Communications Research Centre

CRC CONTROL SYSTEMS LABORATORY GYRO TEST FACILITY

by

W.S. McMath and S.K. Yeung

IC

Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

CRC REPORT 1385

OTTAWA, APRIL 1985

Canada

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

CRC CONTROL SYSTEMS LABORATORY GYRO TEST FACILITY

by
W.S. McMath and S.K. Yeung
(Space Technology and Applications Branch)

CRC REPORT 1385

April 1985
OTTAWA

TABLE OF CONTENTS

CRC Control Systems Laboratory Gyro Test Facility

by

W. S. McMath and S. K. Yeung

Control Systems Group
Space Mechanics Directorate

1.0 Introduction

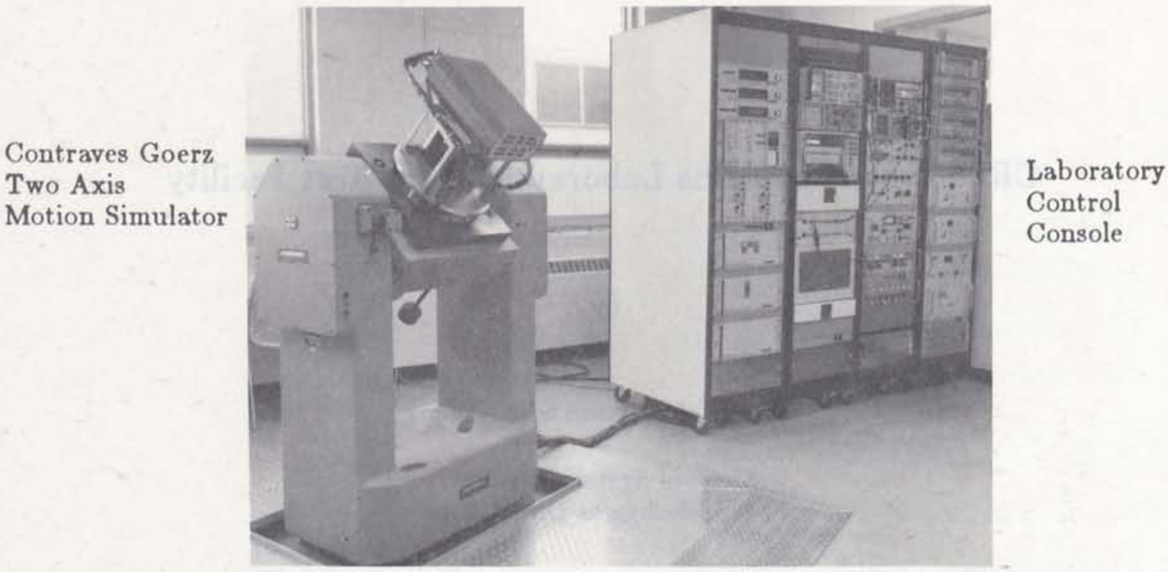
The Control Systems Laboratory was created with the mandate to study spacecraft attitude control concepts and methodologies for testing and evaluating hardware at the component and system level. Through the development of the facility and its personnel, a versatile and independent experimentation, testing, research and development capability has been established. In addition, the laboratory is a specialized resource which can be supportive to and accessible by both government and industry as a facility to evaluate components and systems for future spacecraft attitude control and stabilization systems, and to assist and extend component development testing programs beyond the limits of industrial facilities.

The laboratory has two fundamental technical objectives:

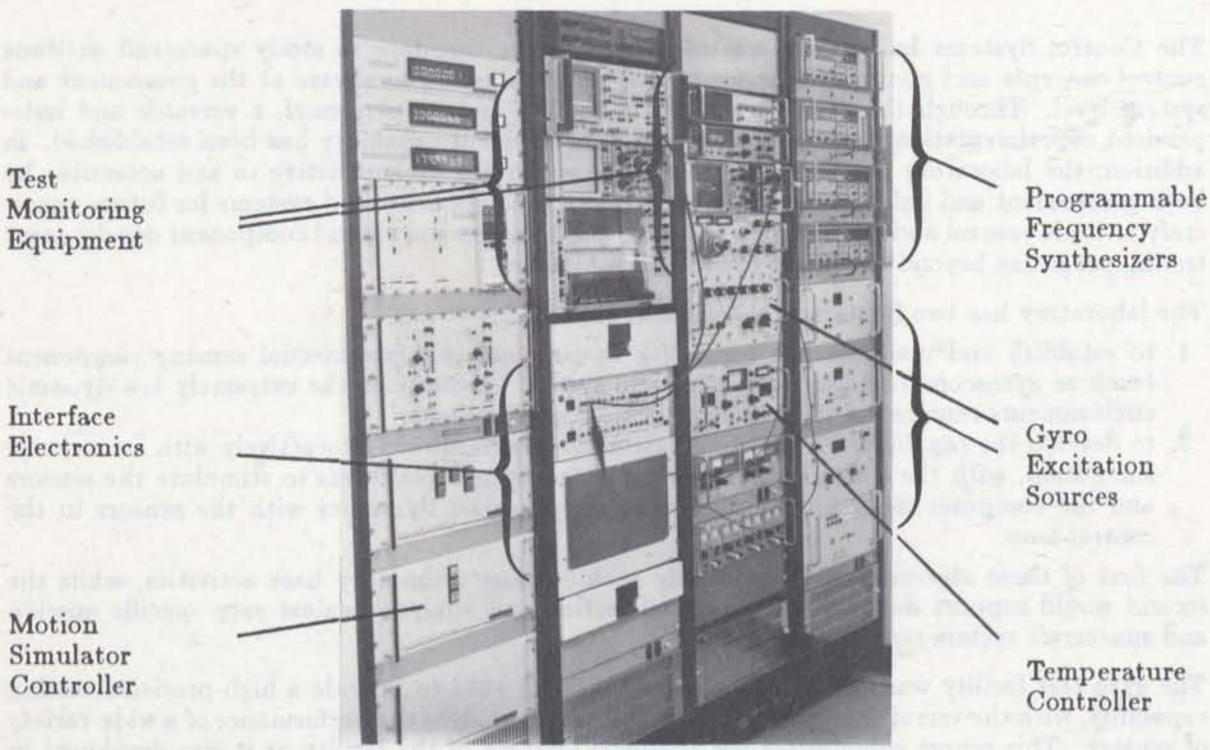
1. to establish and maintain the capability to test and evaluate inertial sensing component (such as gyroscope and accelerometer) and system hardware in the extremely low dynamic environments required of spacecraft attitude control sensors;
2. to develop the capability for real time testing of this hardware interactively with a computer simulation, with the spacecraft motion emulated by test platforms to stimulate the sensors and the computer modelling the appropriate spacecraft dynamics with the sensors in the control loop.

The first of these objectives deals primarily with ongoing technology base activities, while the second would support detailed and advanced testing and analysis against very specific mission and spacecraft system requirements.

The gyro test facility was developed between 1981 and 1984 to provide a high-precision testing capability, with the versatility to stimulate, monitor and analyze the performance of a wide variety of sensors. This report summarizes the technical features of the facility as it was developed in parallel with a Single-Degree-of-Freedom (SDOF) gyro test program. Some of the data from that test program is included as a working example of facility capability. However, the details of the complete gyro evaluation will be covered in a separate report.



a) General Facility Layout



b) Laboratory Control Console

Figure 1 Control Systems Laboratory Gyro Test Facility

2.0 Gyro Test Facility Description

Figure 1 is a photograph showing the gyro test facility layout. Figure 2 is a block diagram of the facility, illustrating the inteconnection of the major component elements. The test article (in this case, a gyro) is linked to the laboratory via sliprings in the motion simulator with a breakout box in the laboratory console. Through this link, stimulus signals are sent to the test article, and output signals are returned for analysis and for use in closing the rebalance control loop around the test article. A total of 100 sliprings is available for test article interfacing.

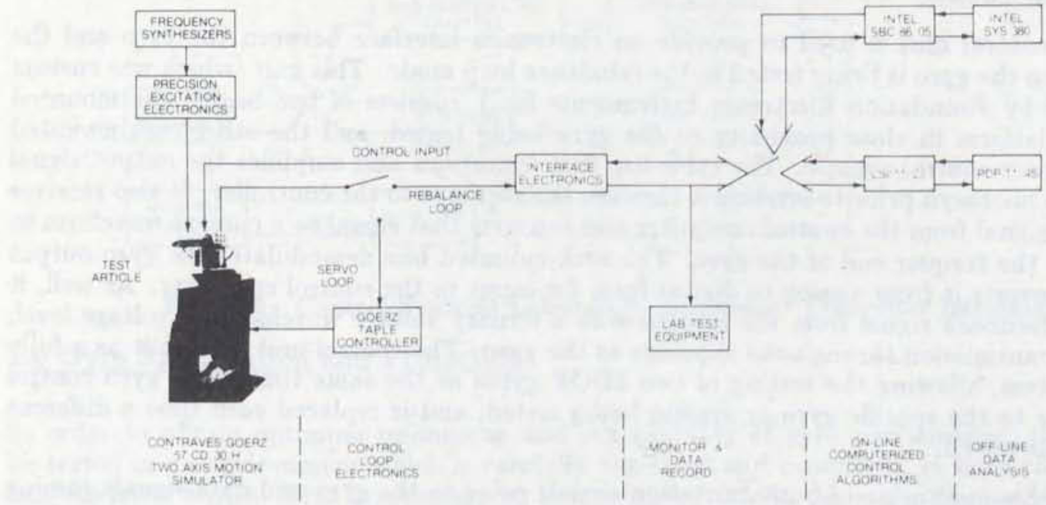


Figure 2 Gyro Test Facility Block Diagram

2.1 Motion Simulator

The test platform is a key element in any test facility. The platform in this facility is a two-axis motion simulator manufactured by Contraves Goerz Corporation. It is a mechanical bearing table, with angular position and rate capability about the Azimuth Axis and position capability about the Elevation Axis. Position readout resolution is 0.36 arc-seconds, (with absolute position repeatability ± 1.0 arc-second). Rates of up to 1000 degrees/second may be applied, with a precision rate range of 0.0001 to 199.9999 degrees/second (± 0.001%). Additional technical specifications are provided in Appendix A. The controller for the motion simulator allows it to be operated in either open loop or closed loop mode. In the former mode, the test platform may be commanded to either an azimuth position or rate, and/or to an elevation position, through the control console keypad. In closed loop mode, the gyro servo module of the controller may be used to slave the test platform to some external command signal. In the case of a gyro test, the platform is slaved to the output signal of the gyro itself. Alternatively, the gyro output signal may be used to drive computer-based control algorithms which close a rebalance loop around the gyro by providing restoring currents to the gyro torquer.

The range of angular rates of interest in our gyro test programs is extremely low, well below the Earth's rate of rotation. Consequently, since the gyro is a rate-sensitive instrument, its orientation with respect to the Earth's axis of rotation must be precisely known and accounted for at all times. To achieve this requirement, the test platform of the motion simulator is aligned very carefully with respect to Earth. The Azimuth Axis is aligned to local vertical, and the Elevation Axis is aligned horizontally in the East-West direction. This permits a rotation about the Elevation Axis to move the Azimuth Axis purely in the North-South vertical plane. The test platform is aligned to within approximately 15 arc-seconds of True North, using a procedure which is detailed in Appendix B.

2.2 Excitation Instrumentation

Excitation signals for the wheel (or motor) and microsyn (or pickoff) of the gyro being tested are provided from programmable frequency synthesizers (manufactured by Adret Electronique) and power conditioned by highly stable voltage supplies (custom manufactured by NH Research Inc.). In addition, a precision DC current source (manufactured by North Hills Electronics Inc.) may be used to provide highly stable current levels directly to the torque generator of the gyro. Technical specifications on this equipment are appended.

2.3 Interface Electronics

A gyroscope control unit is used to provide an electronics interface between the gyro and the computer when the gyro is being tested in the rebalance loop mode. This unit (which was custom manufactured by Foundation Electronic Instruments Inc.) consists of two boxes, one mounted on the test platform in close proximity to the gyro being tested, and the other rack-mounted in the laboratory control console. The table-top unit conditions and amplifies the output signal from the gyro microsyn prior to sending it through the sliprings to the controller. It also receives the feedback signal from the control computer and converts that signal to a current waveform to be applied to the torquer coil of the gyro. The rack-mounted box demodulates the gyro output signal and converts it from analog to digital form for input to the control computer. As well, it converts the feedback signal from the computer to a ternary voltage waveform (± voltage level, or zero) for transmission through the sliprings to the gyro. The control unit was built as a fully duplicate system, allowing the testing of two SDOF gyros at the same time. The gyro control unit is unique to the specific gyro or system being tested, and is replaced each time a different type of gyro is tested.

To facilitate the monitoring of both excitation signals going to the gyro and data signals coming from the gyro, all wiring interconnections are made through breakout boxes. The main breakout box, located in the laboratory console, provides total access to signals at the console side of the motion simulator sliprings. A second breakout box is located on the test platform between the sliprings and the gyro under test. This provides access to signals as close as possible to the gyro, and gives the best possible measurement of what signals the gyro is experiencing and what signals it is producing as data.

2.4 System Computers

To complete the description of the control rebalance loop, the function of the computers should be outlined. As indicated in the block diagram in Figure 2, there are actually two distinct levels of computation performed. A real time, on-line computer is used as a foreground device to accept the output signal from the gyro, process it through the appropriate control algorithms, and send back a restoring signal via the interface electronics to the gyro torquer. A second computer is used off-line as a background device to store data and perform a variety of analytical functions.

For the first part of the gyro test program, the on-line and off-line functions were fulfilled by DEC LSI-11/23 and PDP-11/45 computers respectively. Later, these functions were fulfilled using Intel SBC 86/05 (single board computer) and SYS 380 computers. As Figure 2 indicates, either computing system may be used, at the option of the test operator. The advantage of the Intel configuration is that the single board computer is a more realistic representation of the real time computer which might be configured in a gyro package for flight development. A second advantage of the Intel configuration is that it allows data communication between the SYS 380 computer and several mainframe computers on site at CRC for further analysis. Furthermore, it permits remote users to access test data files (via Datapac telephone lines) to analyze data. This computer interface network is shown in Figure 3.

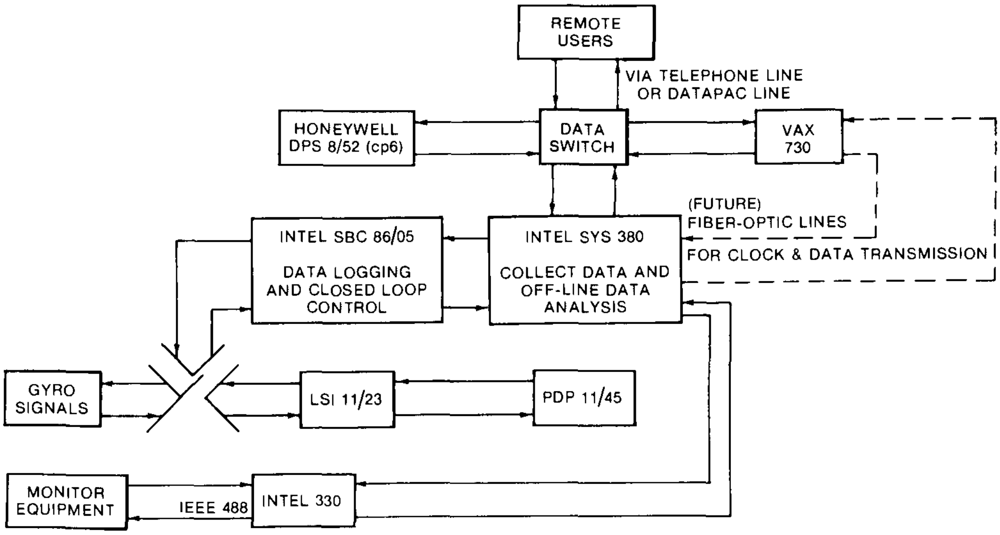


Figure 3 Control Systems Laboratory Hardware/ Computer Interfaces

3.0 Gyro Stabilization and Protection

In order to obtain optimum uniformity and repeatability of gyro performance, the gyro must be tested in an environment which is carefully regulated and controlled, in both the mechanical and electrical senses. This is necessary to isolate the gyro from (as many as possible) sources of disturbance which, if introduced, could produce anomalies in the gyro behavior.

3.1 Mechanical Environmental Control

The motion simulator was installed on a seismic isolation mass in an attempt to shield the test article from external vibration sources such as local vehicular and personnel traffic. This was also necessary as a result of the laboratory's proximity to the CRC Model Shop and its heavy machinery (which includes a metal shear). This seismic isolation consists of a large block of concrete (approximately 5500 kilograms) resting on a buffer layer of silica sand. Tests have indicated limited success in achieving the desired isolation. While higher frequency vibrations have been fairly well eliminated, shocks (particularly those caused by the metal shear) still reach the motion simulator, and their effects appear in test data.

Since gyros are, to varying degrees, temperature-sensitive instruments, thermal control is necessary to obtain maximum uniformity and repeatability of test results. Accordingly, the gyro being tested is enclosed in an aluminum block which is fitted with heaters and temperature sensors. The temperature is controlled at the gyro manufacturer's recommended operating level, usually in the vicinity of 160° F, by inserting thermistors in a resistance bridge of a controller (manufactured by Dynamics Research Corp., technical specifications appended) which regulates heaters in the gyro block. The gyro temperature is effectively controlled to ± 0.1° F.

3.2 Electrical Protection and Isolation

Because of the very low voltage levels (millivolt and lower) which can affect the operation and performance of a gyro, electrical signal stability and cleanliness are of equal or even greater importance than mechanical considerations. The excitation signals must be precise and reliable if the gyro is to function optimally and not suffer damage. Noise in the gyro control loop must be minimized for peak gyro performance and to obtain the best possible test results. Consequently, a number of design precautions were specified for the test facility.

First, to attain grounding stability, all equipment in the facility which is used for excitation or monitoring of the gyro is Earth-grounded to copper rods rather than connected to the hydro ground line. Second, the gyro is protected by the regulation circuitry in the NH Research wheel and microsyn supplies, as well as by fuses on the test platform to guard against excitation equipment malfunction. Third, to protect the gyro against instantaneous power dropouts which could cause damage to it, power to all equipment related to the gyro excitation (the NH supplies, Adret frequency synthesizers, current source, and the loop closure electronics) is provided from an uninterruptable power supply (UPS) (manufactured by Pylon Electronic Development, specifications appended). In effect, all critical equipment is powered from storage batteries which are on continuous charge from the site power lines. In the event of power failure, the UPS will continue to carry the equipment for a period of time before switching everything off, effecting a shutdown of the gyro. The UPS will not restart automatically when site power is recovered, but must be reactivated manually. This is a safety precaution to prevent a rapid series of power starts and dropouts which could burn out the gyro motor. If site power is recovered before the UPS switches off, the equipment will continue to function as if nothing had happened. Finally, any monitoring equipment which is not powered through the UPS is supplied from a dynamic power conditioner (manufactured by Topaz Electronics, specifications appended). Power to the computers is regulated in this manner.

Considerable care and precaution was taken in the design, fabrication and layout of system wiring in order to minimize noise. Twisted, shielded cables were used for any oscillatory signals such as the wheel and microsyn excitations, gyro output signals, and gyro rebalance signals. The grounding practice adopted was that of single-ended grounding back to source (Earth ground). This practice was carried through the sliprings to the test platform as completely as possible. No reference other than Earth ground was used in order to avoid ground loops.

4.0 Modes of Test Facility Operation

At present, there are three modes of operation available, namely: Servo Mode, Rebalance Loop Mode and Direct Current Mode. The latter is not entirely an independent mode of operation, but an adjunct to the other two modes for certain types of gyro test. The essential difference between Servo and Rebalance Loop modes is the manner in which the gyro is driven to (and held at) its null position while under test. In Servo mode, the gyro is mechanically nulled by physically moving it at the necessary angular rate. In Rebalance Loop mode, the nulling is achieved electronically, with the gyro stationary.

It should be noted that these two modes of operation represent completely different rebalancing techniques to null the gyro. In Servo mode, the control loop is analog in nature, and the motion simulator emulates the counter-rotating gimbal of a gimballed gyro system. In Rebalance Loop mode, on the other hand, the control loop is digital, and the gyro is being tested in strapdown configuration, so named because the gyro is strapped down, or solidly attached, to the platform, with no gimbal to offset any applied rates. The electronic rebalance loop must therefore be sufficiently robust to null the gyro without benefit of mechanical counter-rotation.

4.1 Servo Mode

The Input (rate-sensitive) Axis of the gyro is aligned with the Azimuth Axis of the motion simulator, and the output signal from the gyro is fed to the Gyro Servo Module of the motion simulator controller. Any rate-induced or error-induced (due to gyro imperfections) output signals are used to control the motion simulator servomotor and cause the simulator to counter-rotate about its Azimuth Axis to null the gyro. The motion of the test platform is the mechanical restoring action required to null the gyro, and thus is indicative of the gyro output signal. By monitoring this motion, the performance of the gyro can be recorded. This mode of operation is of particular use in studying long term parameters such as gyro drift.

4.2 Rebalance Loop Mode

In this mode of operation, the motion simulator is used as an alignment device to orient the gyro with respect to the Earth's axis of rotation, with respect to gravity, etc. The output signal from the gyro is sent to the computer and processed through a real time rebalance control algorithm. The restoring signal generated by this control algorithm is converted first to a voltage signal and then to a current which is applied to the gyro torque generator, restoring the gyro to its null position. By stationary positioning of the gyro in a variety of attitude orientations, various error terms and parameters of the gyro's behavior can be isolated and identified. This mode of operation is particularly useful for studying short term gyro behavior.

4.3 Direct Current Mode

In this mode, direct current is applied to the torque generator of the gyro. This bias current causes an output from the signal generator even though the gyro is experiencing no motion. If the gyro is being tested in Servo mode at the time, the signal generator output will cause the motion simulator to be driven at a rate sufficient to null out the current bias with an opposing torquer current produced as a result of the gyro rotation. By applying different levels of DC current, the sensitivity of the torque generator and its linearity of performance can be determined.

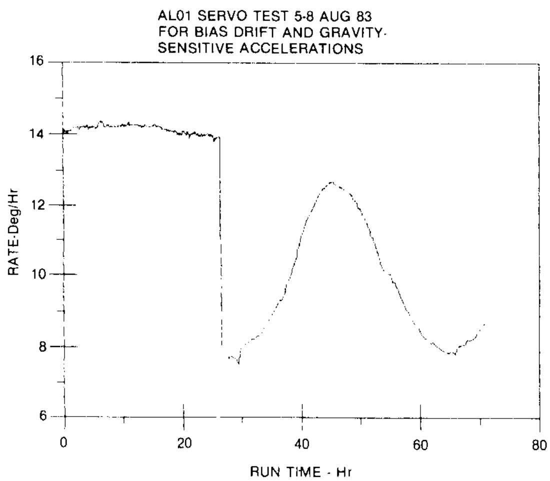
5.0 Sample Test Results

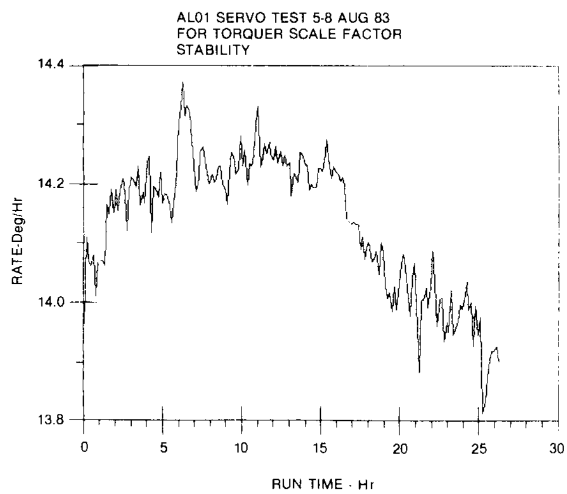
The evolution of the gyro test facility took place in conjunction with a series of tests conducted on several Honeywell GG1111 gyros. While these gyros were being characterized, certain tests were repeated over an extended period of time. This established a high degree of confidence in the results obtained. In addition, and more important as far as the development of the test facility was concerned, observed improvements in the quality of test data as time went by provided an indication of progress in the integration of the component equipment to form a test facility with a minimum of disruptive influences such as noise, instability of excitation signals, interference with test data signals, etc. The three most significant developmental steps in terms of improving data quality were the installation of high-precision excitation instrumentation, the placement of the gyro under close temperature control, and an extensive rewiring of the system to improve grounding and minimize noise effects.

It is therefore appropriate to include in this report a sample of the test data obtained, to give the reader an insight into the degree of precision or capacity for testing which the facility has become capable of achieving. The results presented here are from a series of tests conducted on a model GG1111/AL01 gyro.

Figure 4(a) is a plot of long term gyro drift behavior, with data taken over a period of approximately 70 hours of Servo mode testing. For the first 26 hours, the Input Axis of the gyro was aligned with local vertical. In this orientation, the gyro sensed the vertical component of Earth rate, as well as the effects of bias drift and Input Axis gravity-sensitive error terms. Without interrupting the test, the motion simulator was rotated by 90 degrees about its Elevation Axis, so that the gyro's Input Axis was aligned with horizontal North. The gyro then sensed the local horizontal component of Earth rate, along with the effects of bias drift and gravity-sensitive error terms for the Spin and Output Axes of the gyro, which were rotating slowly in and out of local vertical alignment. The cumulative effect of these inputs to the gyro is the sinusoidal variation in rate over the roughly 45 hours it took for one complete rotation of the gyro. The high and low extremes in this oscillation represent alignment of the Spin Axis of the gyro with (and opposite to) local vertical. The mid-points represent Output Axis alignment with and against local vertical. By analyzing data taken at these four cardinal points of the rotation, along with data taken while the Input Axis is aligned with vertical, the bias drift and gravity-sensitive error terms for the gyro can be isolated and identified.

Figure 4(b) is an expansion of the first part of Figure 4(a), magnifying the scale. This data can be used to evaluate the torque generator scale factor stability, as well as to assess the overall noise content of the test system.





a) Error Term Identification b) Torquer Stability Analysis

Figure 4 Gyro Characterization Data (Aug. 5-8, 1983)

Figure 5 was plotted from data taken in a series of Direct Current mode tests. By applying varying current levels to the torque generator, its sensitivity can be established. The ideal characteristic is a flat line, indicating total insensitivity to torquer current. The discontinuity as applied current approaches zero is a result of a slight physical separation between the electrical and mechanical nulls in the torquer coil.

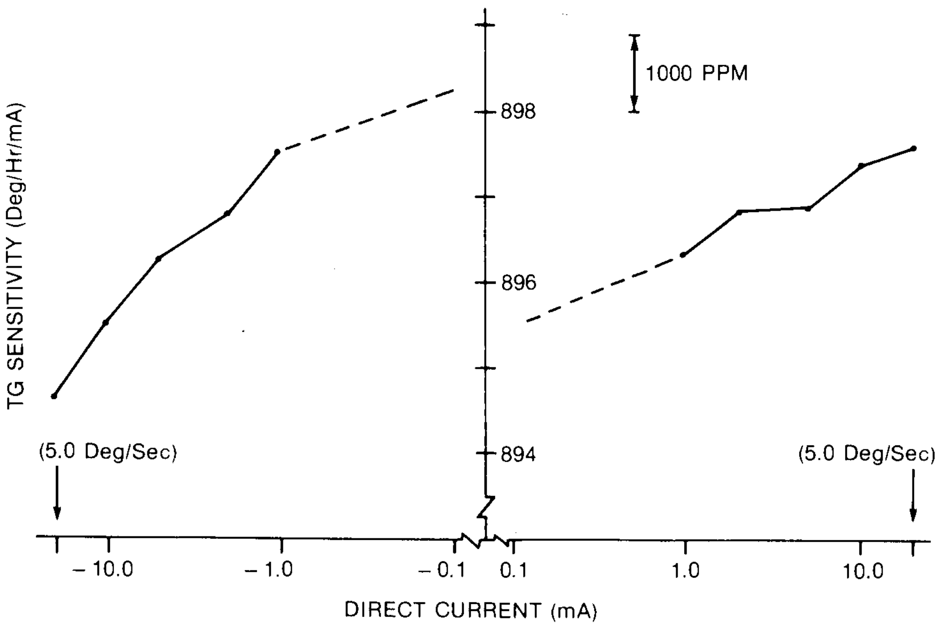


Figure 5 DC Torque Generator Sensitivity (Aug. 2, 1983)

In all of these tests, the results obtained are within the generic specifications for this class of gyro. These tests were repeated many times over a six month period, with very consistent results. The repeat testing allowed extensive comparison of the Servo mode (analog, pseudo-gimballed configuration) with Rebalance Loop mode (digital, strapdown configuration). Consistency and repeatability in each mode were very high, and correlation between the two modes of operation was also excellent.

6.0 Conclusions

The test results obtained for the Honeywell GG1111/AL01 gyro indicate that the gyro test facility is easily capable of characterizing a gyro of this class of performance. The noise characteristics also indicate a high degree of noise elimination in the test system. The consistency and repeatability of test results also suggests that laboratory personnel have become well acquainted with the procedures and precautions required to undertake such a test program.

The next planned activity in the Control Systems Laboratory is a test program to characterize a Canadian prototype Two-Degree-of-Freedom (TDOF) tuned rotor gyro, which is a higher grade of instrument. As a consequence, that program will help to further establish the capabilities (and possibly limitations) of the gyro test facility as currently configured, and hence lead to its further improvement for use with advanced sensors having more rigorous performance requirements.

Appendix A

Gyro Test Facility Equipment Technical Specifications

Contraves Goerz Two Axis Motion Simulator (Model 57CD/30H)

General Features:

Bearings	Mechanical, Ball Bearings
Load Capacity	115 Kg (Vertical) 95 Nm (Moment Load)
Torquing	108 Nm (Azimuth) 30 Nm (Elevation Axis)
Sliprings	110 lines (Azimuth Axis only) 16 @ 5 Amp, 94 @ 1 Amp, 0.01 Ohm noise (10 lines @ 1 Amp for Motion Simulator Control)
Environmental Chamber	16" × 16" × 16" Working Space -100 to + 425 °F Temperature Range
External Data Link	IEEE 488 (1975)

Position Mode (Both Axes):

Transducer	720-pole Inductosyn and Resolver
Range	Infinite (Azimuth Axis) ±185° (Elevation Axis)
Resolution	0.36 Arc-Second, ± 1.0 Arc-Second

Rate Mode (Azimuth Axis Only):

Range (Low)	0.0001 to 199.9999 °/sec (optional 'ERU' (Earth Rate Units)),± 0.001%
Range (Tachometer)	0.001 to 999.9 °/sec, ± 0.1%

Adret Programmable Frequency Synthesizer (Model 3100)

Output	Sine, Positive Square, Negative Square, Symmetrical Square, TTL Square Wave, 90° Phase-Shifted Sine Wave, Variable Phase-Shifted Sine Wave
Voltage	0.0 to 10.0 Volts (p-p) (4.2 Volts for TTL)
Current	100 mA peak
Range	0.01 Hz to 199,999.99 Hz
Resolution	0.01 Hz
Stability	$\pm 2 \times 10^{-5}$ from 0 to 50 °C $\pm 5 \times 10^{-10}$ per day after 8 hours' operation

NH Research Wheel Power Supply (Model SF2599 Rev. A)

Output	2-phase, 3-phase Sine or Square Wave
Voltage Range	6.25 to 99.999 VRMS
Current Range	3 to 333 mA
Frequency Range	350 Hz to 10 KHz
Amplitude Stability:	
Vs Load	±0.005% NL-FL with remote sensing (sine wave mode) ± 0.05% NL-FL with remote sensing (square wave mode)
Vs Line	±0.001% for 115V ±10V Line
Vs Time	±0.0025%/week under constant conditions
Vs Temp	±0.002%/°C average from 15-40 °C
Vs Input Signal	±0.001% for specified input

NH Research Microsyn Power Supply (Model SF1250W Rev. A)

Output	10VA (1A max current), Sine Wave 225 Hz to 32 KHz (usable to 55 KHz) Single Phase, Two Wire, Floating with two wire remote sense
Range	1.0-79.9 VRMS
Accuracy	±1.0% of setting
Repeatability	±0.02% of maximum voltage
Amplitude Stability:	
Vs Load	±0.005% NL-FL with remote sense
Vs Line	±001% for 110V ± 10V Line
Vs Time	±0.005%/week after warmup
Vs Temp	±0.002%/°C over 15-40 °C
Vs Sync	±0.001% for any variation within specified limits

North Hills Precision DC Current Source (Model CS152, Series R)

Output current	0 to ±150 mA
Accuracy	±0.01% of F.S. ± 10 nA
Stability	±2 PPM of F.S. ± 5 nA RMS
Regulation:	
Vs Line	5 PPM
Vs Load	5 PPM
Vs Temp	1 PPM over 20-40 °C

Dynamics Research Temperature Controller (Model TC300)

Inertial component temperature control	±0.1°F, proportional
Block power output	60 watts
Inertial component heater power	15 watts

Pylon Uninterruptable Power Supply

Output:

Output Voltage	117 VAC, sinusoidal
Output Current	4.3 Amp. maximum continuous
Output Power	2000 VA maximum continuous
Surge Power	125% for 10 minutes
Distortion	<5% at unity power factor
Regulation (Load and Line)	<3%
Efficiency	75% at full load
Back-Up Time (Battery)	40 minutes at full load

Protection:

Output	Separate line fuse Short circuit protected Current limiting Foldback limiting Automatic transfer to line in event of inverter failure (transfer 15 msec) Over temperature protected
Battery	Automatic battery low voltage disconnect

Topaz Dynamic Power Conditioner

Output Power	5000 VA
Output Voltage Regulation	+6%,- 8%
Common-mode Noise Attenuation	> 140dB, 10 Hz to 10 MHz
Transverse-mode Noise Attenuation	57 dB
Efficiency	>94%
Output Distortion	No spikes, adds less than 2% total harmonic distortion
Response Time	$\frac{1}{2}$ cycle typical; 1 cycle maximum
Surge Rating	100% overload for 10 seconds 500% overload for 1 cycle

<u>NH Research Sine/Square Wave Differential Wattmeter (Model 4204)</u>

Power Range	0 - 12 Watts
Resolution	100 μW
Frequency Range	375 Hz to 6400 Hz

	2.5 to 12 Watts	< 2.5 Watts
Accuracy	2% of reading for 1.0-1.5 pf loads; derates to 3% at 0.3 pf	50 mW for 1.0-1.5 pf loads; derates to 75 mW at 0.3 pf
Stability:		
Vs Time	±0.1%/week	±2.5 mW/week
Vs Temp (60-100°F)	±0.01%/°F	±250μ W/°F
Vs Line (115V±10V)	±0.005%	±125 μW

Appendix B

Inertial Alignment of Contraves Goerz 57CD Two Axis Motion Simulator

Summary

Ideal inertial alignment of a motion simulator of this type consists of locating the simulator's Azimuth Axis in the North-South-Vertical plane with the Elevation Axis in the East-West-Horizontal plane. This document describes the preparation for, and techniques used to achieve, an accurate inertial alignment of the 57CD motion simulator in the Control Systems Laboratory located in Building 34 at CRC, and summarizes the results obtained. The alignment measurements were made in August - September 1979.

The alignment was carried out in two phases. A theodolite and autocollimator were used to establish simulator azimuth alignment from a Geodetic Survey of Canada reference and to measure East-West elevation, both through optical location of the simulator's Elevation Axis. An electronic level was used to establish East-West and North-South elevation alignment using the simulator's Azimuth Axis. East-West elevation was thus established in two independent ways, providing a confidence factor in the overall alignment achieved.

The theodolite used was a Zeiss model Th2, with direct reading capability to 1 arc-second in both azimuth and elevation. The electronic level used was a Taylor-Hobson Talyvel model M-15, with analog meter readout resolution of 1 arc-second. Two precision first-surface mirrors were used in the alignment procedure. These were 3" diameter, 3/4" thick, fused quartz optical flats with certified optical flatness of .000002" (1/10 λ), which were surfaced by NRC (Optical Components Laboratory, Division of Physics).

It is estimated that inertial alignment of the motion simulator was achieved to within ± 15 arc-seconds.

Location and True North Azimuth Reference

Figure B.1 is a plan layout of the Control Systems Laboratory, including surveying references. To establish an azimuth reference in the laboratory, the theodolite was set up at a Geodetic Survey of Canada (GSC) reference station (point B) on the roof of Building 2, and a sighting was made to Dish EEC (point A) in Area 8.

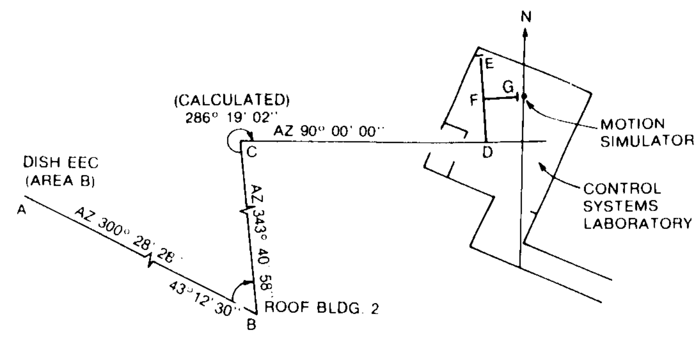


Figure B.1 Control Systems Laboratory - Surveyed Layout

A sighting was then taken on ground transfer point C to establish azimuth B-C. With the theodolite moved to point C, a calculated angle was turned from azimuth C-B to define C-D, an East-West line passing through the outside doorway into the Control Systems Laboratory.

With the theodolite in the laboratory at point D on the East-West line, azimuth D-C (West) was re-established. Using an autocollimator on the theodolite, a return was obtained from a precision mirror fastened to the wall (point E) in the northwest corner of the laboratory. The optical sighting and return (D-E-D) established the laboratory Azimuth Reference, and was measured at 78°10'21" North of West, or 348°10'21" True North Reference. This Azimuth Reference, achieved with just three angle transfers from the GSC reference azimuth, is estimated to be accurate to ± 10 arc-seconds.

Motion Simulator Tilt Axis Location

The Contraves Goerz 57CD motion simulator has two controlled axes of motion, as shown in Figure B.2. The Azimuth Axis is slipring interfaced and has complete freedom of rotation. The Elevation Axis is hardwired and is restricted servo-mechanically to ± 185 degrees of rotation from upright, as shown in Figure B.3.

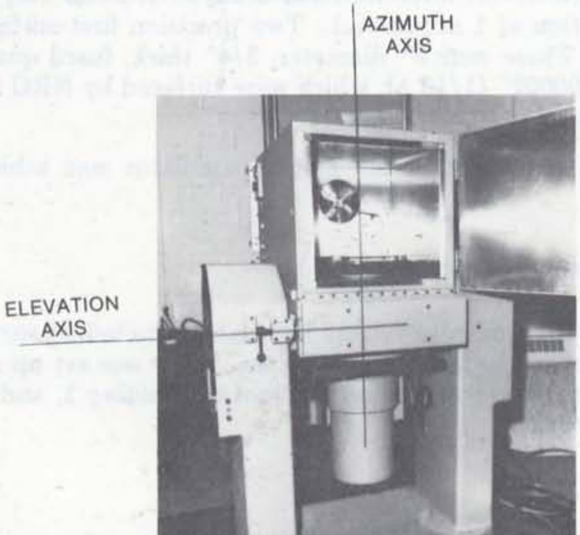


Figure B.2 Contraves Goerz 57CD Motion Simulator

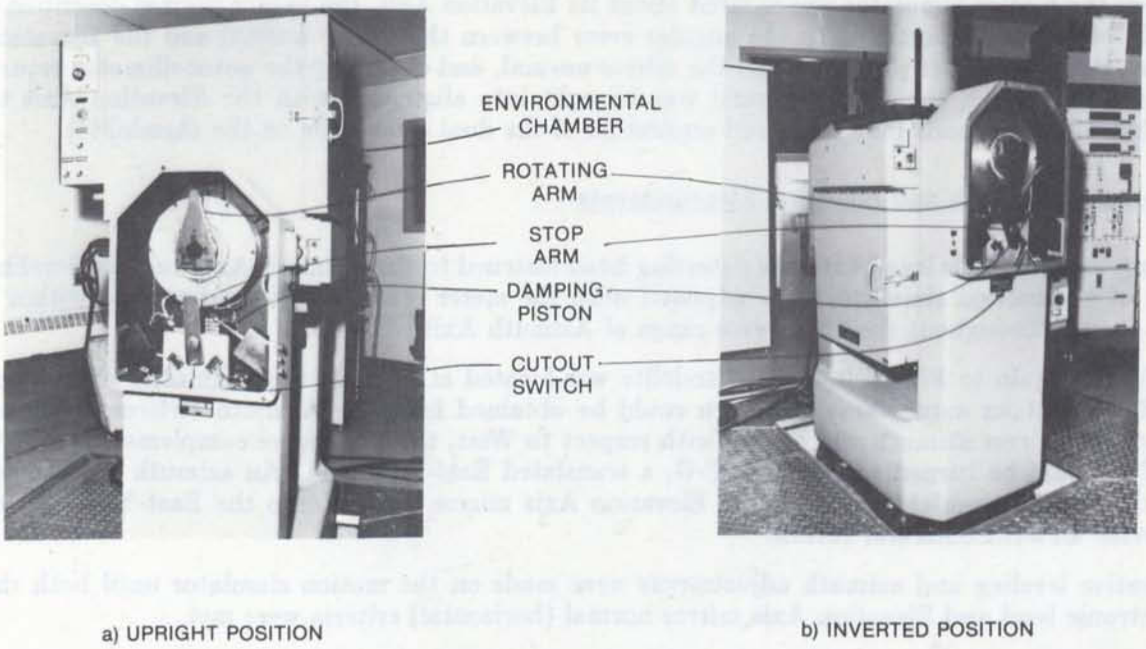


Figure B.3 Motion Simulator Tilt Axis Restraint System

To locate the Elevation Axis, the mechanical constraint arm was removed and replaced by a precision mirror, which was held in a specially designed mount by three steel dowels. These dowels were set on 5 degree taper pins at right angles to the dowels. The taper pin position was thread-adjustable. In this way, a precise means of adjusting the mirror normal was effected, with a controllable adjustment capability of about 2 arc-seconds.

The theodolite was set up as illustrated in Figure B.4, and an intermediate mirror was used to obtain an optical path of 34 feet from the theodolite to the Elevation Axis mirror.

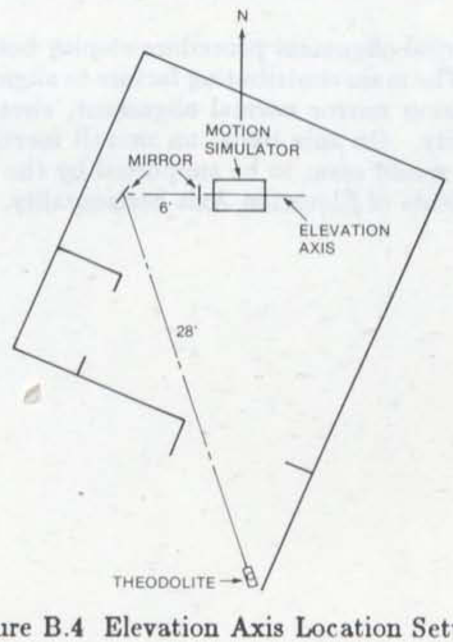


Figure B.4 Elevation Axis Location Setup

When the motion simulator was rotated about its Elevation Axis, the mirror normal described a circle of radius proportional to the angular error between the mirror normal and the Elevation Axis. Using the taper pins to adjust the mirror normal, and observing the autocollimator return on the theodolite, the mirror normal was brought into alignment with the Elevation Axis to within ±2 arc-seconds (the measured separation of the dual cross-hairs on the theodolite).

Simulator Azimuth and Elevation Measurements

Using the electronic level, with the detecting head fastened to the Azimuth Axis hub, the leveling feet of the motion simulator were adjusted until the meter readout was consistent to within 1 arc-second throughout the 360 degree range of Azimuth Axis rotation.

Referring again to Figure B.1, the theodolite was located at point F, approximately on the line D-E, so that an autocollimator return could be obtained from the Azimuth Reference mirror. Since the mirror azimuth was known with respect to West, the 180 degree complementary angle E-F-G could be turned to establish F-G, a translated East-West line. An azimuth adjustment of the motion simulator brought the Elevation Axis mirror normal onto the East-West line to provide an autocollimator return.

Iterative leveling and azimuth adjustments were made on the motion simulator until both the electronic level and Elevation Axis mirror normal (horizontal) criteria were met.

As an independent check of East-West Elevation Axis horizontality, the elevation angle of the Elevation Axis mirror was measured with the theodolite, and was found to be 14 arc-seconds below horizontal. This discrepancy with the electronic level test is in all likelihood due to limitations in theodolite leveling accuracy, and would be influenced by less than perfect orthogonality between the Azimuth and Elevation Axes of the motion simulator. The orthogonality of these axes is specified as 5 arc-seconds by the manufacturer. However, the closeness of agreement between two completely independent means of measuring East-West Axis horizontality provides a high degree of confidence in the accuracy of the overall alignment.

Conclusions

The techniques used in this inertial alignment procedure employ both the Azimuth and Elevation Axes of the motion simulator. The main contributing factors to alignment inaccuracy are Azimuth Reference measurement, Elevation mirror normal alignment, electronic level reading accuracy, and simulator axis orthogonality. On this basis, an overall inertial alignment accuracy of 15 arc-seconds is estimated. This would seem to be supported by the discrepancy between the two different methods of measurements of Elevation Axis horizontality.

DATE DUE
DATE DE RETOUR

LOWE-MARTIN No. 1137