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ANCON-R.814

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DOC-CR-SP-82-059

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D. A. Staley

September 1982

ANCON Space Technology Corporation

12 Elmbank Road • Thornhill, Ont., Canada L4J 2B7 • Tel. (416) 889-0285

Government of Canada   Gouvernement du Canada

Department of Communications

DOC CONTRACTOR REPORT   DOC-CR-SP-82-059

DEPARTMENT OF COMMUNICATIONS - OTTAWA - CANADA

SPACE PROGRAM

TITLE: INTEGRATION AND TEST REPORT FOR THE TWO-AXIS GYROSCOPE TEST PROGRAM

AUTHOR(S): D. A. Staley
C. H. Hersom

ISSUED BY CONTRACTOR AS REPORT NO: ANCON-R.814

PREPARED BY: ANCON Space Technology Corporation
12 Elmbank Road
Thornhill, Ontario
L4J 2B7

DEPARTMENT OF SUPPLY AND SERVICES CONTRACT NO: 06ST.36100-1-0101

DOC SCIENTIFIC AUTHORITY: Dr. W. S. McMath

CLASSIFICATION: Unclassified

DATE: September 1982

INTEGRATION AND TEST REPORT
FOR THE TWO-AXIS GYROSCOPE
TEST PROGRAM

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INTEGRATION AND TEST REPORT FOR THE TWO-AXIS GYROSCOPE TEST PROGRAM

1.0 INTRODUCTION

1.1 General

This report is a record of the integration and test activities which were conducted during the installation and evaluation of a two-axis gyroscope test system. The system is designed for testing either a single two-axis gyroscope or two single axis gyroscopes. The integration procedures and tests reported here were conducted with two single axis Honeywell GG1111 AJ03 gyros.

1.2 Summary

This project has been directed toward the development of a two-axis test system for application to a tuned rotor gyroscope. The thrust of the activities has been toward spacecraft application where very low rates must be measured and high reliability components are essential. Conventional single axis gyros are not well suited for the vacuum environment and long life requirements of space. The tuned rotor gyro offers the capabilities needed. The space applications will emphasize the need for modern instrumentation techniques including built-in calibration and test capabilities and versatile data interchange with other components. Thus, one aspect of the present development has been the introduction of digital feedback control and data logging capabilities. It has also been recognized that a knowledge of the very low frequency performance capabilities of the instrument is needed to design a drift calibration system for spacecraft application. Thus, a second major aspect of the present development has been the introduction of an extensive time series data analysis system on-line with the test equipment and the use of dedicated equipment for extended duration low frequency tests.

2.0 APPLICABLE DOCUMENTS

The following documents have been generated during the course of the development project and provide useful references during evaluation of the test results.

[1] ANCON-R.813 July 1982 DOC-CR-SP-82-058	Integration and Test Plan For the Two-Axis Gyroscope Test Program
[2] LOGBOOK #2 May 29/1982	Logbook for GG1111 AJ03 Two-Axis Gyroscope Integration and Test. (S/N N0001 and N0002)
[3] ANCON-DS.81.601 September 1981	Specification for the Development of a Two-Axis Gyroscope Electronics Unit
[4] ANCON-DS.81.602 October 1981	Software Development Spec. for a Two-Axis Gyroscope Test Facility
[5] ANCON-R.795 August 1980 DOC-CR-SP-80-002	Test Report for a Gyroscope Test Program
[6] Foundation Electronic Instruments Inc.	Gyroscope Control Unit
[7] Andyne Computing Ltd. D8206-1 August 1982	11/23 Gyroscope Control Program - Users Manual

[8] Andyne Computing Ltd. August 31, 1982 — 11/23 Gyro Control Routines Source Listings

[9] Andyne Computing Ltd. AD8206-002 August 1982 — 11/45 Gyroscope Data Analysis Routines

[10] Andyne Computing Ltd. August 1982 — 11/45 Analysis Routines Source Listings

[11] ANCON-TN.821 September 1982 — A FORTRAN Program for Time Series Filtering and Resampling.

[12] Logbook #1 May 1980 — Logbook for the GG1111 AJ03 S/N 9-1 (CRC 18561) Test and Integration History.

3.0 EQUIPMENT DESCRIPTION

3.1 Single-Axis Gyroscope

The Honeywell GG1111 AJ03 unit is a rate integrating single axis gyroscope. It features a synchronous hysteresis motor, a moving-coil signal generator which produces a linear electrical output proportional to angular displacement of the gimbal, and a moving-coil permanent-magnet torque generator. Silicone fluid is used for flotation and damping.

Basic parameters are as follows:

Spinmotor Frequency		800 Hz
Power Consumption		5 watts maximum
Pickoff Excitation		12.8 KHz
Pickoff Sensitivity		68 millivolts/degree
Scale Factor		1.1 degrees/sec./mamp
Drift Rates:	Fixed	+/- 50 degrees/hr.
	G-Sensitive	12 degrees/hr./g
	Random	4 degrees/hr.

3.2 Two-axis Gyroscope

The Litton CSG unit is a rate integrating two-axis gyroscope. It features a tuned, elastically suspended, rotor with a three phase synchronous-hysteresis motor, two variable reluctance differential transformers which produce linear electrical outputs proportional to angular displacements of the two gimbal axes, and two permanent magnet torque generators. No damping fluid is required as the motor and rotor are dynamically uncoupled at resonant frequency. A thermistor is included to monitor unit temperature.

Basic parameters are as follows:

Spinmotor Frequency		408 Hz
Power Consumption		3 watts
Pickoff Excitation		54 KHz
Pickoff Sensitivity		1.3 Vrms/mrad (22.7 Vrms/deg)
Scale Factor		1400 deg/hr./ma (.39 deg/sec./ma)
Drift Rates:	Non g-sensitive	+/-3.0 degrees/hr.
	G-sensitive	+/-10.0 degrees/hr.
	Random deviation	0.005 degrees/hr.

3.3 Rate Table

A precision rate table, installed in the controls laboratory of the Communications Research Centre, was used for the tests. It is a two-axis table manufactured by Contraves-Goerz Corp., model number 57CD/30H. Azimuth range is 0-360 degrees continuous and elevation range is +/-185 degrees. Rate range is 0-1000 degrees/sec. or 0-1000 times the earth rate. Both position and rate modes are available for the azimuth but only the position mode may be used for elevation. Resolution is .0001 degree and .001 deg/sec. The table has 110 slip rings, sixteen of which have a capacity of 5 amps and the remaining are rated at 1 amp.

3.4 Gyro Control Unit

The GCU, manufactured by Foundation Electronic Instruments Limited, consists of two separate boxes. The main box is a rack-mounted unit containing the loop closure electronics, computer interface and torquer pulse time (T levels) generator. A remote box is mounted on the rate table along with the gyro and contains the H-switches to generate the torquer current pulses and a pre-amplifier to boost the gyro pickoff secondary output prior to transmitting this signal through the table slip rings.

Drive signals for the gyro spinmotor and the excitation for the gyro pickoff are generated externally by auxillary test equipment.

The pickoff excitation is used by the GCU to provide a synchronous demodulation of the pickoff secondary. The demod output is filtered to produce a dc voltage proportional to gyro angular error. This voltage is sampled by the computer via an A/D and is used as the digital error signal in the control algorithm. Outputs of the algorithm are numbers which represent the positive, negative and zero torquer current pulse widths to be delivered to the gyro in order to correct the detected error.

In the Computer mode of operation, the control algorithm is implemented by the computer. When in the Auto mode of operation, the digital error is loaded directly into the counter registers which generate the T times. Compensation can be switched In or Out to affect the analog portion of the error processing.

The digital error is a 12 bit number in offset binary code. The torquer pulse counts are 16 bit binary numbers with a range of 0-65535 counts. The GCU clock is 10 megahertz. There are four T times implemented in the electronics:

T1 - positive current on-time.

T2 - zero current on-time after positive pulse.

T3 - negative current on-time.

T4 - zero current on-time after negative pulse.

A fifth T time is the sum of the other four times and represents the total period of the cycle. This T5 value is implemented in the test software.

The GCU is a two-axis unit with duplicate electronics for error processing and T time generation. Channels are combined into a common computer interface.

3.5 Computer Facility

The computers of the Hybrid Computer Facility at CRC were used for the test program. An LSI-11/23 computer was used to conduct the tests and interface with the GCU. A DMA link to a PDP-11/45 was used to transmit test data periodically for storage and off-line processing. The computer programs for the LSI-11/23 and PDP-11/45 computers were designed and implemented by Andyne Computing Limited.

4.0 INTEGRATION AND TEST OF SINGLE-AXIS GYRO(S)

The following sections describe the integration checks and the performance test of two single-axis gyros.

4.1 Inspection of a Used AJ03 Gyro

The original gyro used in the 1980 tests, Serial Number U-1, was reinspected as described in Section 6.1 of the Test Plan (Reference [1], ANCON-R.813). The bonding check indicated that there was no bonding of Pin 2 to the case. The isolation check was successful and the measured DC resistance values are presented below. The column marked "Former" refers to the results reported in Reference [5].

	Present	Former
a) Torquer coil	88.3 ohms	89 ohms
b) Pickoff secondary	337 ohms	341 ohms
c) Pickoff primary	87.6 ohms	88 ohms
d) Phase 1 spin motor	9.2 ohms	
e) Phase 2 spin motor	9.3 ohms	

While using this unit in preliminary investigations, it failed to start. The spin motor circuit indicated continuity, and voltage and current appeared normal, but the spin motor did not turn. Hence this unit was declared unserviceable and two new AJ03 units were unpacked and inspected. Their Serial Numbers were N0001 and N0002.

The inspection tests of Section 6.1 were repeated for each gyro in turn. Bonding and isolation checks were affirmative. It was noted that these gyros reflected a design change which incorporated a bonding strap from

Pin 2 to the case. The measured DC resistance values for each unit are presented below along with the corresponding specification values:

	Serial Number N0002	Serial Number N0001	Specification Value
a) Torquer coil	79.2	85.3	132 ohms maximum
b) Pickoff secondary	329	314	340 +/-20% ohms
c) Pickoff primary	99.2	101.8	96 +/-20% ohms
d) Phase 1 spin motor	9.1	8.7	Reference
e) Phase 2 spin motor	9.9	9.7	Reference

4.2 Gyro/GCU Checkout

The tests reported in this section were repeated for each of the new gyros. The configuration used the single gyro fixture mounted to the table such that the input axis of the gyro was parallel to the table azimuth axis. The table was tilted to give one earth rate instead of zero earth rate as required by the test plan. This change in the procedure was an oversight but does not invalidate the test results. The nature of the tests described below is largely qualitative and, with the exception of the null amplitude measurements, the gyro data is similar to that obtained with Serial Number U-1 in the 1980 tests.

4.2.1 Spin Motor Start-up

A current probe was used with a storage oscilliscope to monitor and display the spin motor current. Peak-to-peak current values were measured from photographs taken during start-up and continuous operation. Division by 2.8 provided the data presented in Appendix A, Section A.1.

4.2.2 Pickoff Output

Strip chart recordings of the responses of the gyros to table rate inputs indicate normal behaviour. However, it was noted that Serial Number N0002 gyro had a null amplitue of only -16.6 dbV (about 2 mV rms after dividing by the preamplifier gain of 38 and the bandpass filter gain of 1.7) whereas Serial Number N0001 gyro had a null of -28.2 dbV (0.6 mV rms). After discussions with John Sinkiewicz of Draper Laboratories, a resistor was selected to shunt the excitation primary; the result was a null of -26.3 dbV (0.8 mV rms). A discussion of this adjustment will be presented in Section 5.

Null amplitude data is presented in Appendix A, Section A.2. In addition, the amplitudes of the secondary outputs (measured at the output of the bandpass filter) are recorded here and, assuming a pickoff sensitivity of 68 mV/deg, the angular positions of the positive and negative stops are calculated.

		Serial Number	
		N0001	N0002
Positive stop,	dbV	+8.7	+14.2
	deg	0.67	1.16
Negative stop,	dbV	+10.5	+13.6
	deg	0.76	1.09

4.2.3 Torquer Characteristics

The open loop response of the gyros in Auto mode was checked using external voltages to simulate the error; it was found to be normal. Each gyro was checked using the corresponding channel of the electronics.

4.2.4 Auto Mode

Using table rate inputs, the response of the gyros in Auto mode was checked and found to be normal. Again, each gyro was checked using the corresponding channel of the electronics.

4.3 Gyro/GCU/Computer Checkout

With the LSI-11/23 connected to the GCU, the test described in Section 4.3.1 was performed using the Serial Number N0001 gyro only; the test described in Section 4.3.2 was repeated for both gyros.

4.3.1 Torque Pulse Count Bits

With the computer operating open loop in Mode 1, torque pulse count numbers, which increase in binary steps from 1 to 32768, were transmitted to T1, T2, T3, and T4. Both X and Y channels were used. The resultant T-times were monitored on the front panel of the GCU and measured with a timer-counter. The results were generally as expected, with occasional errors (four occurrences out of 128). These spurious values appeared as only a single clock period instead of the commanded value. When this happened, the remaining T-times measured for the command were usually normal. It seemed that the front panel test points were susceptible to trigger noise and that the correct pulse was being transmitted to the gyro.

4.3.2 Open Loop Response

The response of both gyros was recorded open loop in Computer mode, using values of T1 and T3 to yield a net positive and negative torquer current. Data recorded on the strip charts appeared to be normal.

4.4 Inspection of New AJ03 Units

As a result of the failure of the U-1 gyro, this inspection was performed earlier than planned. The report has been presented in Section 4.1 above.

4.5 Two Gyros/GCU Checkout

The planned tests (ANCON-R.8139 were not performed because the interfaces and functions had already been checkedd. It will be remembered that the tests discussed in Section 4.2 were done using each of the two units and the corresponding electronics in turn.

4.6 Two Gyros/GCU/Computer Checkout

The planned tests were not performed for the reasons indicated in Section 4.5 above.

4.7 Two Gyro Performance Tests

The performance tests discussed in Section 6.3 of ANCON-R.813 were done. These tests were based on the proposed selection of tests for the two-axis tuned rotor gyro, CSG. Tests which would be meaningful for the single axis gyros, and which could be adapted and translated into the existing system configuration, were selected from the CSG repertoire. The calculations presented in Appendix A are based on the Litton calculations with appropriate changes, where necessary, to account for the digital method of torquer current measurement and the differences in axis nomenclature.

The results of the tests are presented in Appendix A and the data is discussed in Section 6.3 of this report.

5.0 ADJUSTMENTS AND CALIBRATIONS

The following sections describe adjustments and calibrations which were performed on the system prior to the performance tests referred to in Section 6.3.

5.1 Torquer Coil Matching

Since the electronics generated square wave torquer current pulses as though interfaced with a purely resistive load, the actual delivered current waveform indicated an overshoot as a result of the inductive component of the torquer coil impedance. An impedance matching network was made for each gyro so that the electronics would see an effective resistive load.

The resistance of the torquer coil was measured using a four terminal meter. Then the inductance of the coil was measured using an impedance bridge. A resistor was selected which had a value as close as possible to the internal resistance of the coil. This required carbon resistors to be filed until the value was acceptable. The value of the external capacitor was calculated using the expression

$$C = L/R^2$$

where C is in farads
L is in henrys
R is in ohms.

The values of coil resistance and inductance for the two units are given below:

	Serial Number		
	N0001	N0002	
Coil resistance	83.9	79.2	ohms
Coil inductance	1.65	1.70	millihenrys

Capacitors were selected to provide the calculated value and the networks of external resistance and capacitance in series were installed across the coil at the terminal boards.

5.2 Delays in Torquer Current

Although the matching networks removed the current overshoot, the rise and fall times were not noticeably affected. The following measurements of leading and trailing edge delays were made:

T1:	Leading edge	3.5 microseconds
	Trailing edge	1.5 microseconds
T3:	Leading edge	3.8 microseconds
	Trailing edge	1.4 microseconds

Hence, calibration of the T-times require the following corrections:

T1 actual = T1-20

T2 actual = T2+23

T3 actual = T3-24

T4 actual = T4+21

where T1 through T4 are current pulse counts, each count representing a current pulse of 1.0 milliamp for 100 nanoseconds or 0.1 milliamp-microseconds.

However, since the performance tests for the single-axis gyros were conducted in the binary pulsing mode (only T1 and T3 times), the errors were negligible.

5.3 Plateau in Torquer Current

During the investigations concerning the current waveform it was observed that a plateau of about one microsecond duration occurred during the transition from either positive or negative current to the zero current state. Photographs taken during the investigations clearly show this to be a consistent feature. It is suspected that the fault lies in the switching electronics, but no definitive explanation has yet been proposed. In any case, since the plateau effect is equal and opposite in the two opposing waveforms (T1 and T3), the net result is an error in scale factor but not a bias.

5.4 Pickoff Primary Balance

During the integration check discussed in Section 4.2.2 above, it was noted that the null amplitude of Serial Number N0002 was about 12 db higher than that of Serial Number N0001. It was found that by installing a resistor across the primary input, from Pin 8 to Pin 5, the level of the null amplitude could be reduced. An optimum resistor value of about 15 Kohms was selected. This resistor provides shunting of the primary transformer coil. The result is a current which cancels out circulation currents in the transformer, thereby eliminating the quadrature effect. The Serial Number N0001 gyro unit did not require any such adjustment.

5.5 Pickoff Secondary Phase Adjustment

When the primary input and the secondary output (output of bandpass filter) were displayed on the oscilloscope in the X-Y mode, an elliptical Lissajou figure formed. The gyro was rotated in its gimbals by stimulating the torquer coil with the current from a multimeter set in the 20 Kohm range. The Lissajou figure was observed to rotate from one side to the other about the centre of the ellipse. However, the figure collapsed and apparently inverted as it passed through null (that is, secondary output minimum).

In an attempt to prevent the collapse of the figure and to maintain its shape as it rotated, several values of capacitance were connected across the secondary output, between Pins 10 and 4. The exercise was without success. Since both gyros exhibited the same behaviour, this matter was not pursued further.

5.6 Excitation Frequency Adjustment

The specified value of the excitation frequency is 12.8 kHz. However, the excitation frequency generator in use for these tests was the synthesizer circuitry contained in the single-axis control electronics unit described in Reference [5] (ANCON-R.795). This unit produces 13*1024 = 13.312 kHz because of the nature of its synthesizer. When the excitation source was changed to an Adret synthesizer, the required 12.8 kHz was used. When the analog error output from the MONitor test point was displayed on the oscilloscope and spectrum analyzer, low frequency components were observed. When the excitation frequency was changed slightly, the frequency of the modulation also changed. This seemed to represent a 'beating' effect. Therefore, the excitation frequency was changed until the beat frequency became zero. The excitation frequency was then 13.3337 kHz.

Other frequencies which appeared in the spectrum were 800 Hz from the spin motor excitation, 200 Hz from the fundamental period of the computer (T5), and 250 and 270 Hz to which no source has been attributed. The above-mentioned frequencies are clearly observable and consistent, although the control loop frequency (1/T5) changes with the computer setting.

5.7 Calibration of the Analog Loop

The analog portion of the control loop was calibrated using the following procedure:

a) With the GCU disconnected from all other boxes, connect the oscillator phase-shifted output to the excitation in the breakout box and the unshifted output to the pickoff output of each channel in turn.

b) Set the excitation signal to 14 volts peak-to-peak and the pickoff output to about 1 volt peak-to-peak.

c) Observe the bandpass filter output. (Expect a gain of about 1.7).

d) Observe the Synchronous Demodulator output and adjust the loop gain to get a stable waveform (full wave rectified signal) at phase angles of 0 and 180 degrees.

e) Adjust RV1, one of the five calibration potentiometers on each of the analogue boards (Reference [6] drawing package), to minimize the excitation required to get a good waveform.

f) Measure the DC voltage at the Synch Demod output and adjust RV2 (the second of the five calibration potentiometers) to get symmetry for phases of 0 and 180 degrees.

g) Measure the DC voltage at the inverter output and adjust RV3 to get symmetry for phases of 0 and 180 degrees. (Expect a gain of -1 over the Synch Demod output.)

h) Measure the DC voltage at IC7-6, the output of the compensation network (Reference [6] drawing package), and adjust RV4 to get symmetry for phases of 0 and 180 degrees. (Expect a gain of 1.1 over the Synch Demod output.)

i) Measure the DC voltage at the Low Pass Filter output (labelled MON) and adjust RV5 to get symmetry for phases of 0 and 180 degrees. (Note: there is a gain of 2.2 through the low pass filter).

When checking the calibration later, the inverter and the compensation network were not used in the loop, so that only the adjustments of steps e), f) and i) were performed.

5.8 Calibration of Analog/Digital Converters

The 12 bit A/D converters used to convert the analog error signal from the Low Pass Filter into the digital error data from the computer have a range of 4096 bits. These A/D's are used for a voltage range of +/-5 volts. The computer provides the digital output in the range of -2047 to +2048 counts.

An attempt to calibrate the A/D's by using the extender board seemed to introduce too much noise. The top of the GCU was removed and the potentiometers on the Interface Board were accessed in this way. A precision voltage supply was set to -4.9988 volts (-full scale less 1/2 lsb) and RV2 was adjusted to dither between -2046 and -2047. The supply was then set to +4.9963 (+full scale less 3/2 lsb) and RV1 was adjusted to dither between +2046 and +2047. This latter adjustment proved to be more difficult as there were about 2 bits of noise at the top of the range.

5.9 Alignment of the Gyros

With the two gyros mounted in the fixture on the table, an alignment procedure was attempted as described in the May 20, 1982 memorandum from W. S. McMath (Reference CRC 6657-8). The procedure involved two operations, the first to align the input axes about the output axes, and the second to align the input axes about the spin reference axes. In practical terms, the first operation aligns the spin reference axes with the table azimuth axis and the second aligns the input axes with the table elevation axis. The two gyros were mounted with S/N N0002 as the x-axis and S/N N0001 as the y-axis.

With the table rotating at 20 degrees/second, outputs from the gyros were used to detect the misalignment error. The table was stopped and the gyros rotated in the fixture about their output axes. The table was rotated again to check the result. Note that both gyros indicated a positive error if misaligned in a clockwise direction when viewing down the output axis. The Y-gyro (S/N N0001) could only be adjusted by hand as the spring washer adjustment did not allow motion about the output axis.

The second procedure requires that the elevation lock be removed and that the input axis of the gyro be aligned with the elevation axis. The table is swung around the elevation axis by hand through about 90 degrees of arc. The spring washer mounts were adjusted to minimize the response and slow the time constant, but the two gyros cannot be adjusted independently because of the single fixture holding both. Time constants of the order of one second were attained. The first procedure was repeated and the gyros adjusted by rotation only.

6.0 TESTS

6.1 Inspection Tests for AJ03 Units

The inspection tests were performed on the units with Serial Numbers U-1, N0001 and N0002, and the results are reported in Section 4.1 above.

6.2 Selection of Performance Tests

In order to evaluate the procedures required to test the planned Litton two-axis gyro (CSG), the Litton specification was used as a guide for the selection of the tests for the two single-axis AJ03 units. Some of the tests for the CSG were not applicable to the AJ03 because of the different nature of the units, namely, time constant, resonant frequency, and 1N pickoff modulation. Pickoff scale factor and pickoff offset tests could not be performed using existing equipment. The remaining tests were applied directly, or with appropriate changes in axes. The data reduction was reorganized to take advantage of the digital nature of the torquer current measurements (see Appendix A).

6.3 Performance Tests of Two Single-Axis Gyros

The performance tests described below were conducted despite a discrepency in the test system which introduces a distortion of the time scales. A factor of 2 has been introduced in the results as an approximate compensation. The source of time scale contraction will require resolution before precise time measurements will be possible.

6.3.1 Spin Motor Performance

The differential watt meter for this test failed and the test data, which is presented in Appendix A, Section A.1, was generated using the technique described in Section 4.2.1.

6.3.2 Null Quadrature

The data presented in Appendix A, Section A.2, was obtained using the computer in Mode 2 (closed loop mode). The data indicates a reduction in amplitude of the pickoff null for Serial Number N0002 which resulted from the adjustment described in Section 5.4. The ability of the computer algorithm to maintain the null is also evident.

6.3.3 Torquer Scale Factor

The scale factor test was repeated several times at various times of the day and night. Results were not very consistent. It is apparent from the data reduction that the scale factor is affected by differences of small numbers. It has been noted that although the drift rate is within the specification range, the change in current which results from a change in drift rate is of the order of the current variations measured during the test. Since data must be averaged over about 20 measurements for each of four positions, the time for the test is about 1.5 hours. Overnight data runs indicate that the current changes with time which suggests that there is a temperature effect on the drift rate. Further instrumentation and analysis is recommended.

The data presented in Appendix A, Section A.3, was obtained in late afternoon on a Friday when the vibration environment was quiet and the temperature was quite stable. One gyro indicated almost exactly the specification value of the torquer scale factor while the other gyro was about six percent low. These measured values of K_x and K_y were used throughout the data reduction.

6.3.4 Torquer Axis Misalignment

Misalignment results were generated from the scale factor data described above, and hence have the same reliability. The measured values of less than one degree for misalignment are surprisingly good when one considers that the alignment was done by hand. The data itself is presented in Appendix A, Section A.4.

6.3.5 Drift Rates and Repeatability

Time was taken to perform only three cycles (three power restarts) of the drift rate test. The g-sensitive and non-g-sensitive drift rates determined by this test are within the specification limits and appear to be reasonable. The g-sensitive drift rate is less consistent for the Y-gyro (Serial Number N0001), as is indicated by the higher standard deviation. The data is presented in Appendix A, Section A.5.

6.3.6 Random Drift

The values for random drift are unexpectedly small when compared with the specification value of 4 degrees/hour. The data is presented in Appendix A, Section A.6.

7.0 LONG TERM NOISE TESTS

Two long term noise tests were conducted, one of a little more than 120 hours duration and the second of approximately 40 hours duration. These were identified as T650-6 and T650-11. The first, T650-6 was the long 120 hour test. Some unusual discontinuities are evident within the data plots for the longer tests shown in Figure 7-1 and 7-2 for the X and Y axes respectively. The shorter 40 hour test is shown plotted in Figures 7-3 and 7-4 (the time scale contraction identified in Section 6.3 is evident in these figures). The analysis programs were applied to this data.

The short test, T650-11 contains 487 data points for each of the X and Y axes and these were padded with zeros in the program PERIODOGRAM to 512 points before taking the Fourier Transform. The long tests, T650-6, consist of 1541 data points. Since the computer on which the analysis was conducted will only accept 1024 points for the Fourier Transform, it was necessary to remove the higher frequencies from the data and resample to provide 1024 points.

The SPECTRUM program was then applied. After some experimentation, a small degree of spectrum smoothing was found to provide the most reasonable results and a single pass filter was used with a two point half-width. A calibration factor was also applied to convert from current pulse counts per sample interval to degrees per hour per Hertz. This calibration factor is given by:

$$\frac{T\,(K\ n')^2}{(1.5 \times 10^9)^2}$$

with K the scale factor K_x or K_y obtained in the tests of Section 6.3.3, n' the number of points in the extended data set and T the sample interval. The values used in the data analysis are:

	T	K	n'	calibration factor
T650-11XA	300	3967	512	5.5005E-04
T650-11YA	300	3709	512	4.8083E-04
T650-6XA	300	3967	1024	2.2002E-03
T650-6YA	300	3709	1024	1.9233E-03

The results have been plotted on a log-log scale in Figures 7-5 to 7-8. The solid lines superimposed on these plots show a rough model which appears to fit the data reasonably well. For the shorter test, 11XA and 11YA, the model consists of two terms, a correlated first order noise source and a constant or white noise source. That is:

$$w_g = x_1 + n_2$$

$$\frac{dx_1}{dt} = - B\, x_1 + n_1$$

where w_g is the total random output rate from the gyro, 1/B is a correlation time and n_1 is a random noise component with a mean square value of Q_1 $(deg/hr)^2/Hz$ and n_2 is a noise component with a mean square value of Q_2 $(deg/hr)^2/Hz$. The mean square random noise will then be given by:

$$\frac{B\,Q_1}{2} + \frac{1}{2}\frac{Q_2}{T}$$

The parameter values obtained from the figures are:

T650-11XA

$1/B = 20$ hrs
$Q_1 = 2.3 \times 10^5$ $(\text{deg/hr})^2$ / Hz
$Q_2 = 3.0 \times 10^2$ $(\text{deg/hr})^2$ / Hz
rms drift rate = 1.5 deg/hr

T650-11YA

$1/B = 16$ hrs
$Q_1 = 6.1 \times 10^5$ $(\text{deg/hr})^2$ / Hz
$Q_2 = 1.2 \times 10^4$ $(\text{deg/hr})^2$ / Hz
rms drift rate = 5.0 deg/hr

The spectra for the longer tests show a number of peculiarities. At the higher frequencies, the rapid cut-off above 5×10^{-4} Hz is a result of the resampling operation. The low frequency characteristics indicate the presence of an additional noise source, a second order noise component. This could be a reflection of the discontinuities in the original data or diurnal temperature effects. If this additional term is ignored, and only the first order and constant terms are used, the following results may be obtained:

<u>T650-6XA</u>

$$1/B = 17 \text{ hrs}$$

$$Q_1 = 4.0 \times 10^5 \ (\text{deg/hr})^2 / \text{Hz}$$

$$Q_2 = 8.0 \times 10^2 \ (\text{deg/hr})^2 / \text{Hz}$$

$$\text{rms drift rate} = 2.1 \ \text{deg/hr}$$

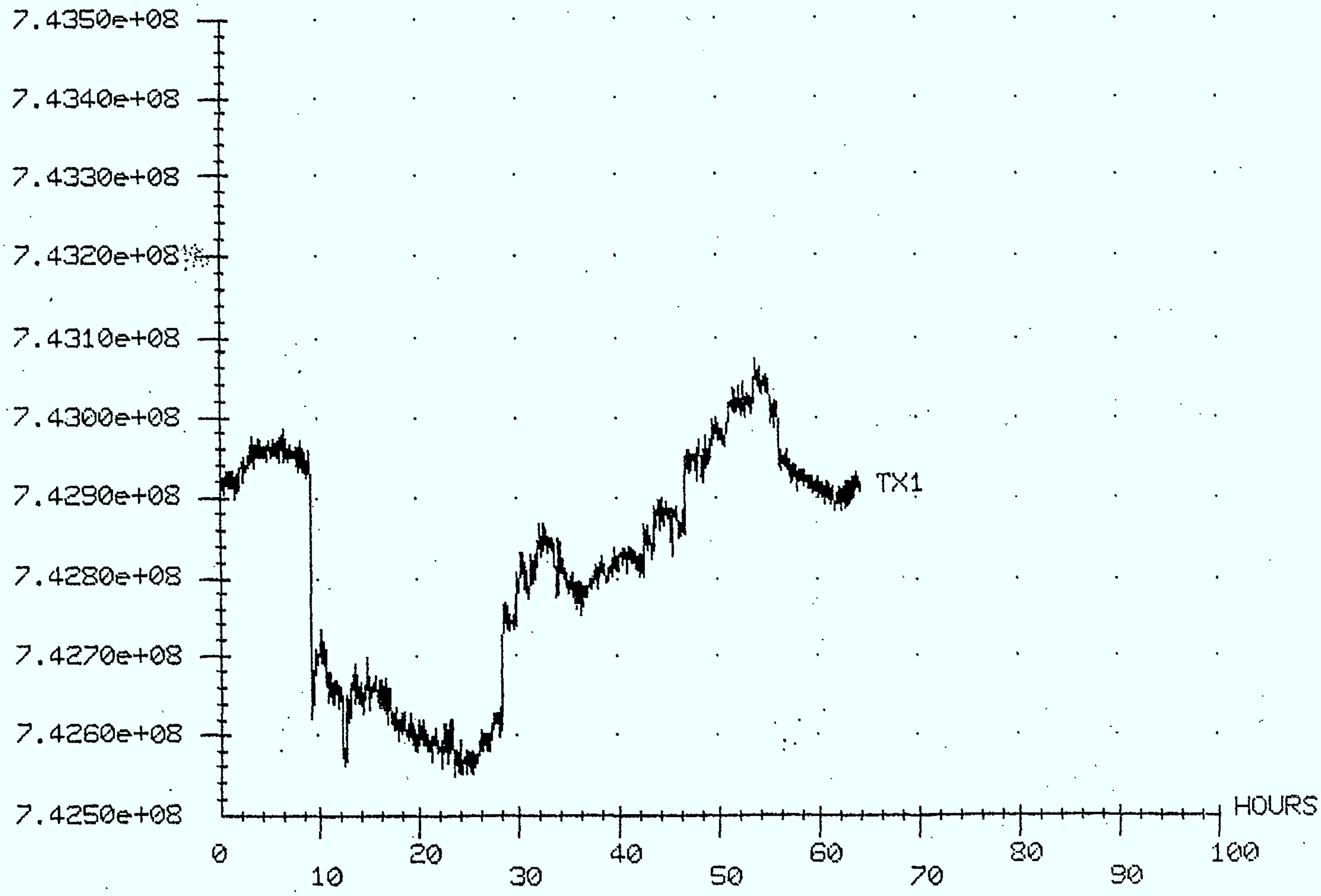
<u>T650-6YA</u>

$$1/B = 13 \text{ hrs}$$

$$Q_1 = 5.0 \times 10^5 \ (\text{deg/hr})^2 / \text{Hz}$$

$$Q_2 = 3.0 \times 10^3 \ (\text{deg/hr})^2 / \text{Hz}$$

$$\text{rms drift rate} = 3.2 \ \text{deg/hr}$$



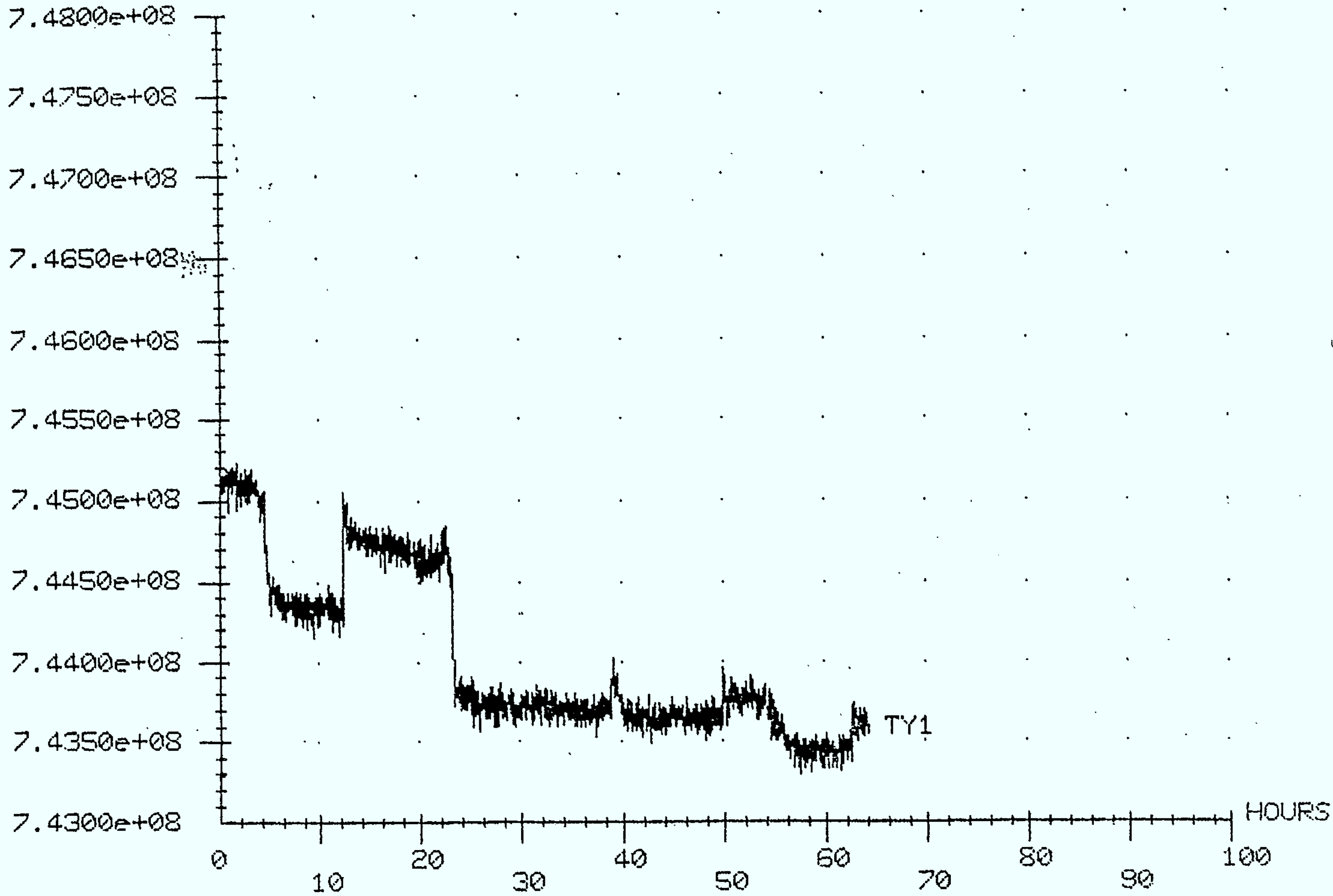

```
show subset: DK:T650.XM
show subset: DK:T650.6XM

DK:T650.6XM
from data file     DK:T650.6
data count         1541
start time         0 min.  0 sec.  0 msec.
time interval      150 sec.  0 msec.
processing         unprocessed file
selected using     subset start   1
                   subset end     1541
                   subset freq.   1
                   data col.      TX1

6.5 noise data from 14:00 aug 9 - 15:00 aug 14/82
5 min (real time) data, t5=6 msec

COMMAND>
```

Figure 7-1 X-AXIS DATA FOR 120 HOUR TEST

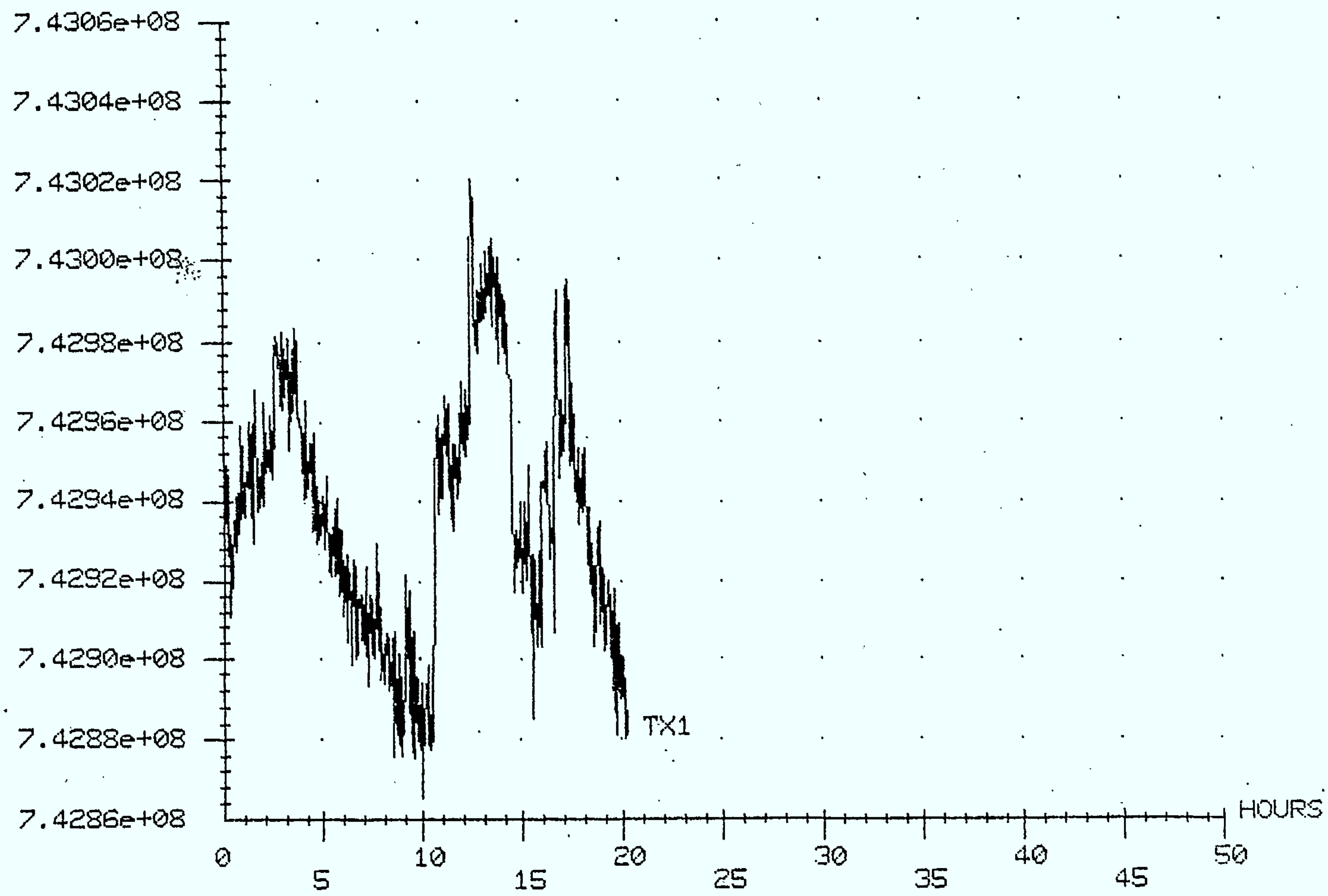



```
show subset: DK:T6506YDK:T650.6YM

DK:T650.6YM
from data file    DK:T650.6
data count        1541
start time        0 min.  0 sec.  0 msec.
time interval     150 sec.  0 msec.
processing        unprocessed file
selected using    subset start   1
                  subset end     1541
                  subset freq.   1
                  data col.      TY1

6.5 noise data from 14:00 aug 9 - 15:00 aug 14/82
5 min data, t5=6 msec
```

Figure 7-2 Y-AXIS DATA FOR 120 HOUR TEST

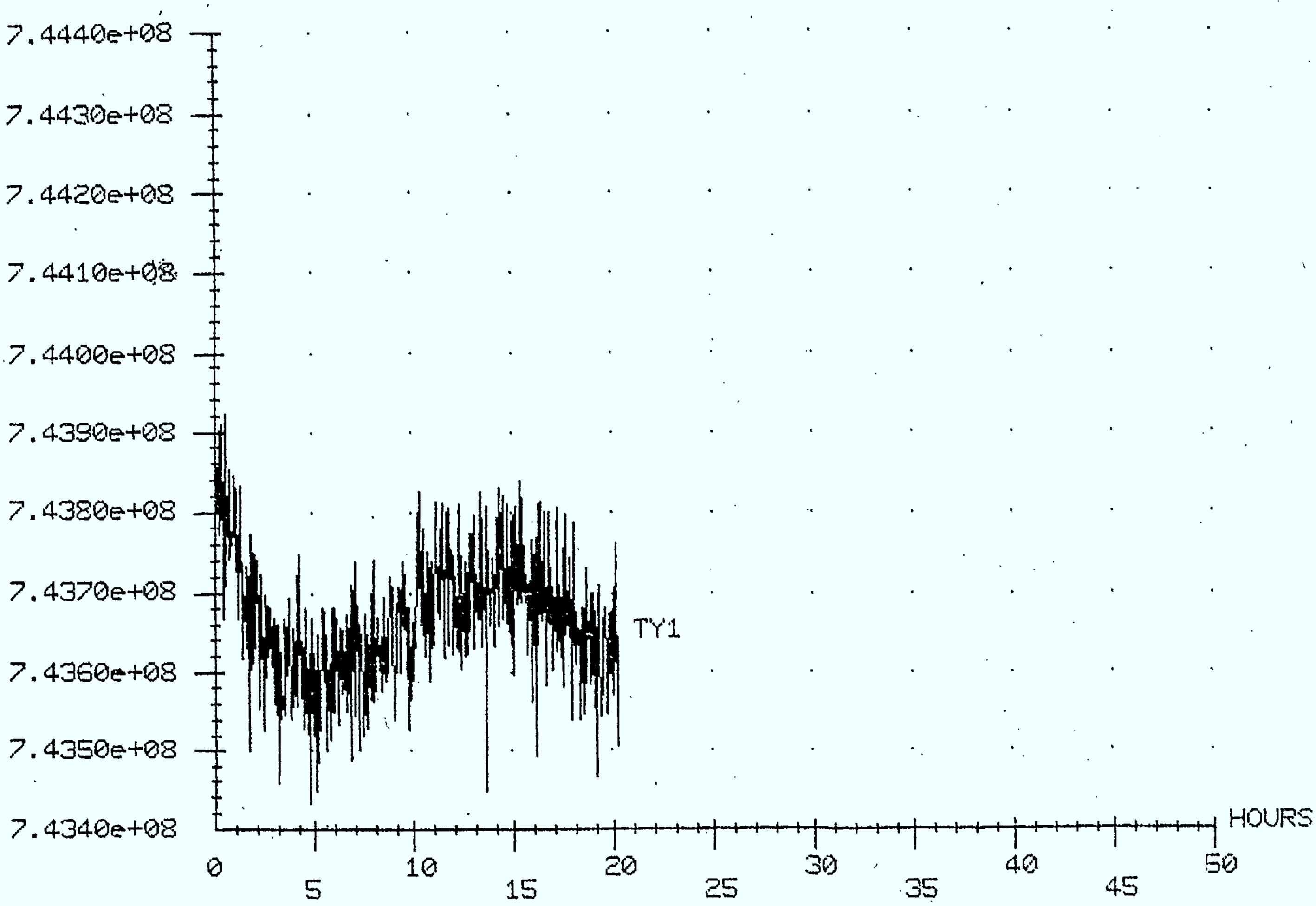



```
show subset: P650.11X

P650.11X
from data file    DK:T650.11
data count        487
start time        0 min.  0 sec.  0 msec.
time interval     150 sec.  0 msec.
processing        unprocessed file
selected using    subset start   1
                  subset end     487
                  subset freq.   1
                  data col.      TX1

6.5 NOISE TEST FROM 16 AUG 82 - 1710 HRS
5 MIN (REAL TIME), T5=6msec
TEMP PROBES IN
```

Figure 7-3 X-AXIS DATA FOR 40 HOUR TEST




```
show subset: P650.11Y

P650.11Y
from data file     DK:T650.11
data count         487
start time         0 min.   0 sec.   0 msec.
time interval      150 sec.   0 msec.
processing         unprocessed file
selected using     subset start   1
                   subset end     487
                   subset freq.   1
                   data col.      TY1

6.5 NOISE TEST FROM 16 AUG 82 - 1710HRS
5 MIN (REAL TIME), T5=6msec
TEMP PROBES IN

COMMAND>
```

Figure 7-4 Y-AXIS DATA FOR 40 HOUR TEST

11XA.smooth2

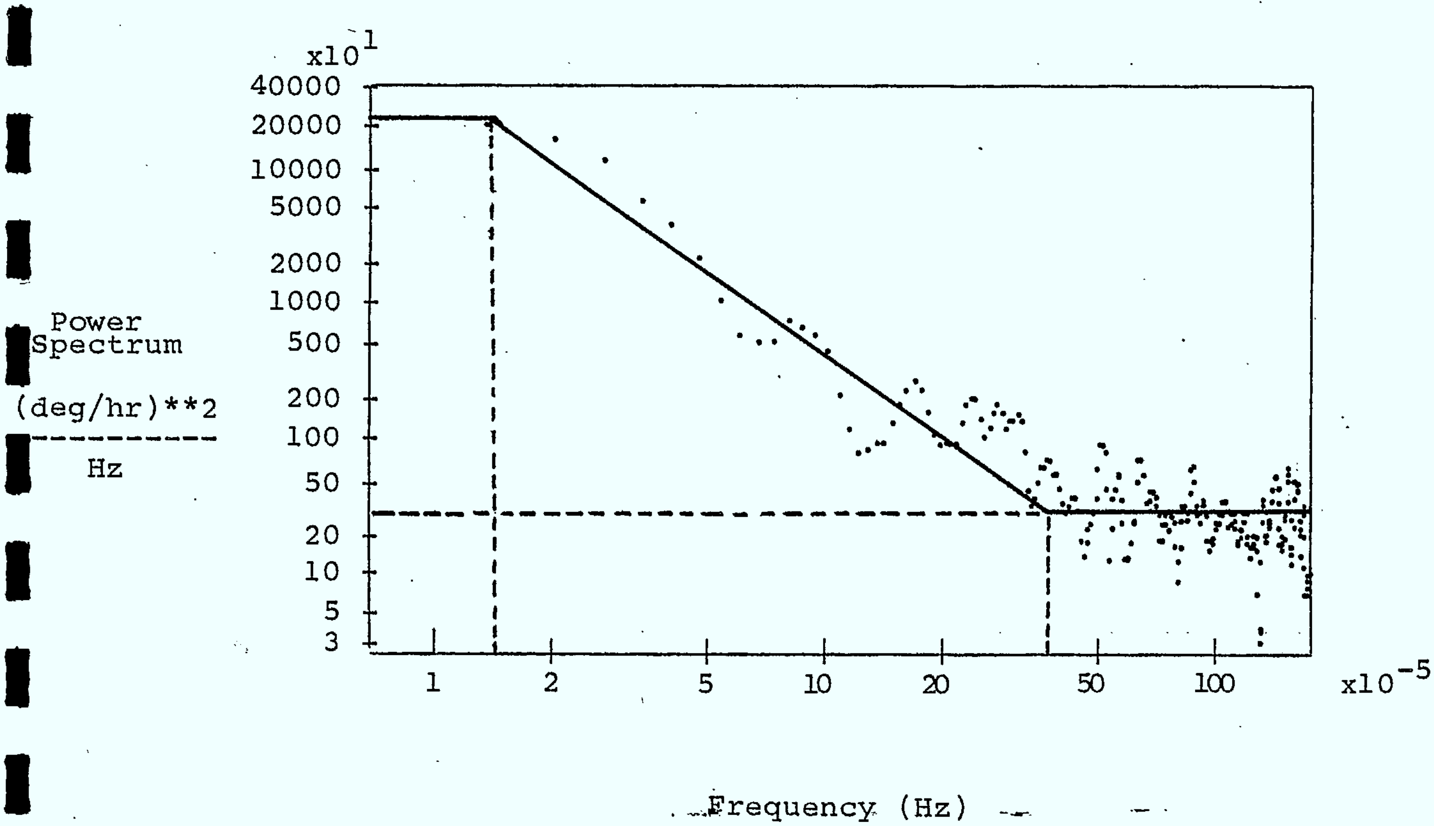


Figure 7-5 X-AXIS POWER SPECTRUM FOR 40 HOUR TEST

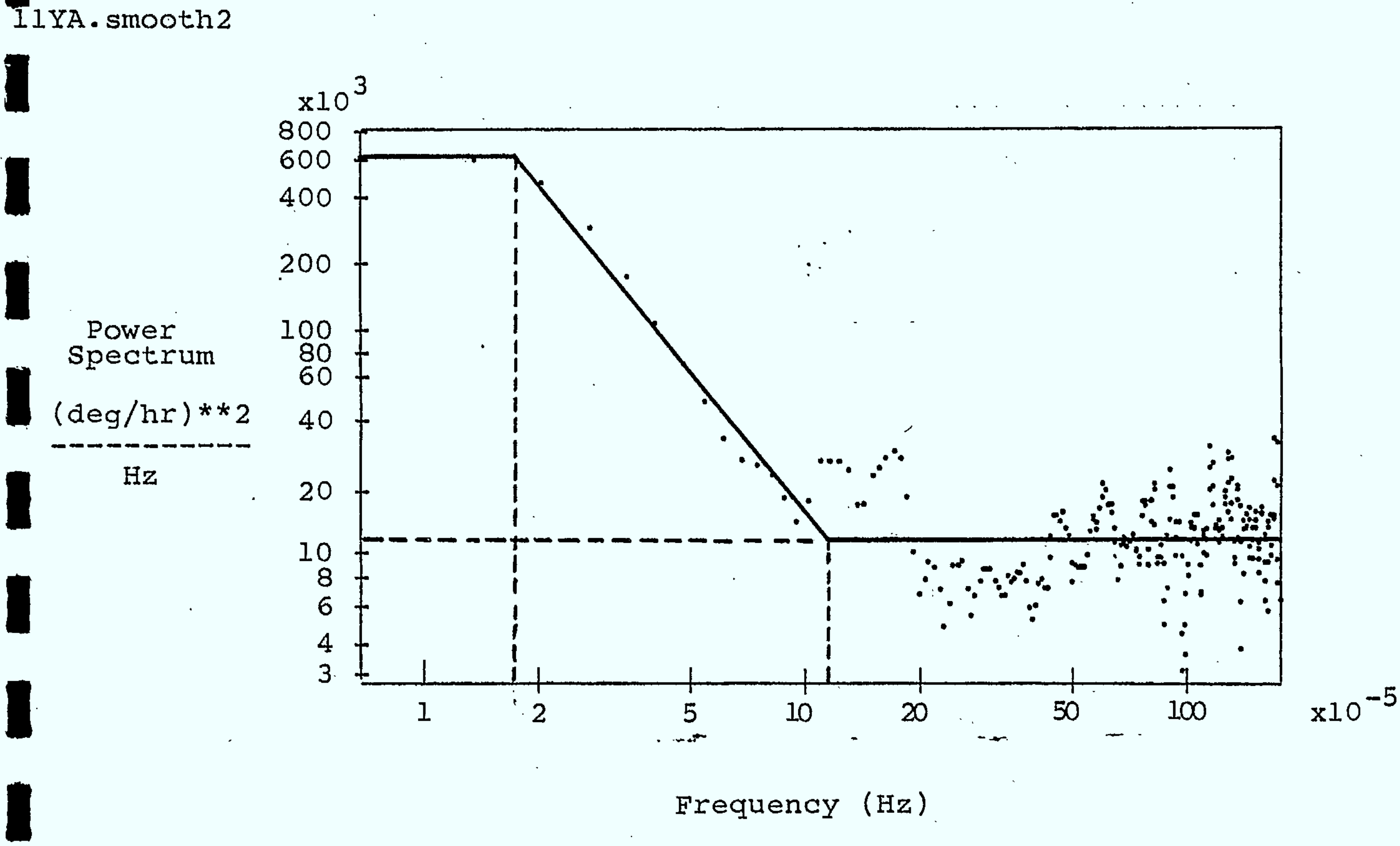


Figure 7-6 Y-AXIS POWER SPECTRUM FOR 40 HOUR TEST

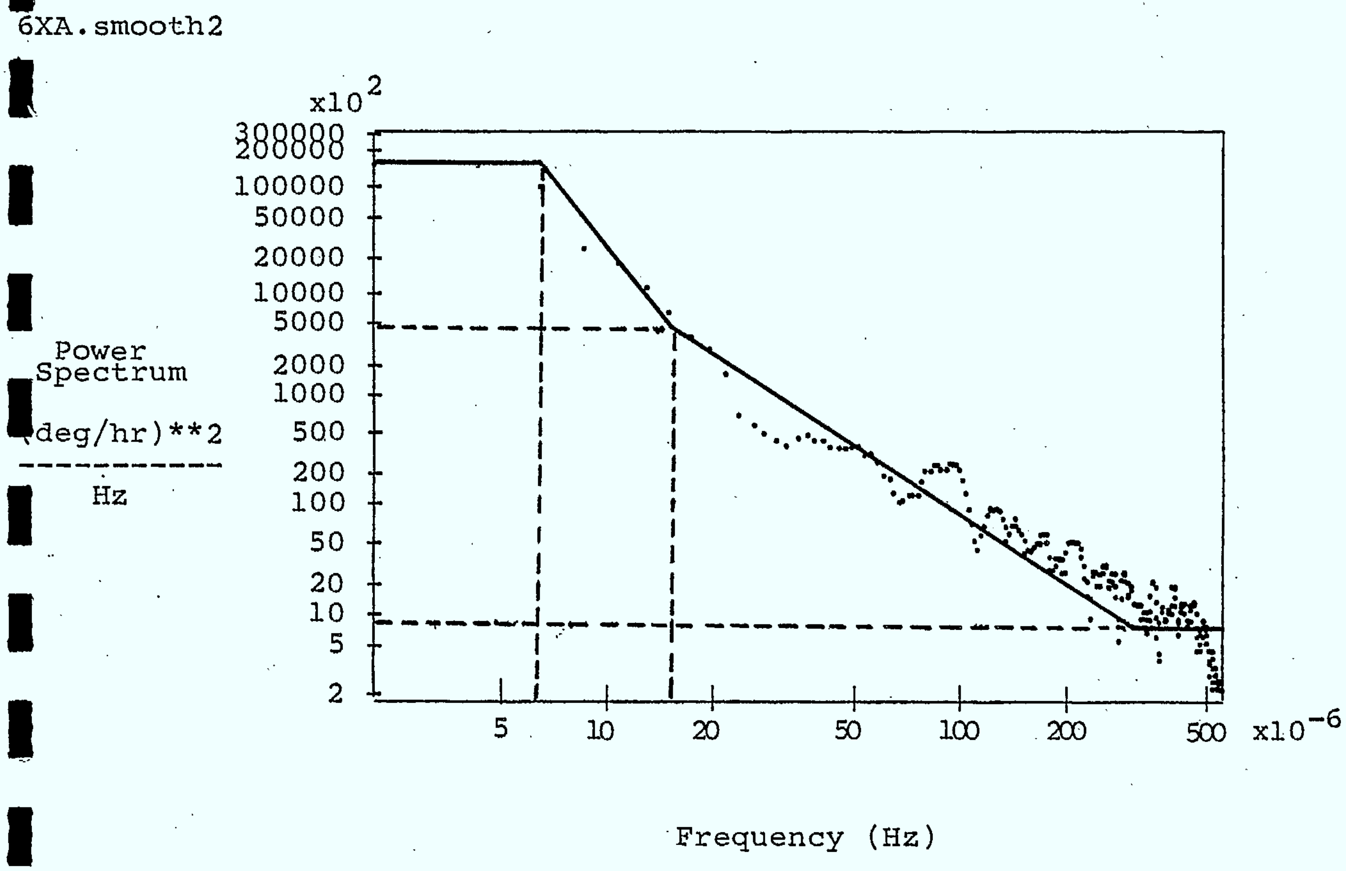


Figure 7-7 X-AXIS POWER SPECTRUM FOR 120 HOUR TEST

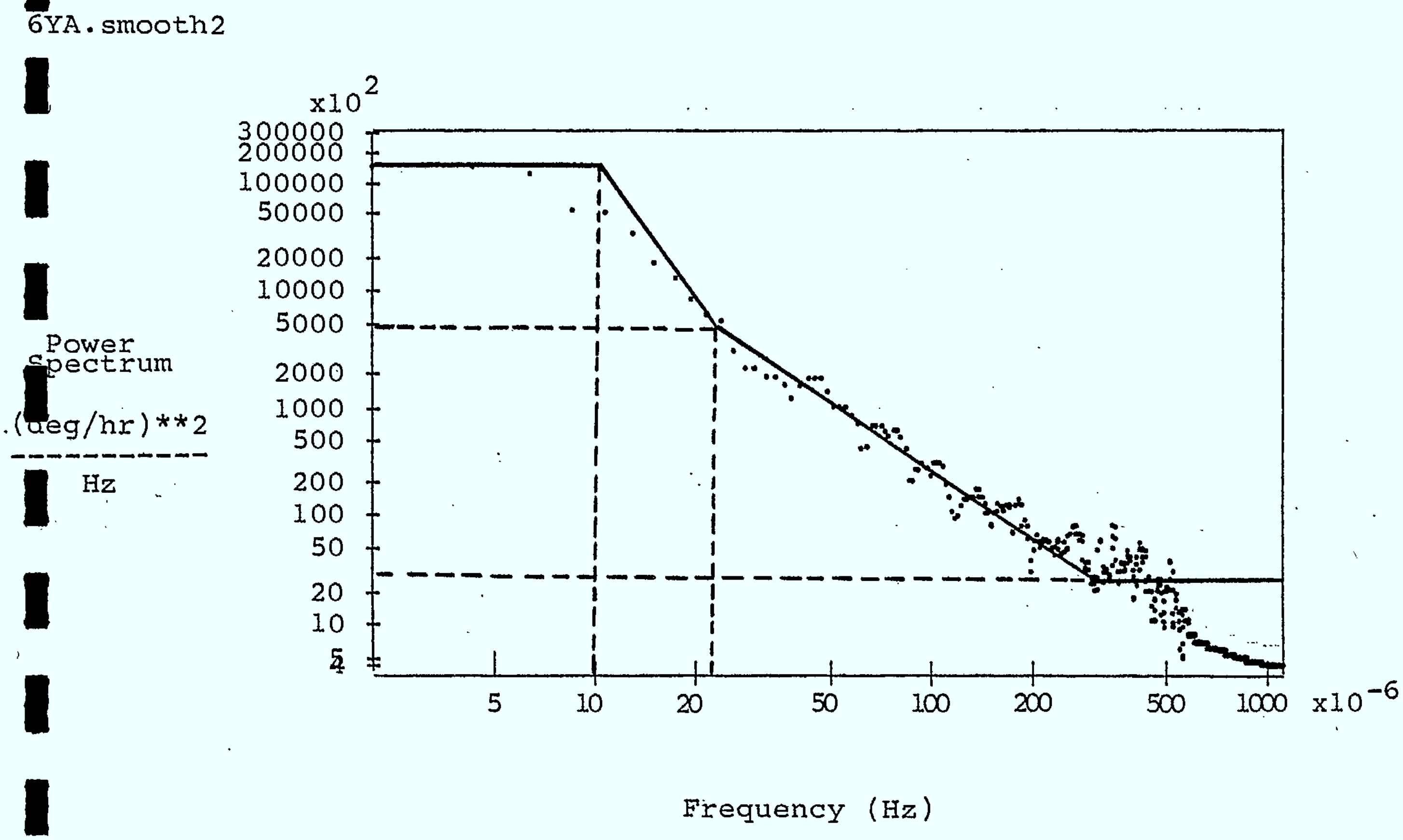


Figure 7-8 Y-AXIS POWER SPECTRUM FOR 120 HOUR TEST

Appendix A: Work Sheets

Two Single-Axis Gyros

	X-gyro N0002	Y-gyro N0001	Units
A.1 Spin Motor Performance			
Start-up power(5 watts max.)	2.9	2.9	watts
Running power (4 watts max.)	2.5	2.5	watts
Run-up time (15 sec max.)	7	8	sec
A.2 Null Quadrature			
BPF output(dbV rms)	-26.3	-28.2	dbV rms
(exp dbV/8.7)	49	39	mV rms
Divide by (38*1.7=65) (7 mV rms max.)	0.75	0.6	mV rms

		X-gyro N0002	Y-gyro N0001	Units

A.3 Torquer Scale Factor

		X-gyro N0002	Y-gyro N0001	Units
Average current of 4 samples	<X1>,<Y1>	-.012053	-.009434	mA
current, I=(T1-T3)/T5 mA	<X2>,<Y2>	-.009359	-.006504	mA
<I>=2*<T1>/T5-1	<X3>,<Y3>	-.006660	-.009347	mA
where T5=60000*25000	<X4>,<Y4>	-.009298	-.012272	mA
Torquer axis misalignment from A.4 below	a,b	-.011311	-.012083	rad
$K_x=21.398/((\langle X3\rangle-\langle X1\rangle)*(1+a*b))$ $K_y=21.398/((\langle Y2\rangle-\langle Y4\rangle)*(1+a*b))$ (3960 deg/hr/mA min.)	K_x,K_y	3967	3709	deg/hr/mA

A.4 Torquer Axis Misalignment

		X-gyro N0002	Y-gyro N0001	Units
a=(<X2>-<X4>)/(<X3>-<X1>) b=(<Y1>-<Y3>)/(<Y2>-<Y4>)	a,b	-.011311	-.015083	rad
For arc-sec, mult. by 206.3E3 (reference)	a,b	-2330	-3107	arc-sec

A.5 Drift Rates and Repeatability

		X-gyro N0002	Y-gyro N0001	Units
Average of all 4 positions	<X1>,<Y1>	-.007685	-.005210	mA
for each of 7 runs	<X2>,<Y2>	-.009059	-.006221	mA
<I>=2*<T1>/1.5E9-1 mA.	<X3>,<Y3>	-.008067	-.005056	mA
From A.3	<X4>,<Y4>			mA
K_x 3967 ; K_y 3709 deg/hr/mA	<X5>,<Y5>			mA
From A.4	<X6>,<Y6>			mA
a-.011311; b-.015083 rad	<X7>,<Y7>			mA
Non-g-Sensitive Drift for each run	B1	-30.8	-19.0	deg/hr
	B2	-35.6	-22.7	deg/hr
$B_x(i)=K_x*X(i)-K_y*b*Y(i)$	B3	-32.3	-18.4	deg/hr
$B_y(i)=K_y*Y(i)+K_x*a*X(i)$	B4			deg/hr
	B5			deg/hr
X(i),Y(i) = <Xi>,<Yi> above	B6			deg/hr
	B7			deg/hr
Average Non-g-Sensitive Drift Rate (50 deg/hr max.)		-32.9	-20.0	deg/hr
Non-g-Sensitive Repeatability -Standard deviation of B1-7		2.5	2.3	deg/hr

		X-gyro N0002	Y-gyro N0001	Units
g-Sensitive Drift Rate for each run	MU1	-5.0	-4.7	deg/hr/g
	MU2	-9.8	-7.6	deg/hr/g
	MU3	-4.9	-0.9	deg/hr/g
$MU_x(i)=K_x*(X1-X3)/2-K_y*b*(Y1-Y3)/2$	MU4			deg/hr/g
$+10.699$	MU5			deg/hr/g
$MU_y(i)=K_y*(Y2-Y4)/2+K_x*a*(X2-X4)/2$	MU6			deg/hr/g
$+10.699$	MU7			deg/hr/g
Average g-Sensitive Drift Rate (12 deg/hr/g max.)	MU	-6.6	-4.4	deg/hr/g
g-Sensitive Repeatability -Standard deviation of MU1-7		2.8	3.4	deg/hr/g

	X-gyro N0002	Y-gyro N0001	Units
A.6 Random Drift			
Non-g-Sensitive Random Drift			
-Stnd dev of T1 for #1	19586.6	25601.8	counts
mult. by K_x*2/1.5E9 (or K_y) (4 deg/h max)	0.10	0.13	deg/hr
g-Sensitive Random Drift			
-Stnd dev of T1 for #2	12326.1	25601.8	counts
mult. by K_x*2/1.5E9 (or K_y)	0.07	0.17	deg/hr
-Stnd dev of T1 for #3	29932.2	15048.1	counts
mult. by K_x*2/1.5E9 (or K_y)	0.16	0.07	deg/hr