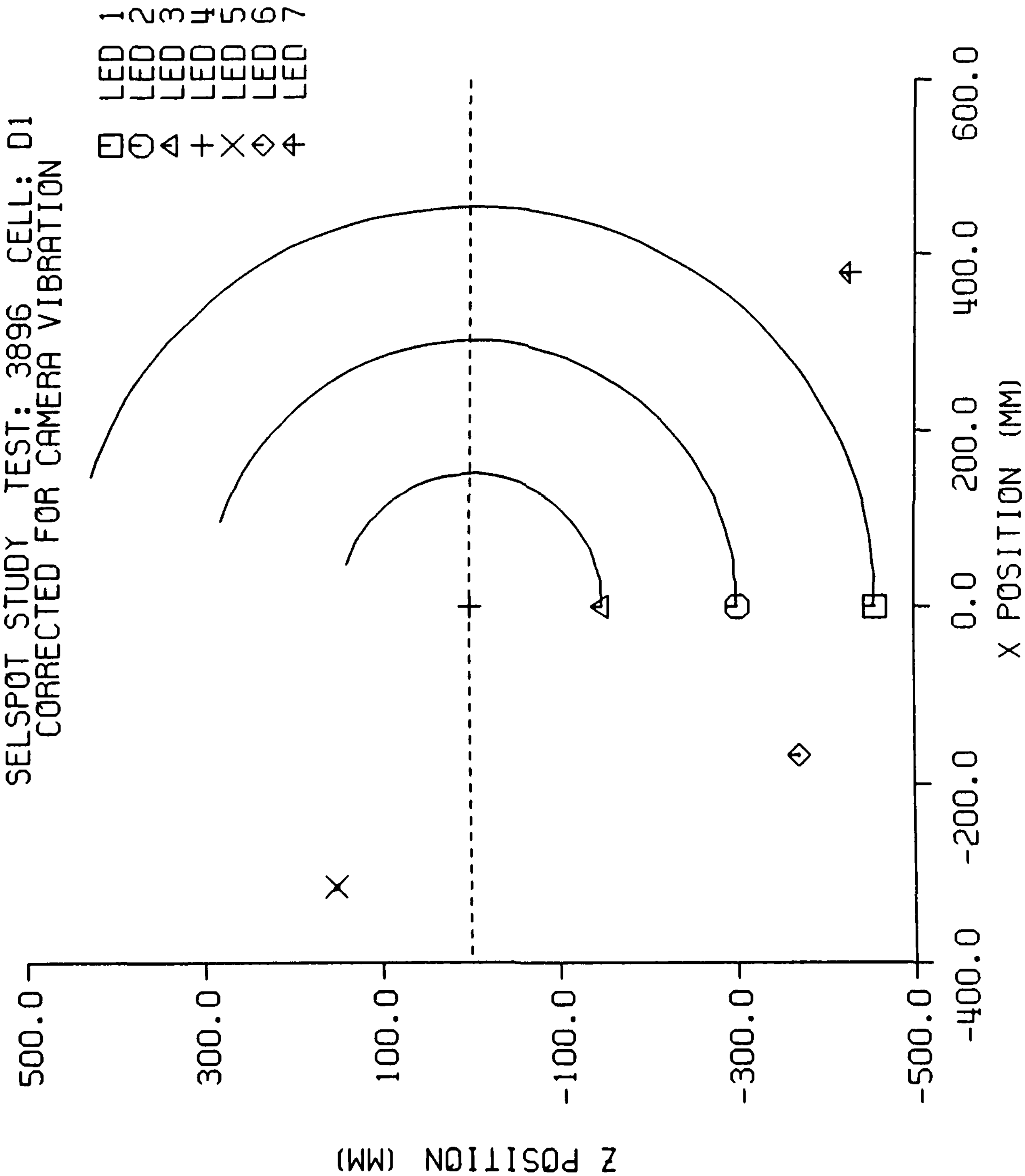

SELSPOT STUDY TEST: 3896 CELL: D1
SLED X ACCEL (G)
SLED Z ACCEL (G)
SLED Y ACCEL (G)
SLED VELOCITY (M/SEC)
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
25.00
-50
0
50
100
150
TIME IN MILLISECONDS



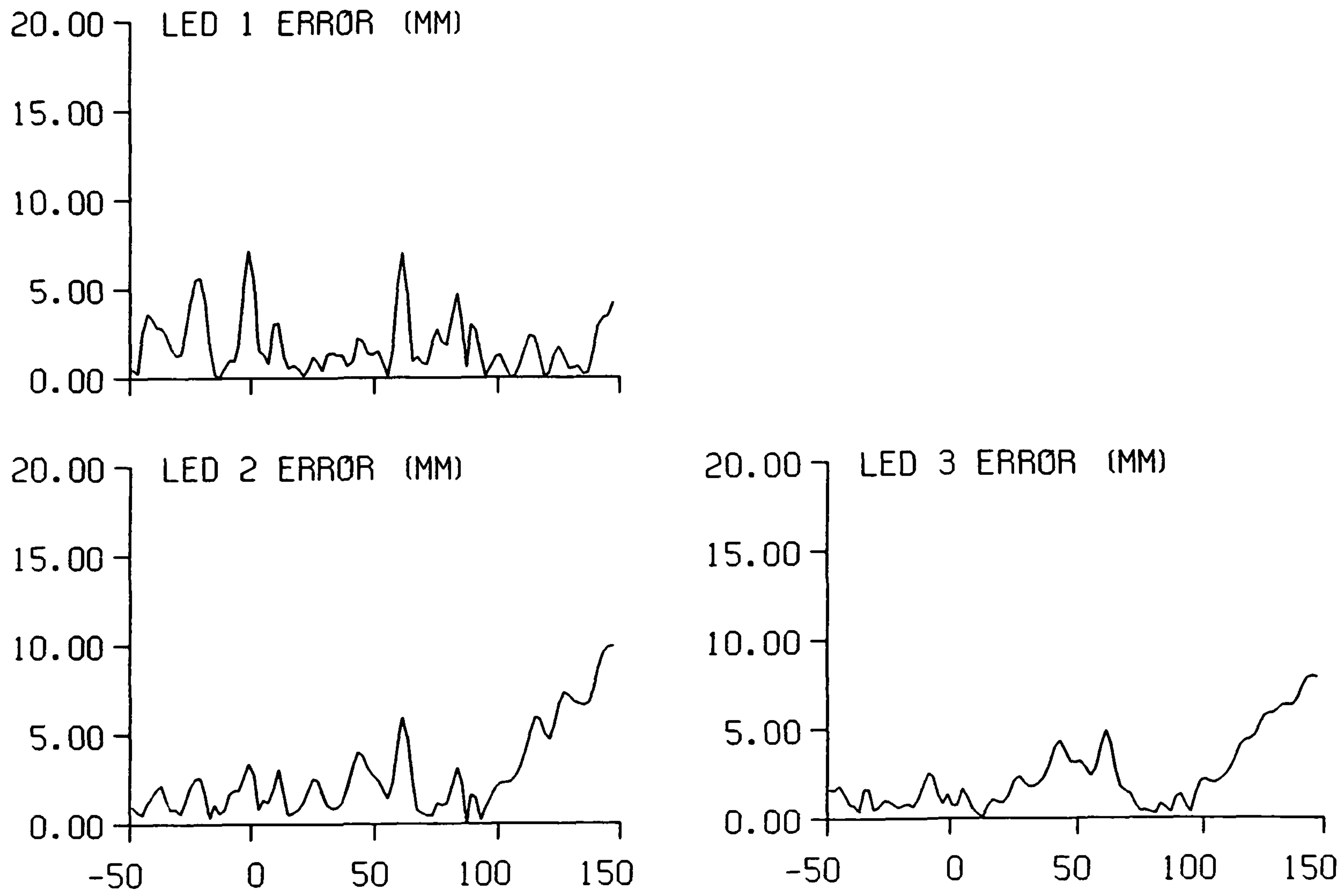
SELSPOT STUDY TEST: 3896 CELL: D1
ANGULAR ACCEL (RAD/SEC2)
1000.0
500.0
0.0
-500.0
-1000.0
-50
0
50
100
150
TIME IN MILLISECONDS

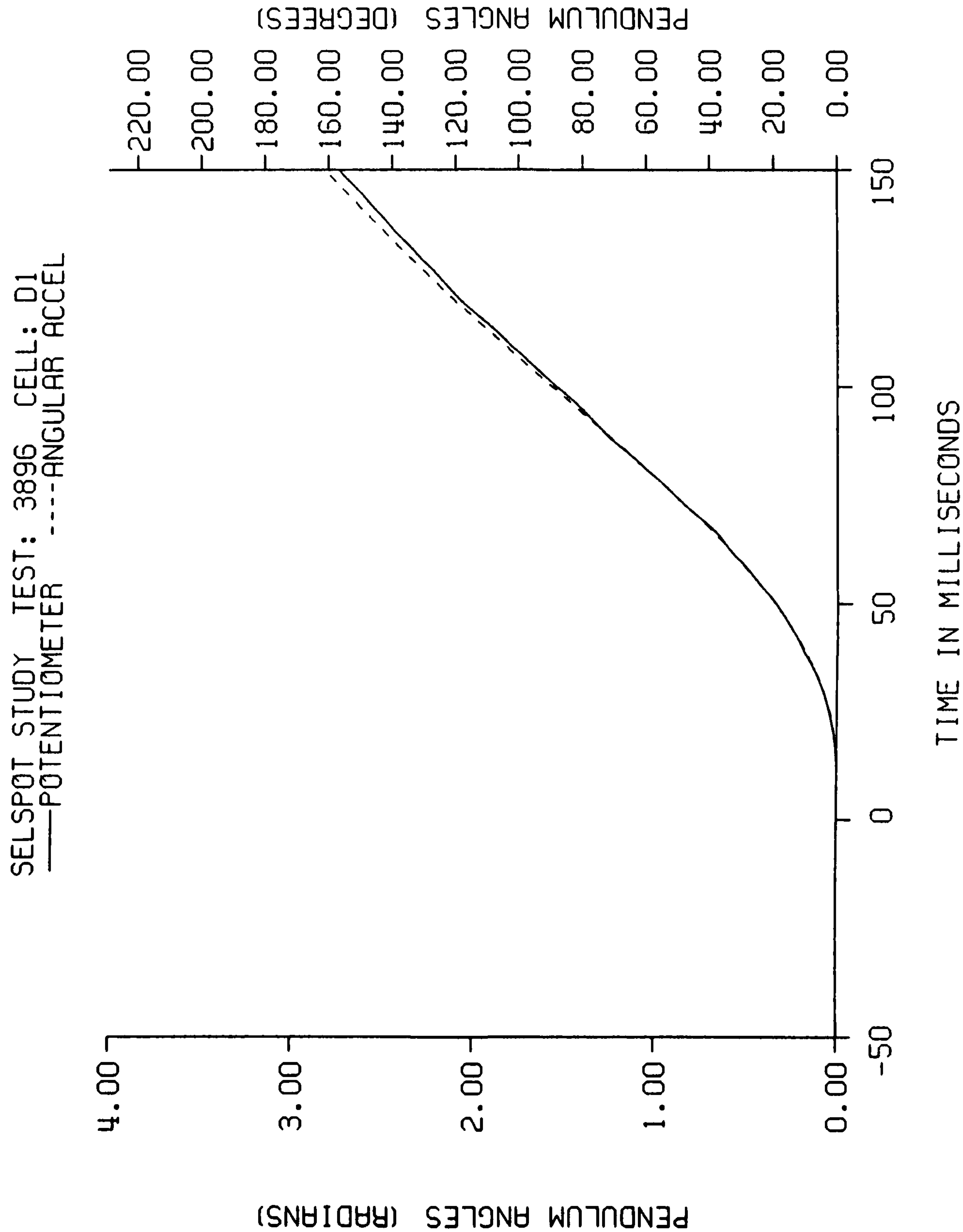


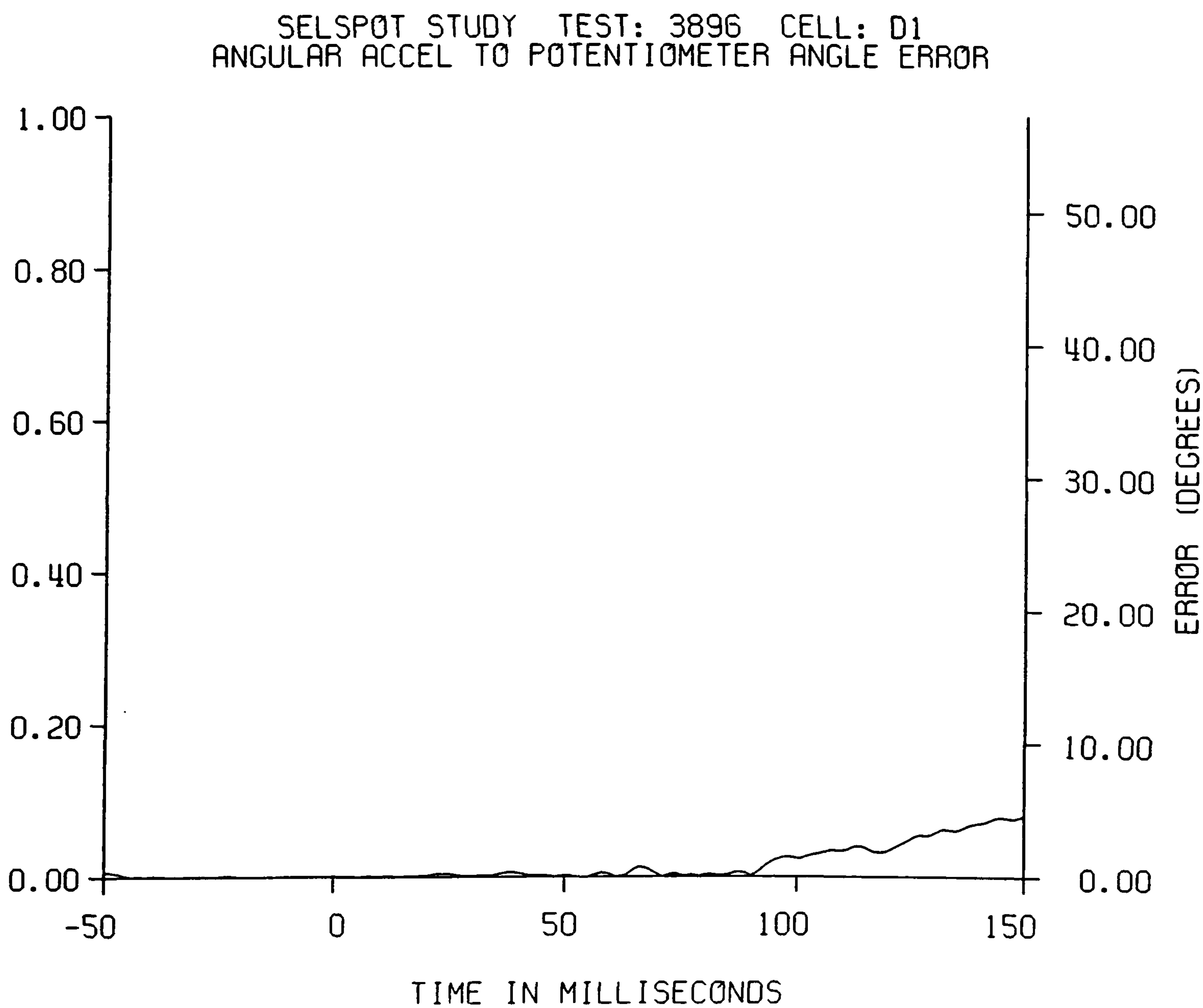
SELSPOT STUDY TEST: 3896 CELL: D1
NOT CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
500.0
300.0
100.0
-100.0
-300.0
-500.0
Z POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0
X POSITION (MM)

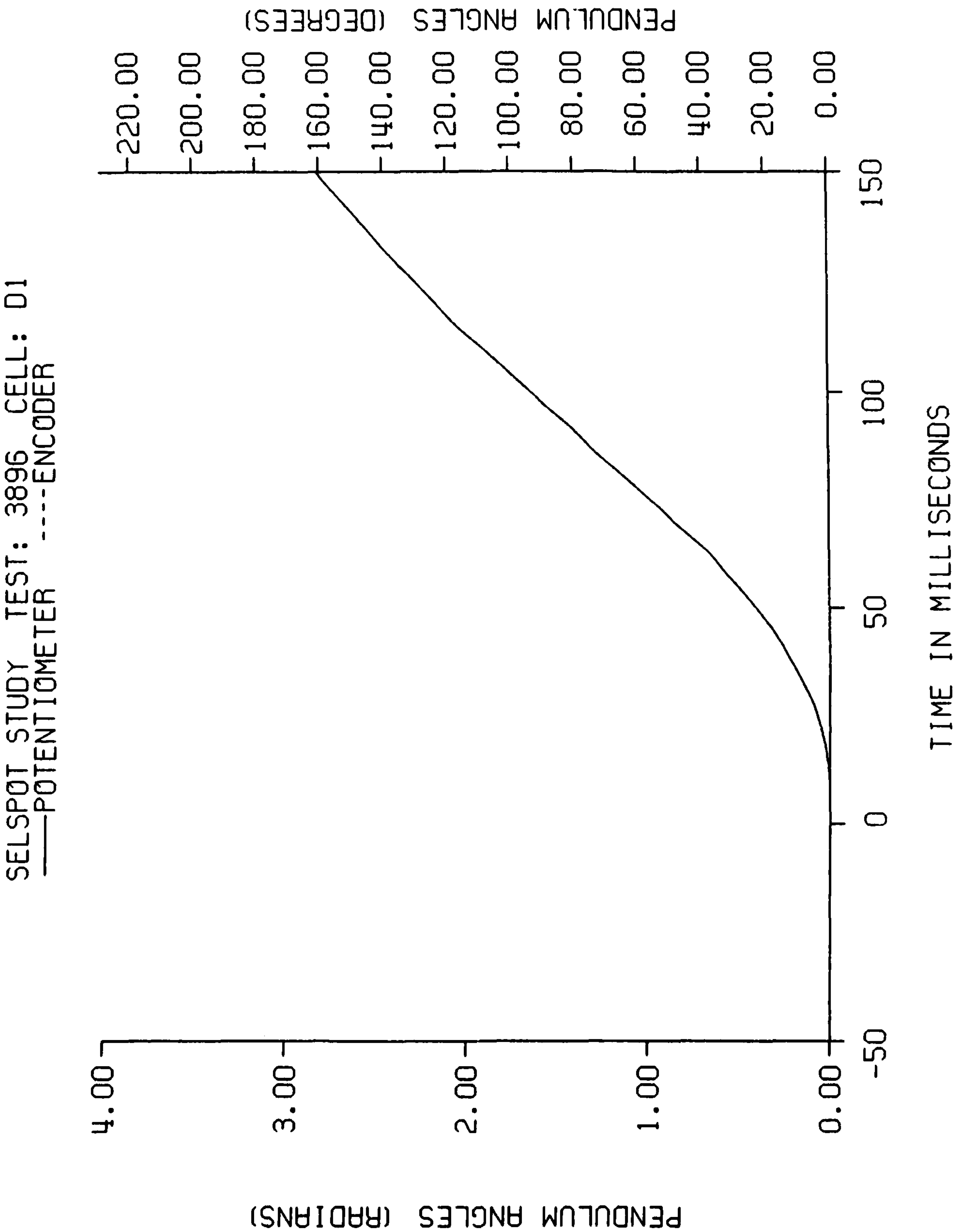

SELSPOT STUDY TEST: 3896 CELL: D1
CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
Z POSITION (MM)
500.0
300.0
100.0
-100.0
-300.0
-500.0
X POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0

SELSPOT STUDY TEST: 3896 CELL: D1
SELSPOT TO POTENTIOMETER DISPLACEMENT ERROR




SELSPOT STUDY TEST: 3896 CELL: D1
——POTENTIOMETER ----ANGULAR ACCEL
PENDULUM ANGLES (DEGREES)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
PENDULUM ANGLES (RADIANS)
0.00
1.00
2.00
3.00
4.00
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY TEST: 3896 CELL: D1
ANGULAR ACCEL TO POTENTIOMETER ANGLE ERROR
ERROR (RADIANS)
1.00
0.80
0.60
0.40
0.20
0.00
ERROR (DEGREES)
50.00
40.00
30.00
20.00
10.00
0.00
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY TEST: 3896 CELL: D1
——POTENTIOMETER ----ENCODER
PENDULUM ANGLES (RADIANS)
0.00
1.00
2.00
3.00
4.00
PENDULUM ANGLES (DEGREES)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
TIME IN MILLISECONDS
-50
0
50
100
150

SELSPOT STUDY TEST: 3911 NOM G: 20.0 CELL: E9

DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
REFERENCE MARK TIME (MS)				-152.0	
SLED ACCELERATION (G)					
X AXIS	0.07	20.15	-0.44	20.0	148.0
Y AXIS	0.00	2.78	-2.14	34.0	41.0
Z AXIS	1.00	4.41	-0.80	47.0	52.0
SLED VELOCITY (M/SEC)	0.00	15.35	-0.04	151.0	0.0
POTENTIOMETER ANGLE (RAD)	0.00	3.25	0.00	150.0	7.8
POTENTIOMETER DISP (MM)					
AT LED 1		914.38	-0.79	144.0	8.0
AT LED 2		609.59	-0.53	144.0	8.0
AT LED 3		304.80	-0.26	144.0	8.0
ANGULAR ACCEL (RAD/SEC2)	-0.86	3463.75	-1034.24	152.0	44.0
ANG ACCEL ANGLE (RAD)	0.00	3.33	0.00	150.0	7.0
LED 1 POSITION (MM)					
X AXIS		458.05	-70.37	84.0	150.0
Y AXIS		20.90	-16.03	98.0	60.0
Z AXIS		452.95	-459.15	140.0	2.0
LED 1 DISPLACEMENT (MM)		909.98	3.00	140.0	2.0
LED 1 DISP ERROR (MM)		9.01	0.00	146.0	150.0
LED 2 POSITION (MM)					
X AXIS		303.41	-48.18	84.0	150.0
Y AXIS		14.06	-11.13	128.0	60.0
Z AXIS		299.58	-301.78	142.0	2.0
LED 2 DISPLACEMENT (MM)		599.04	0.94	140.0	6.0
LED 2 DISP ERROR (MM)		13.71	0.00	146.0	150.0
LED 3 POSITION (MM)					
X AXIS		151.10	-23.72	84.0	150.0
Y AXIS		16.41	-5.31	150.0	58.0
Z AXIS		149.99	-147.93	140.0	2.0
LED 3 DISPLACEMENT (MM)		297.38	1.35	140.0	2.0
LED 3 DISP ERROR (MM)		8.90	0.00	144.0	150.0
LED 4 POSITION (MM)					
X AXIS		0.88	-1.83	142.0	24.0
Y AXIS		71.49	65.39	140.0	146.0
Z AXIS		3.19	-0.01	132.0	50.0

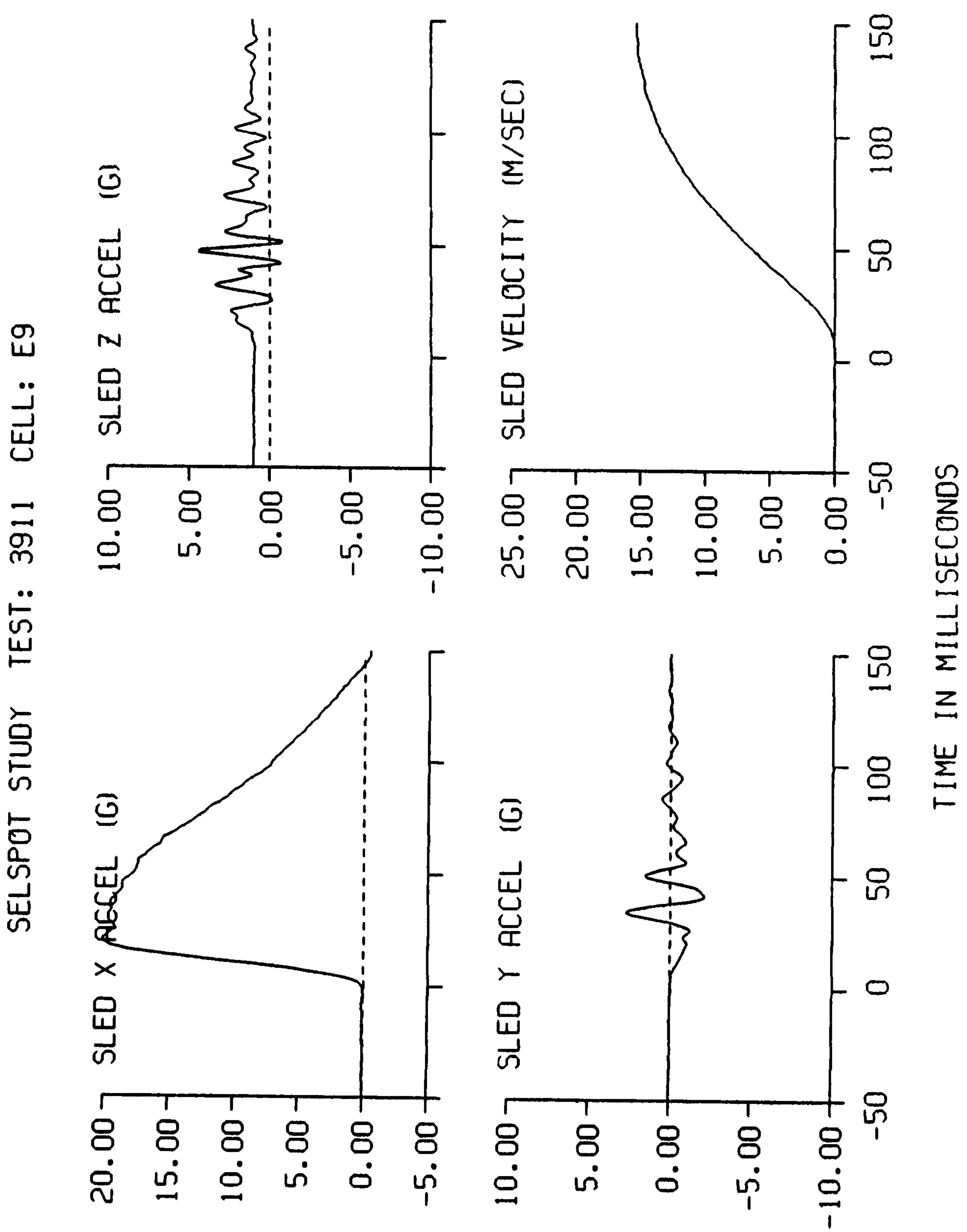
Page 1 of 2

SELSPOT STUDY TEST: 3911 NOM G: 20.0 CELL: E9

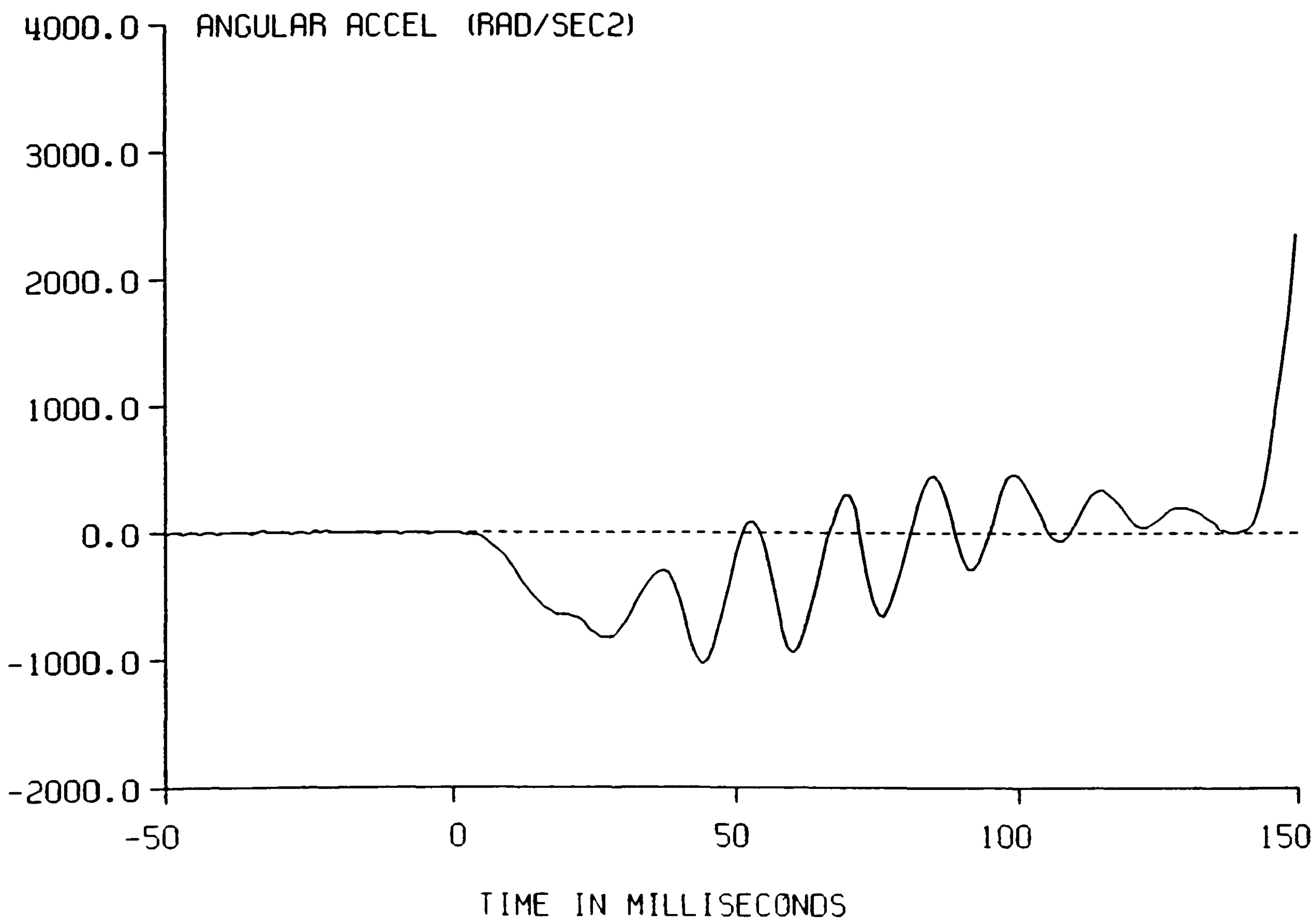
DATA ID	IMMEDIATE PREIMPACT	MAXIMUM VALUE	MINIMUM VALUE	TIME OF MAXIMUM	TIME OF MINIMUM
LED 5 POSITION (MM)					
X AXIS		-310.68	-316.09	126.0	42.0
Y AXIS		207.19	193.55	118.0	42.0
Z AXIS		155.60	152.37	8.0	72.0
LED 6 POSITION (MM)					
X AXIS		-169.14	-172.18	110.0	76.0
Y AXIS		214.45	207.94	10.0	52.0
Z AXIS		-370.47	-372.76	70.0	38.0
LED 7 POSITION (MM)					
X AXIS		378.78	374.74	126.0	44.0
Y AXIS		205.01	195.61	42.0	120.0
Z AXIS		-425.09	-431.17	36.0	132.0
ANGLE ERROR (RADIANS)		0.13	0.00	150.0	16.0

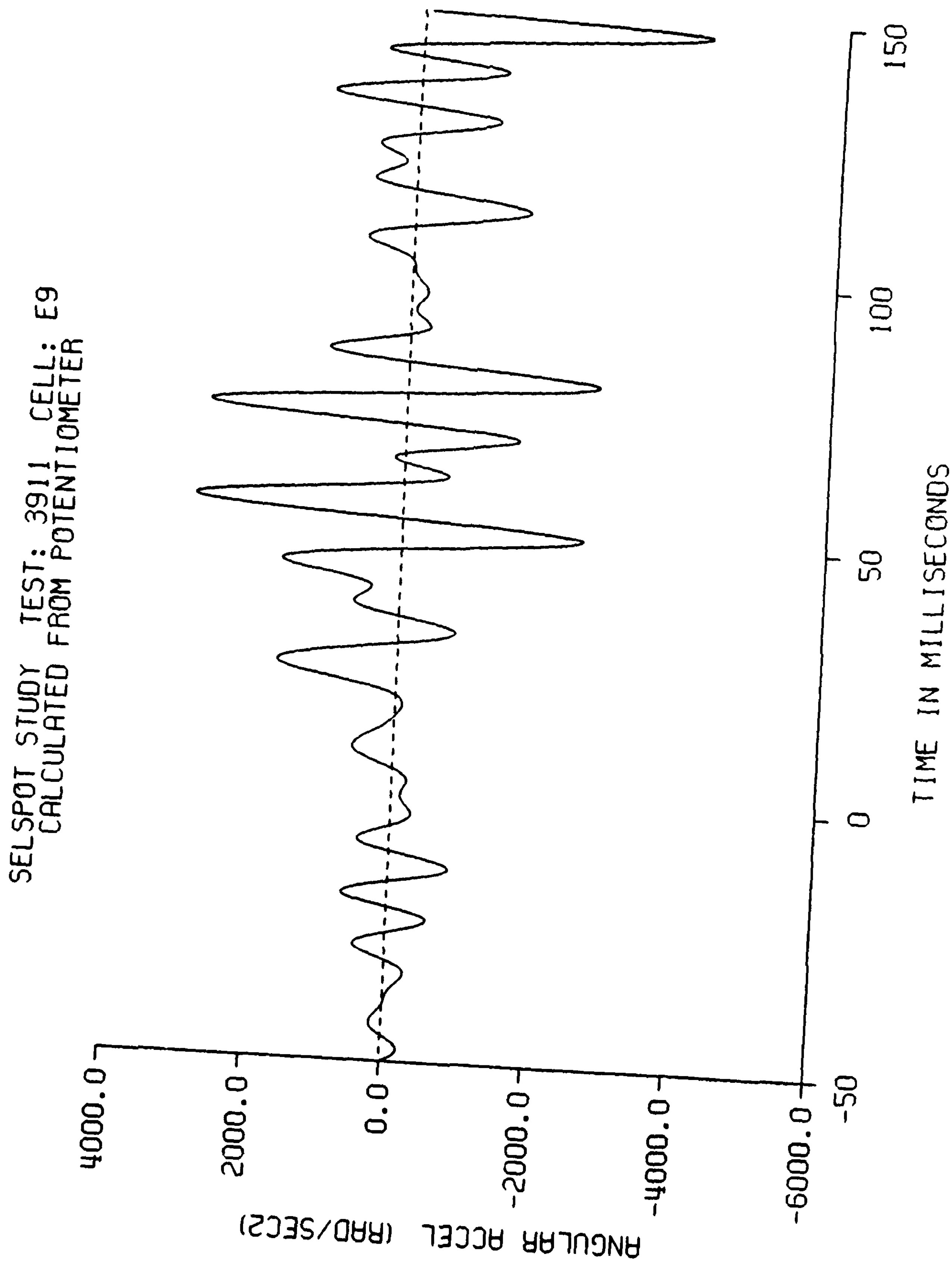
Page 2 of 2

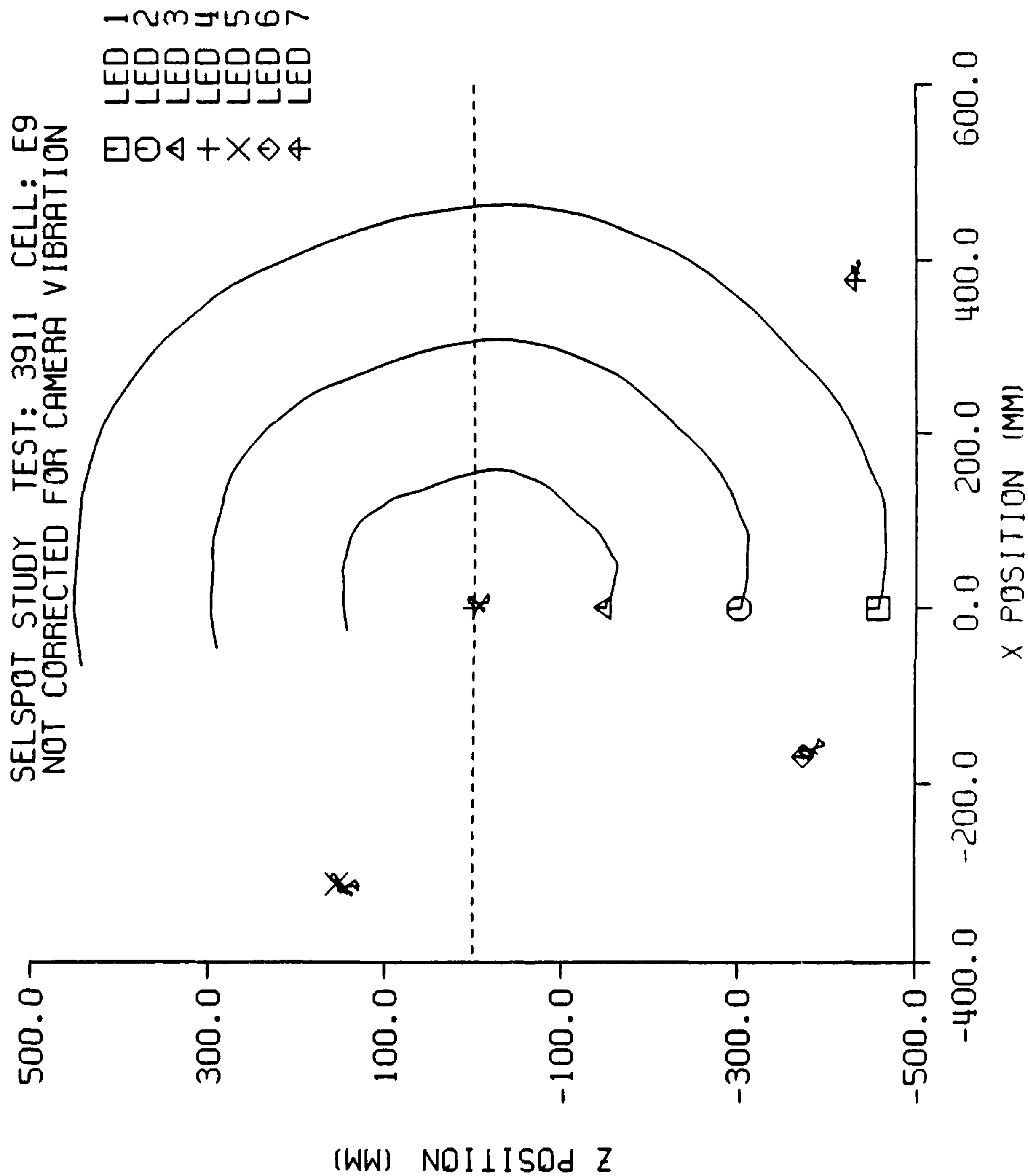
	DISPLACEMENT ERROR			ANGLE ERROR	
TIME (MS)	LED 1-POT (MM)	LED 2-POT (MM)	LED 3-POT (MM)	TIME (MS)	ANG ACC-POT (RADIANS)
0.00	2.4369	3.4616	0.3003	0.00	0.0018
2.00	2.9692	2.6459	1.3093	2.00	0.0035
4.00	3.4075	1.8771	2.2357	4.00	0.0022
6.00	4.0627	1.3204	2.5270	6.00	0.0008
8.00	3.8108	3.4670	2.1289	8.00	0.0008
10.00	3.9131	4.4413	2.0303	10.00	0.0001
12.00	4.3675	1.9360	2.5302	12.00	0.0015
14.00	2.9648	1.6728	2.8877	14.00	0.0023
16.00	1.0196	2.0152	2.7686	16.00	0.0001
18.00	1.4219	1.5436	2.9395	18.00	0.0023
20.00	2.9082	1.3768	2.9303	20.00	0.0011
22.00	4.6965	1.8301	2.9397	22.00	0.0007
24.00	5.3633	2.9910	2.5414	24.00	0.0045
26.00	5.7962	4.3731	2.9101	26.00	0.0096
28.00	6.2440	5.1984	3.7519	28.00	0.0127
30.00	5.4100	5.2105	4.1068	30.00	0.0144
32.00	3.6153	4.9189	4.5124	32.00	0.0117
34.00	2.5176	4.8095	4.8035	34.00	0.0052
36.00	2.8204	4.6574	4.9673	36.00	0.0025
38.00	3.3115	4.0323	4.7537	38.00	0.0052
40.00	2.9532	3.3254	4.2321	40.00	0.0079
42.00	2.4697	3.4915	4.0112	42.00	0.0076
44.00	2.5446	4.1937	3.9355	44.00	0.0080
46.00	1.6858	3.3727	3.2635	46.00	0.0113
48.00	1.4973	0.2042	1.6377	48.00	0.0122
50.00	4.4900	2.4842	0.2205	50.00	0.0060
52.00	3.1535	1.3655	0.7152	52.00	0.0021
54.00	2.0291	2.6283	2.9022	54.00	0.0018
56.00	5.4613	5.0536	4.5604	56.00	0.0043
58.00	3.6739	3.6534	4.1687	58.00	0.0139
60.00	0.1605	0.9073	2.6971	60.00	0.0221
62.00	1.4830	0.2163	1.8111	62.00	0.0207
64.00	0.9216	0.4950	1.2683	64.00	0.0148
66.00	2.0268	2.1054	0.0600	66.00	0.0098
68.00	4.2477	4.0140	1.5417	68.00	0.0087
70.00	3.5443	3.2785	1.3144	70.00	0.0086
72.00	0.2137	0.1982	0.6937	72.00	0.0076
74.00	1.9869	1.3977	2.1359	74.00	0.0101
76.00	0.7875	0.3915	1.4032	76.00	0.0165
78.00	4.4735	3.2100	0.5316	78.00	0.0209
80.00	4.8698	4.2600	1.8904	80.00	0.0177
82.00	2.6331	3.5912	2.0870	82.00	0.0113
84.00	0.7645	2.6058	1.5313	84.00	0.0103
86.00	0.0056	1.8122	0.6803	86.00	0.0182
88.00	0.4614	1.3298	0.0201	88.00	0.0287
90.00	0.4642	1.6513	0.0610	90.00	0.0348
92.00	0.3583	2.6748	0.6372	92.00	0.0369
94.00	0.9313	3.2645	1.0280	94.00	0.0394
96.00	0.3523	3.0866	1.1483	96.00	0.0439
98.00	0.0428	3.4513	1.7196	98.00	0.0490
AVERAGE	2.6749	2.7499	2.2756		0.0118
STANDARD DEV	1.7170	1.4248	1.4127		0.0119

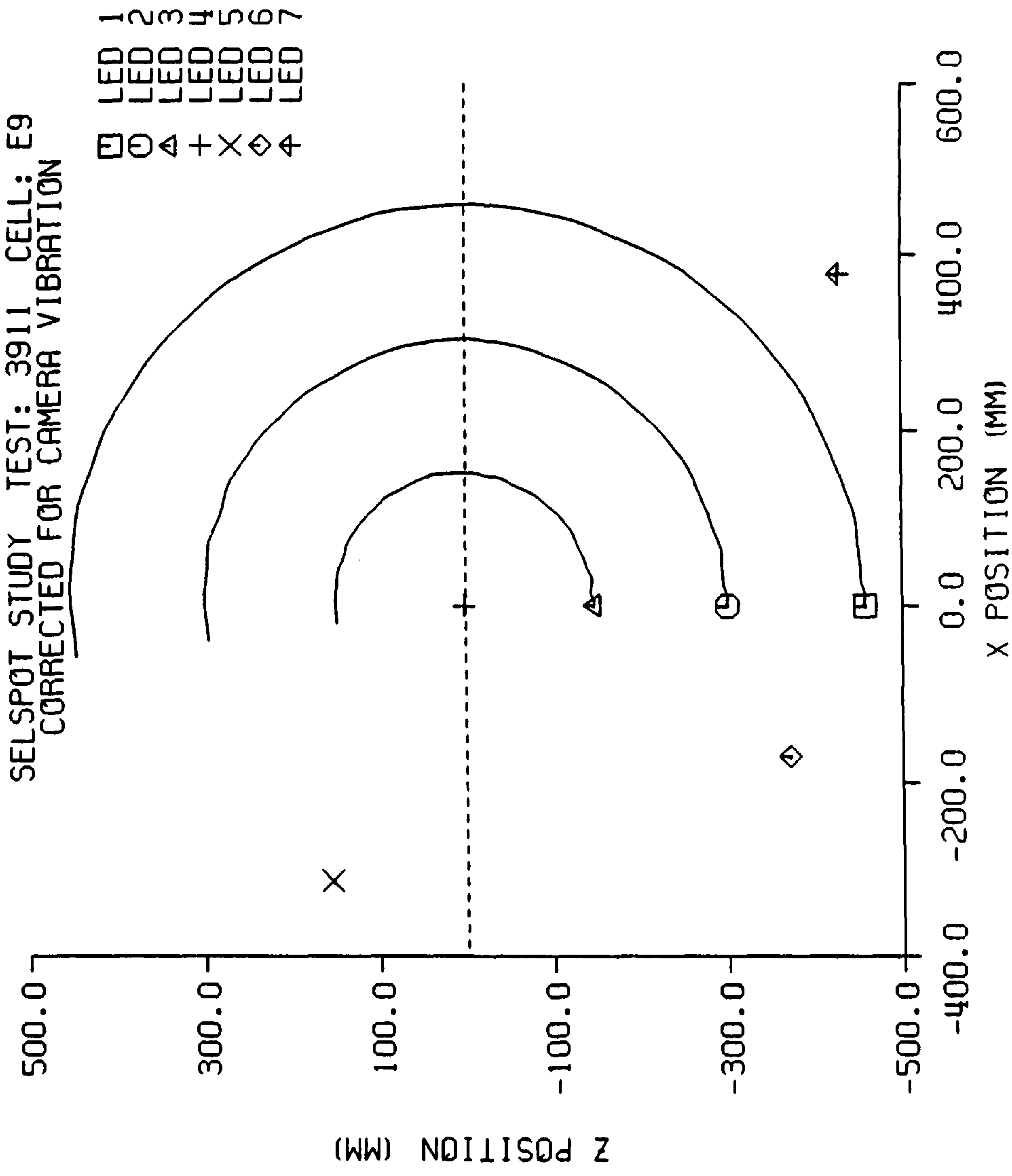

SELSPOT STUDY TEST: 3911 CELL: E9
SLED X ACCEL (G)
SLED Z ACCEL (G)
SLED Y ACCEL (G)
SLED VELOCITY (M/SEC)
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
25.00
-50
0
50
100
150
TIME IN MILLISECONDS

SELSPOT STUDY TEST: 3911 CELL: E9

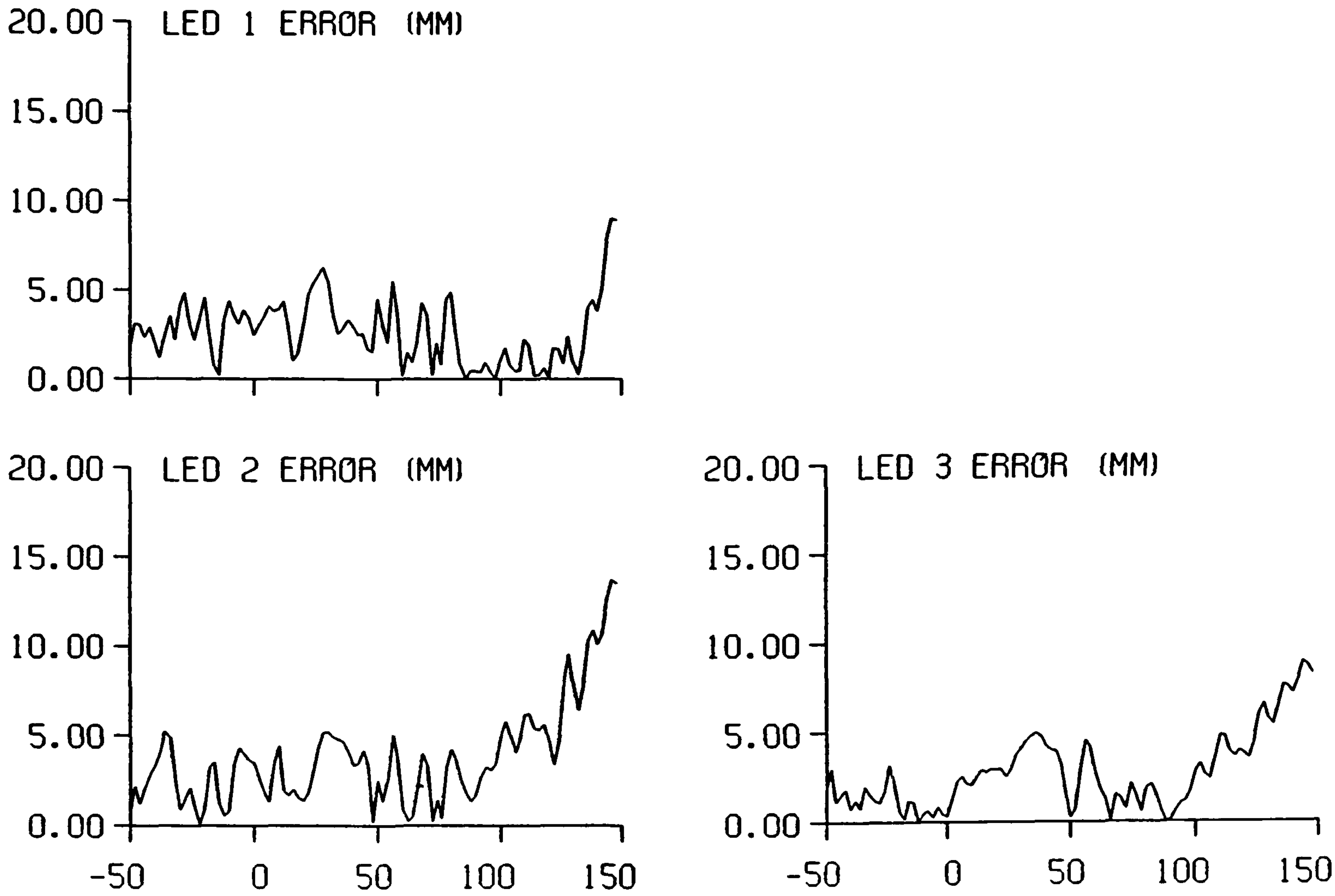


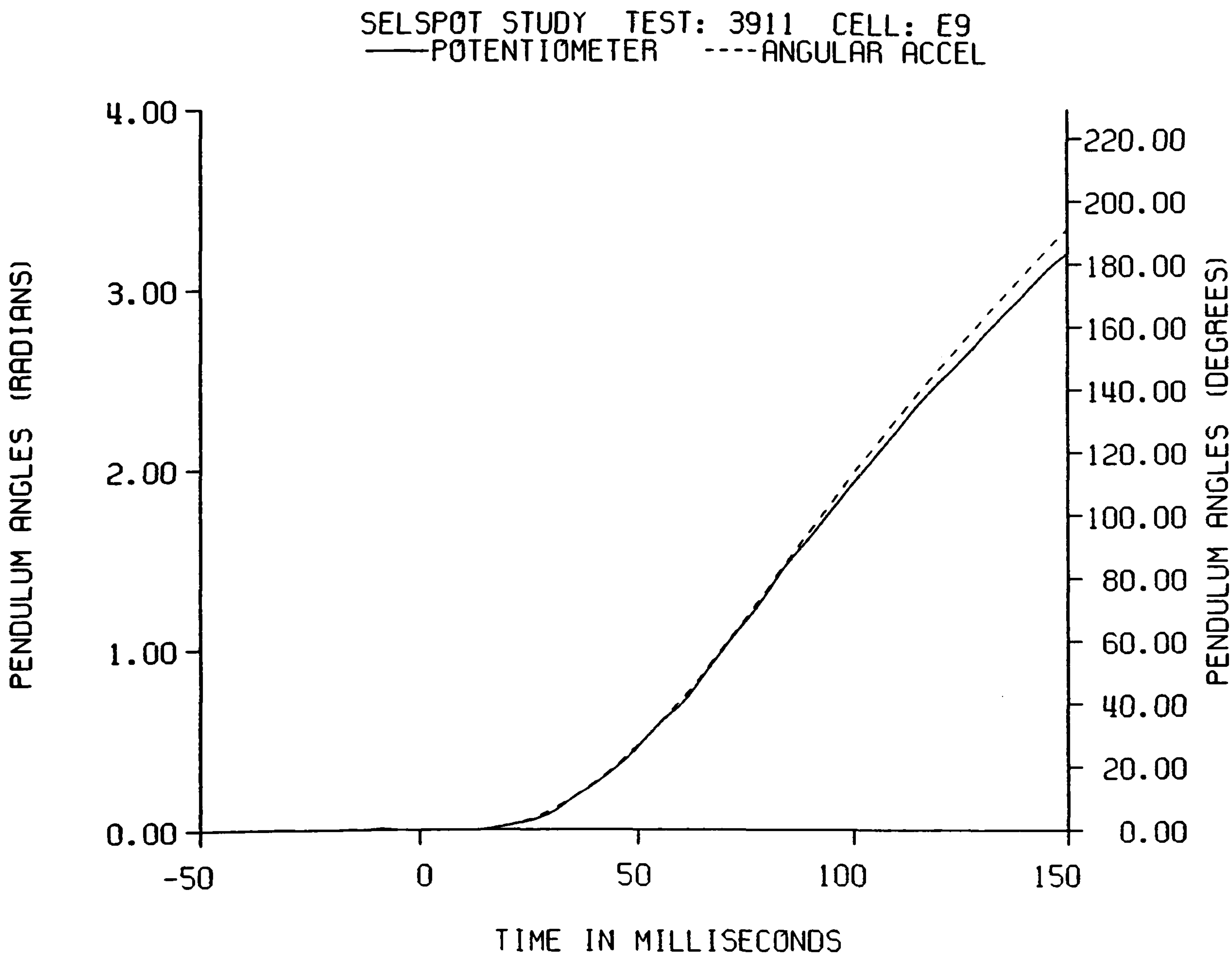

SELSPOT STUDY TEST: 3911 CELL: E9
CALCULATED FROM POTENTIOMETER
4000.0
2000.0
0.0
-2000.0
-4000.0
-6000.0
ANGULAR ACCEL (RAD/SEC2)
-50
0
50
100
150
TIME IN MILLISECONDS

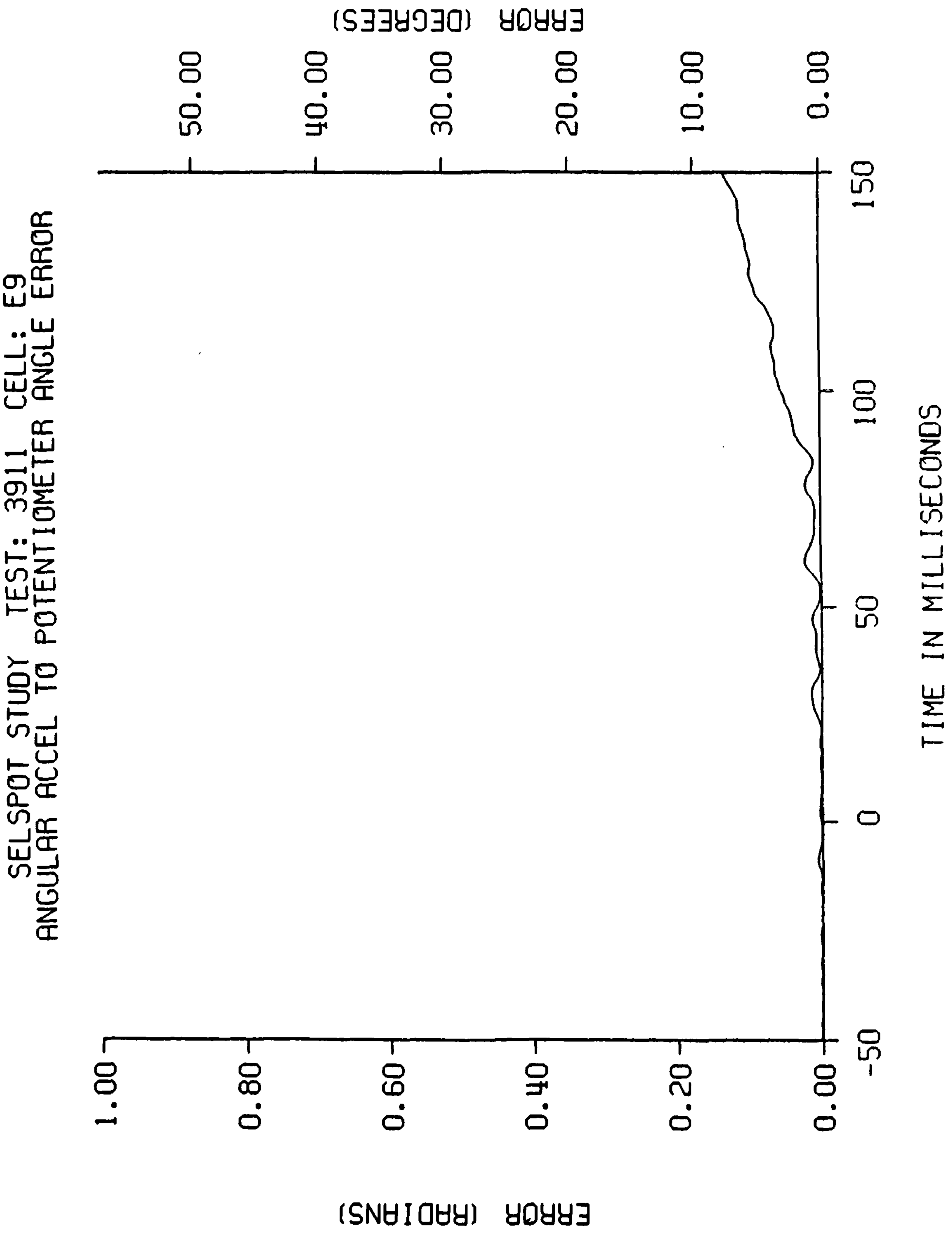

SELSPOT STUDY TEST: 3911 CELL: E9
NOT CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
500.0
300.0
100.0
-100.0
-300.0
-500.0
Z POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0
X POSITION (MM)

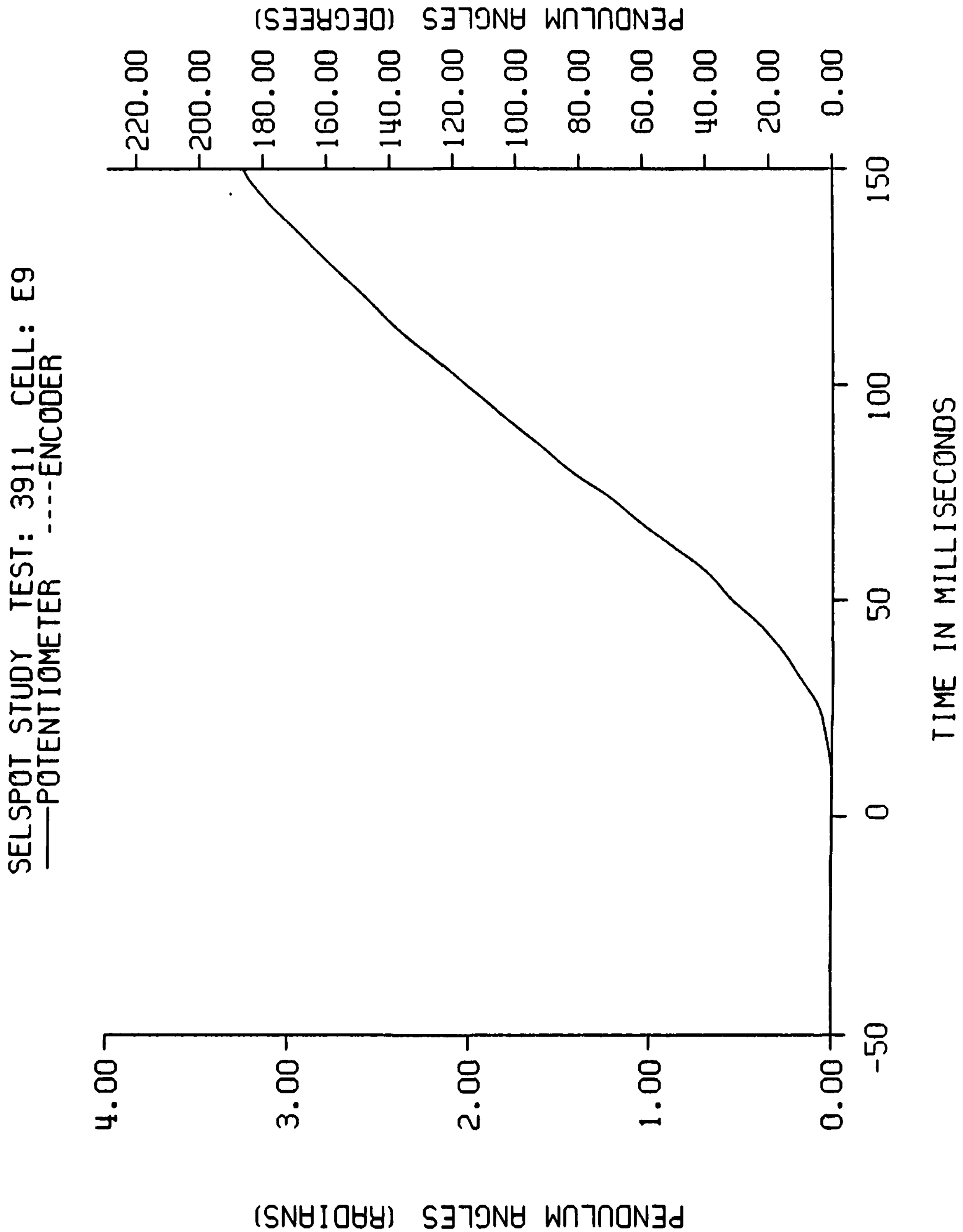

SELSPOT STUDY TEST: 3911 CELL: E9
CORRECTED FOR CAMERA VIBRATION
LED 1
LED 2
LED 3
LED 4
LED 5
LED 6
LED 7
Z POSITION (MM)
500.0
300.0
100.0
-100.0
-300.0
-500.0
X POSITION (MM)
-400.0
-200.0
0.0
200.0
400.0
600.0

SELSPOT STUDY TEST: 3911 CELL: E9
SELSPOT TO POTENTIOMETER DISPLACEMENT ERROR




SELSPOT STUDY TEST: 3911 CELL: E9
——POTENTIOMETER ----ANGULAR ACCEL
4.00
3.00
2.00
1.00
0.00
PENDULUM ANGLES (RADIANS)
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
PENDULUM ANGLES (DEGREES)
-50
0
50
100
150
TIME IN MILLISECONDS


SELSPOT STUDY TEST: 3911 CELL: E9
ANGULAR ACCEL TO POTENTIOMETER ANGLE ERROR
ERROR (DEGREES)
50.00
40.00
30.00
20.00
10.00
0.00
ERROR (RADIANS)
1.00
0.80
0.60
0.40
0.20
0.00
-50
0
50
100
150
TIME IN MILLISECONDS



☆ U.S.Government Printing Office:1990—548-018/20213