IEEE Std 529-1980
(Supplement to IEEE Std 517-1974, R1980)

Supplement for Strapdown Applications to IEEE Standard Specification Format Guide and Test Procedure for Single-Degree-of-Freedom Rate-Integrating Gyros

Sponsor
Gyro and Accelerometer Panel
of the
IEEE Aerospace and Electronic Systems Society

Approved September 27, 1979
IEEE Standards Board

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Foreword

(This Foreword is not a part of IEEE Std 529-1980, Supplement for Strapdown Applications to IEEE Standard Specification Formal Guide and Test Procedure for Single-Degree-of-Freedom Rate-Integrating Gyros.)

This standard was prepared by the Gyro and Accelerometer Panel of the Aerospace Electronics Systems Society of the Institute of Electrical and Electronics Engineers. It is a supplement to IEEE Std 517-1974 (R1980), Standard Specification Format Guide and Test Procedure for Single-Degree-of-Freedom Rate-Integrating Gyros, which consists of two parts.

Part I of IEEE Std 517-1974 (R1980) is a specification format guide for the preparation of a rate-integrating gyro specification. Part II is a compilation of recommended procedures for testing a rate-integrating gyro.

The paragraphs in this supplement are to be used in substitution for or in addition to comparable paragraphs of IEEE Std 517-1974 (R1980). The numerical identification should make it readily apparent when a paragraph is substituted or added; a User's Cross Reference has also been included. The supplement contains additional performance requirements and tests which should be specified for a single-degree-of-freedom rate-integrating gyro when it is used as a strapdown sensor in operating environments typical of aircraft and missile applications.

This supplement applies to both parts of IEEE Std 517-1974 (R1980) and must be used in conjunction with both Parts I and II. The format of the supplement is the same as that of IEEE Std 517-1974 (R1980), and the same use is made of blank spaces, brackets, and boxed comments. Refer to the Foreword in that standard for guidelines on their use. The terminology used conforms to the gyro terminology that is contained in ANSI/IEEE Std 100-1977, Standard Dictionary of Electrical and Electronics Terms.

This supplement, when combined with IEEE Std 517-1974 (R1980), defines the requirements and test procedures in terms of characteristics unique to the gyro or those applications in which the dynamic angular inputs are significantly greater than the limitations identified in IEEE Std 517-1974 (R1980). The strapdown rate-integrating gyro, because it is captured through an external loop using the gyro torquer, provides a voltage, current, or pulse train proportional to angular rate about the input axis. An example of a model equation containing the additional terms which describe the gyro in strapdown applications is contained in 6.3. The characteristics of the external capture loop are considered to the extent necessary to define the gyro performance, even though such a loop is not part of the gyro.

This standard represents a group effort on a large scale. A total of 111 individuals attended 26 meetings of the Gyro and Accelerometer Panel while this standard was in preparation.

At the time this standard was approved the members of the working group were:

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User's Cross Reference

This cross reference compiles the sections of IEEE Std 517-1974 (R1980) affected by the Strapdown Supplement. All of the supplement sections of IEEE Std 517-1974 (R1980) are indicated by an asterisk (*) and the sections of this supplement are listed as either superseding or providing additional information. The title of each subsection in this supplement is listed in the table of contents.

IEEE Std 517-1974 (R1980)			**STRAPDOWN SUPPLEMENT**	
SECTION			**SUPERSEDING INFORMATION**	**ADDITIONAL INFORMATION**
Part I — Specification Format				
*1.	Scope			1
2.	Applicable Documents			
*2.2	Standards		2.2.2(1)	
3.	Requirements			
	*3.2.2	Definitions	3.2.2	
	*3.3.9	Torquer Performance		3.3.9.2.1 3.3.9.2.2
	*3.3.18	Output Noise	3.3.18	
	*3.3.22	Reference Constants		3.3.22.5
	3.3.23	Polarity		
				3.3.24 3.3.25 3.3.25.1 3.3.25.2 3.3.25.3 3.3.26 3.3.27 3.3.28
	*3.6.4	Environments	3.6.4.1 3.6.4.1.1 3.6.4.1.2	
4.	Quality Assurance Provisions			
*4.6	Test Methods			4.6 4.6.18.5.1 4.6.18.5.2
5.	Preparation for Delivery			
6.	Notes			
*6.3M	Model Equation		6.3	
Part II — Test Procedure				
7.	Scope			
8.	Description			

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SECTION				SUPERSEDING INFORMATION	ADDITIONAL INFORMATION
9.	Test Conditions and Test Equipment				
		*9.1.1	Ambient Environment	9.1.1.4 9.1.1.4.1 9.1.1.4.2	
		*9.2.2	Standard Operating Equipment	9.2.2	
10.	Test Procedures				
	*10.7	Torquer Test Series		10.7	
		*10.7.1	Purpose	10.7.1	
		*10.7.2	Test Equipment	10.7.2	
		*10.7.3	Test Setup and Procedure	10.7.3 10.7.3.1 10.7.3.1.1 10.7.3.1.2	
					10.7.3.1.3 10.7.3.1.4 10.7.3.1.5 10.7.3.1.6 10.7.3.1.6.1 10.7.3.1.6.2 10.7.3.4
		*10.7.4	Test Results		10.7.4.1.3 10.7.4.1.4 10.7.4.1.5 10.7.4.1.6 10.7.4.1.6.1 10.7.4.1.6.2
				10.7.4.4	
	10.10	Axis Alignment		10.10.3.1	
		*10.10.3	Test Setup and Procedure	10.10.3.2 10.10.4.1	
		*10.10.4	Test Results		
	10.13	Drift Rate Test Series			
		*10.13.1	Purpose	10.13.1	
		*10.13.2	Test Equipment	10.13.2	

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SECTION			SUPERSEDING INFORMATION	ADDITIONAL INFORMATION
	*10.13.3	Test Setup and Procedure		10.13.3.5 10.13.3.5.1 10.13.3.5.2 10.13.3.6 10.13.3.7 10.13.3.7.1 10.13.3.7.2 10.13.3.8 10.13.3.9
	*10.13.4	Test Results		10.13.4 10.13.4.5 10.13.4.5.1 10.13.4.5.2 10.13.4.6 10.13.4.6.1 10.13.4.6.2 10.13.4.7 10.13.4.7.1 10.13.4.7.2 10.13.4.8 10.13.4.9
10.14	Output Noise			
	10.14.1	Purpose		
	*10.14.2	Test Equipment	10.14.2	
	*10.14.3	Test Setup and Procedure	10.14.3 10.14.3.1 10.14.3.2	
	*10.14.4	Test Results	10.14.4 10.14.4.1 10.14.4.2	
*10.18	Environmental Test Series		10.18	

TABLES

*Table 3 Environmental Test Series	Table 3

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CLAUSE PAGE

Part I—Specification Format

1. Scope 1
3.2.2 Definitions 1
3.3.9.2.1 Command Rate Scale Factor Errors 2
3.3.9.2.2 Command Rate Scale Factor Sensitivities 2
3.3.18 Output Noise 2
3.3.22.5 Torquer Time Constant 3
3.3.24 Anisoinertia Drift Rate Coefficient 3
3.3.25 Cross-Coupling Drift Rate 3
3.3.25.1 Nonoscillatory 3
3.3.25.2 Spin-Input Rectification 3
3.3.25.3 Spin-Output Rectification 3
3.3.26 Torquer Current Rectification Drift Rate 3
3.3.27 Rate Hysteresis Error 3
3.3.28 Output Axis Rate Error 4
3.6.4.1 Vibration 4
3.6.4.1.1 Linear 4
3.6.4.1.2 Angular 4
4.6 Test Methods 4
4.6.18.5.1 Vibration, Linear 4
4.6.18.5.2 Vibration, Angular 4
6.3 Model Equation 4

Part II—Test Procedure

9.1.1.4 Vibration 7
9.1.1.4.1 Linear 7
9.1.1.4.2 Angular 7
9.2.2 Standard Operating Equipment 7
10.7 Torquer Test Series 7
10.7.1 Purpose 7
10.7.2 Test Equipment 8
10.7.3 Test Setup and Procedure 8
10.7.3.1 Command Rate Scale Factor 8
10.7.3.1.1 High Input Rate Test 8
10.7.3.1.2 Low Input Rate Test 8
10.7.3.1.3 Nonlinearity 8
10.7.3.1.4 Asymmetry 8
10.7.3.1.5 Repeatability 8
10.7.3.1.6 Command Rate Scale Factor Sensitivities 9
10.7.3.1.6.1 Temperature 9
10.7.3.1.6.2 Magnetic 9
10.7.3.4 Torquer Time Constant 9
10.7.4.1.3 Nonlinearity, K_{TN} 9
10.7.4.1.4 Asymmetry, K_{TA} 9
10.7.4.1.5 Repeatability 9
10.7.4.1.6 Command Rate Scale Factor Sensitivities 9
10.7.4.1.6.1 Temperature 9

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CLAUSE PAGE

10.7.4.1.6.2 Magnetic 10
10.7.4.4 Torquer Time Constant 10
10.10.3.1 Alignment of the IRA to the Projection of the IA on the IRA-SRA Plane 10
10.10.3.2 Alignment of the IA to the IRA-SRA Plane 11
10.10.4.1 Alignment of the IRA to the Projection of the IA on the IRA-SRA Plane 11
10.13.1 Purpose 11
10.13.2 Test Equipment 11
10.13.3.5 Anisoinertia Drift Rate Coefficient 11
10.13.3.5.1 Constant Rate Method 11
10.13.3.5.2 Oscillatory Method 12
10.13.3.6 Cross-Coupling Drift Rate 12
10.13.3.7 Torquer Current Rectification Drift Rate 13
10.13.3.7.1 Angular Rate Sensing Mode, Method 1 13
10.13.3.7.2 Angular Displacement Sensing Mode (Rate-Integrating Mode), Method 2 13
10.13.3.8 Rate Hysteresis Error 14
10.13.3.9 Output Axis Rate Error 14
10.13.4 Test Results 14
10.13.4.5 Anisoinertia Drift Rate Coefficient 14
10.13.4.5.1 Constant Rate Method 14
10.13.4.5.2 Oscillatory Method 15
10.13.4.6 Cross-Coupling Drift Rate 15
10.13.4.6.1 Spin-Output Rectification 15
10.13.4.6.2 Spin-Input Rectification 15
10.13.4.7 Torquer Current Rectification Drift Rate 15
10.13.4.7.1 Angular Rate Sensing Mode, Method 1 15
10.13.4.7.2 Angular Displacement Sensing Mode (Rate-Integrating Mode), Method 2 15
10.13.4.8 Rate Hysteresis Error 16
10.13.4.9 Output Axis Rate Error 16
10.14.2 Test Equipment 16
10.14.3 Test Setup and Procedure 16
10.14.3.1 Method 1 16
10.14.3.2 Method 2 17
10.14.4 Test Results 17
10.18 Environmental Test Series 18

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Supplement for Strapdown Applications to IEEE Standard Specification Format Guide and Test Procedure for Single-Degree-of-Freedom Rate-Integrating Gyros

Part I—Specification Format

1. Scope

This specification defines the requirements for a single-degree-of-freedom rate-integrating gyro to be used as a strapdown sensor for an [inertial navigation system, an attitude reference unit,_____] in an [aircraft, missile,_____] application. The characteristics of the external capture electronics are considered where necessary to define gyro performance.

2.2.2

1) ANSI/IEEE Std 100–1977, Standard Dictionary of Electrical and Electronics Terms.

3.2.2 Definitions

The following standard and the model equation of 6.3 define terminology used in this specification:

ANSI/IEEE Std 100–1977, Standard Dictionary of Electrical and Electronics Terms

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3.3.9.2.1 Command Rate Scale Factor Errors

1) *Nonlinearity.* The absolute value of the maximum deviation of the command rate scale factor from the nominal value (K_{TO})shall be less than _____ [(rad/s)/mA, (rad/h)/mA, (°/s)/mA, (°/h)/mA].

This error can also be expressed in parts per million (ppm) of K_{TO}.

K_{TO} is frequently obtained from a least-squares linear fit to the data. A higher order fit of scale factor variation with rate may be specified as an alternate to a linear model.

2) *Asymmetry.* The difference between the command rate scale factor measured with positive and negative command rates shall not exceed _____ [(rad/s)/mA, (rad/h)/mA, (°/s)/mA, (°/h)/mA].

This error can also be expressed per million (ppm) of K_{TO}.

3) *Repeatability.* _____ [(rad/s)/mA, (rad/h)/mA, (°/s)/mA, (°/h)/mA] [maximum spread, 1σ, _____].

This error can also be expressed in parts per million of K_{TO}. Repeatability involves changes in command rate scale factor that occur between periods of operation. Motor shutdowns, cool downs, time between runs, and other factors pertinent to the particular application shall be specified.

3.3.9.2.2 Command Rate Scale Factor Sensitivities

1) *Temperature.* The change in command rate scale factor resulting from a change in steady-state operating temperature shall not exceed ± _____[((rad/s)/mA)/°C, ((rad/h)/mA)/°C, ((°/s)/mA)/°C, ((°/η)/μA)/°C].

This sensitivity can also be expressed in ppm/°C.

2) *Magnetic*. The change in command rate scale factor resulting from a change in steady-state ambient magnetic field shall not exceed ± _____[((rad/s)/mA)/mT, ((rad/s)/mA)/G, ((rad/h)/mA)/mT, ((rad/h)/mA)/G, ((°/s)/mA)/mT, ((°/s)/mA)/G, ((°/h)/mA)mT, ((°/h)mA)/G].

This sensitivity can also be expressed in ppm/mT or ppm/G. Gyro axes and characteristics of the field shall be defined. If exposure to a varying field is required, the nature of the variation shall be described. Demagnetization may be necessary following exposure.

3.3.18 Output Noise

The equivalent input angle noise in the electrical output signal for zero input shall not exceed _____ (μrad, arc seconds) rms as determined by the square root of the integral of the power spectrum between _____Hz and _____Hz. The equivalent rate noise shall not exceed _____ [μrad/s, ″/s, °/h] rms as determined by the square root of the integral of the power spectrum between _____Hz and _____ Hz.

If necessary, the power spectral density of input angle noise and/or rate noise may be specified over a specific frequency range in the place of rms error. In any case, it must be recognized that the electronics associated with the gyro contribute to the total noise error.

For certain applications, inputs other than zero may be specified.

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3.3.22.5 Torquer Time Constant

_____ s.

3.3.24 Anisoinertia Drift Rate Coefficient

_____ ± _____ [(rad/h)/(rad/s)^2, (°/h)/(°/)^2].

> It should be noted that anisoinertia can vary due to decoupling of the spin-motor moment of inertia from the moment of inertia of the gimbal in the presence of angular acceleration about the spin axis. The decoupling will occur at angular accelerations which exceed the pull-out torque capability of the motor.

3.3.25 Cross-Coupling Drift Rate

> This drift rate results from nonoscillatory and/or oscillatory rotations about an axis other than the input axis.

3.3.25.1 Nonoscillatory

0 ± _____[rad/h, °/h].

> The gyro input axis misalignment (3.3.20) and the hangoff angle due to the null offset and finite gain of the capture electronics must be considered when specifying this drift rate.

3.3.25.2 Spin-Input Rectification

0 ± _____ [rad/h, °/h].

> The selected conditions under which the drift rate is to be specified should be defined.

3.3.25.3 Spin-Output Rectification

0 ± _____ [rad/h, °/h].

> The selected conditions under which the drift rate is to be specified should be defined.

3.3.26 Torquer Current Rectification Drift Rate

0 ± _____ [rad/h, °/h].

> The selected conditions under which the drift rate is to be specified should be defined.

3.3.27 Rate Hysteresis Error

_____[rad /h, °/h], maximum.

> The selected conditions under which the rate error is to be specified should be defined.

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3.3.28 Output Axis Rate Error

_____ [rad/h, °/h] maximum.

> The selected conditions under which the rate error is to be specified should be defined.

3.6.4.1 Vibration

3.6.4.1.1 Linear

Sinusoidal: _____ [cm, in] DA (double amplitude) _____ to _____ Hz; _____ [m/s_2, *g*] peak, _____ to _____ Hz. Sweep rate: _____ minutes per octave (continuous). Exposure time: _____ per axis.

3.6.4.1.2 Angular

Sinusoidal: _____ rad/s^2 _____ to _____ Hz. Sweep rate shall be _____ minutes per octave (continuous). Exposure time: _____ per axis.

> Axes shall be defined.
>
> When available, supply the specific vibration characteristics including dwell frequencies, frequency spectrum, time duration, etc.
>
> If exposure to random vibration is required, power spectral density, bandwidth, peak acceleration level, and duration shall be specified.

4.6 Test Methods

4.6.18.5.1 Vibration, Linear

4.6.18.5.2 Vibration, Angular

6.3 Model Equation

The model equation of a single-degree-of-freedom rate-integrating gyro is defined as a series which mathematically relates the output of a gyro to the several inputs applied to the gyro. Following is the assumed model equation for the single-degree-of-freedom rate-integrating gyro used in a strapdown application when each term has the dimension of angular velocity.

$$\left(\frac{J_O}{H} + \tau_\alpha\right)\ (\ddot{\theta}_O + \ddot{\phi}_O)\ + \frac{C}{H}\dot{\theta}_O + \frac{K}{H}\theta_O$$

$=\omega_I$ (rate, in inertial space, about the IRA)

$+ D_F$ (acceleration-insensitive drift rate)

$+ D_I a_I + D_O a_O + D_s a_s$ (acceleration-sensitive drift rate)

$+ D_{II} a_I^2 + D_{SS} a_S^2 + D_{IS} a_I a_s + D_{IO} a_I a_O$

$+ D_{OS} a_O a_S$ (acceleration-squared-sensitive drift rate)

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$+ K_T\, i$ (command rate)

$+\frac{(J_S - J_I)}{H}\ \omega_I\omega_s$ (anisoinertia drift rate)

$- \theta_O\ \omega_S$ (cross-coupling drift rate)

$+ D_\omega\ (\omega_O)$ (output axis rate error)

The model equation stated is the result of summing torques about the OA, normalized to have dimensions of angular velocity by division by angular momentum. The sign convention chosen is such that a positive torque about the OA is associated with a positive rate.

For most of the testing required by this standard, a steady-state version of the above equation may be used wherein the dynamic terms on the left side of the equation are zero.

Cross-coupling anisoinertia terms such as $((J_S — J_I)/H)\ (\omega_I^2 — \omega_S^2)\ \theta_O$ are usually negligible. However, they may need to be considered for precise applications and where the gyro axes are not the principal axes of inertia.

Where significant, other terms should also be included in the model equation.

Symbols used in the model equation are defined as follows:

J_I, J_O, J_S	= gimbal moments of inertia about the input, output, and spin axes, respectively
H	= rotor angular momentum
τ_α	= time constant increment due to fluid mass coupling

τ_α is a function of dynamic fluid effects and is negligible at frequencies below the inverse of the nominal characteristic time. It is considered basically due to the mass of damping fluid. The degree to which the fluid mass is coupled-in depends on the gyro design and the fluid velocity and acceleration at each point in the damping gap and is therefore also a function of the frequency of angular accelerations applied to the output axis.

θ_O	= gimbal angular displacement about the output axis with respect to the case
ϕ_O	= case angular displacement about the output axis with respect to inertial space
C	= damping coefficient about the output axis with respect to the case
K	= elastic restraint coefficient about the output axis with respect to the case
$\omega_I, \omega_O, \omega_S$	= angular velocity, with respect to inertial space, of the gyro case about the input, output, and spin reference axes, respectively
D_F	= acceleration-insensitive drift rate
a_I, a_O, a_S	= components (along input, output, and spin reference axes, respectively) of the vector sum of the apparent acceleration due to gravity and the second time derivative of a position vector in inertial space; on the earth, the positive direction of this apparent acceleration due to gravity is defined as that of an upward acceleration of the gyro case.
$D_I a_I$	= drift rate attributable to acceleration along the input axis, where D_I is a drift rate coefficient
$D_O a_O$	= drift rate attributable to acceleration along the output axis, where D_O is a drift rate coefficient
$D_S a_S$	= drift rate attributable to acceleration along the spin axis, where D_S is a drift rate coefficient
$D_{II} a_I^2$	= drift rate attributable to the square of acceleration along the input axis, where D_{II}, is a drift rate coefficient
$D_{SS} a_S^2$	= drift rate attributable to the square of acceleration along the spin axis, where D_{SS} is a drift rate coefficient
$D_{IS} a_I a_S$	= drift rate attributable to the product of accelerations along the input axis and spin axis, where D_{IS} is a drift rate coefficient
$D_{IO} a_I a_O$	= drift rate attributable to the product of accelerations along the input axis and output axis, where D_{IO} is a drift rate coefficient

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$D_{OS}a_Oa_S$ = drift rate attributable to the product of accelerations along the output axis and spin axis, where D_{OS} is a drift rate coefficient

K_T = command rate scale factor
= $K_{TO} + K_{TN} + K_{TA}$
where
K_{TO} = nominal value of command rate scale factor
K_{TN} = command rate scale factor nonlinearity
K_{TA} = command rate scale factor asymmetry

The polarity of K_T should be consistent with the polarity convention of Fig 1 and 3.3.23.1 and 3.3.23.3. The preferred sign convention for K_T is (+).

Additional terms may be included in K_T when digital pulse torquing is used.

For rates that are generated by torques which are a function of other than the first power of i (that is, by variable reluctance torquers, pulse torquing, etc), the term $K_T i$ should be replaced with a rate term consistent with the torquer or technique used and with the sign convention established.

i = torquer current, which is a function of θ_O, capture electronics loop, and command rate

$\frac{J_S - J_I}{H}$ = inertia drift rate coefficient

$\theta_O\omega_S$ = drift rate attributable to the product of the instantaneous gimbal angular displacement about the output axis and the instantaneous angular velocity of the gyro case about the spin reference axis (θ_O is small-angle approximation for sin θ_O).

For oscillatory inputs the cross-coupling drift rate is the sum of spin-input and spin-output rectifications. The average value is given by the equation:

$$\vartheta_O\omega_S = G_1(f)\,\frac{\Omega_I\Omega_S}{2}\cos\alpha_1 + \phi_1(f)$$

(spin-input rectification)

$$+ G_2(f)\,\frac{\Omega_O\Omega_S}{2}\cos\alpha_2 + \phi_2(f)$$

(spin-output rectification)

where

$G_1(f), \phi_1(f)$ =magnitude and phase of gyro frequency response to ω_I
$G_2(f), \phi_2(f)$ =magnitude and phase of gyro frequency response to ω_O
$\Omega_I, \Omega_O, \Omega_S$ =amplitude of input rates $\omega_I, \omega_O, \omega_S$, respectively
α_1, α_2 =phase angle between input axis and spin axis rates and between output axis and input axis rates, respectively

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D_ω ($^\omega$ o) = rate error attributable to angular rate about the output axis where D_ω is a function of ω_o.

D_ω (ω_o) represents an apparent IA misalignment caused by angular rates about the OA. This effect, in terms of the resultant rate errors, is a function of various orders of OA angular rate and may be discontinuous. The misalignment effect varies with the type of OA suspension used in the gyro design and is negligible in certain gyros.

9.1.1.4 Vibration

The following limits apply to each of the three axes of a coordinate system:

9.1.1.4.1 Linear

1) *Acceleration.* _____ *g* maximum
2) *Frequency Range.* _____ to _____ Hz

9.1.1.4.2 Angular

1) *Acceleration.* _____ rad/s^2 maximum
2) *Frequency Range.* _____ to _____ Hz

9.2.2 Standard Operating Equipment

Standard operating equipment is the equipment used to provide standard gyro operation and shall be listed here by name, manufacturer, model, part number, or by performance requirements. In the strapdown gyro the capture electronics are part of the standard operating equipment. The capture electronics will significantly influence the test results and consequently must be completely specified.

10.7 Torquer Test Series

10.7.1 Purpose

The purpose of this test series is to measure gyro command rate scale factor, command rate scale factor errors, command rate scale factor sensitivities, maximum command rate, and continuous command rate.

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10.7.2 Test Equipment

In addition to the standard operating equipment from 9.2.2, the following test equipment from 9.2.3 is required for this test and shall be listed in this section:

1) Single-axis rate table
2) Single-axis dividing head
3) Means of measuring gyro torquer output
4) Timing device
5) Means of measuring gyro temperature
6) Rate table mountable means of generating magnetic fields
7) Rate table mountable temperature environmental chamber
8) Means of measuring impedance

10.7.3 Test Setup and Procedure

10.7.3.1 Command Rate Scale Factor

10.7.3.1.1 High Input Rate Test

Align the rate table rotational axis to within _____ arc seconds of vertical. Mount the gyro in the fixture on the rate table so that the IA is parallel to the table rotational axis within _____ arc seconds. Connect the gyro to the capture electronics and measuring equipment. Operate the gyro in accordance with the standard test conditions of 9.1. Apply an input rate of _____ °/s [through an angle of _____ degrees, for a duration of__s] in a [cw, ccw] direction. Record torquer [current, pulse count] at a sample interval of ____ [″, °, rev], input rate (°/s), and [cw, ccw] rotation. Repeat this test for rates of _____ °/s and [cw, ccw] rotation.

Operating the gyro at high rates may induce time dependent, thermally related scale factor errors. It may be desirable to specify the loop closure time and the time interval from the application of the input rate to the taking of readings. The sequence of tests may be selected to identify effects such as hysteresis and thermal sensitivity. During the test it may be desirable to monitor the gyro pickoff output.

10.7.3.1.2 Low Input Rate Test

For some applications it may be required to establish the performance of the gyro in the low input rate region. The procedure in 10.7.3.1.2 of IEEE Std 517-1974 (R1980) may be used for recording pulse count in place of torquer current where applicable.

10.7.3.1.3 Nonlinearity

To be determined from the procedures of 10.7.3.1.1 and 10.7.3.1.2.

10.7.3.1.4 Asymmetry

To be determined from the procedures of 10.7.3.1.1 and 10.7.3.1.2.

10.7.3.1.5 Repeatability

Repeat the procedure of [10.7.3.1.1, 10.7.3.1.2]_____times.

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10.7.3.1.6 Command Rate Scale Factor Sensitivities

The purpose of the sensitivity tests is to determine the changes in command rate scale factor caused by variations in the thermal and magnetic environments.

10.7.3.1.6.1 Temperature

Enclose the gyro in a temperature-controlled chamber. Stabilize the gyro at _____°C ± _____C for_____[min, h]. Repeat selected procedures of [10.7.3.1.1, 10.7.3.1.2.] Record the gyro temperature in addition to the data listed in [10.7.3.1.1, 10.7.3.1.2.] Repeat the test at _____°C.

10.7.3.1.6.2 Magnetic

Position the magnetic field generator on the rate table to subject the gyro to an ambient magnetic field with a flux density of _____ [mT, G]. Repeat selected procedures of [10.7.3.1.1, 10.7.3.1.2.] Record the magnetic flux density in addition to the data listed in [10.7.3.1.1, 10.7.3.1.2.] Repeat the test at _____ [mT, G].

> Field conditions of the application such as flux distribution and time variation should be considered in establishing the test values.

10.7.3.4 Torquer Time Constant

Connect the impedance measuring equipment to the gyro torquer. Record the inductance and resistance at frequency and voltage settings of _____±_____Hz and _____±_____ ς.

> For successful impedance matching with capture electronics, the second-order characteristics of the torquer may need to be considered.

10.7.4.1.3 Nonlinearity, K_{TN}

The absolute value of the maximum deviation from the least-squares straight line that can be generated from the input-output data obtained in 10.7.3.1.1 is the command rate scale factor nonlinearity and shall conform to the requirements of Section _____.

10.7.4.1.4 Asymmetry, K_{TA}

The difference between the command rate scale factor measured with a positive and a negative command rate obtained in 10.7.3.1.1 shall conform to the requirements of Section _____.

10.7.4.1.5 Repeatability

The variation in the command rate scale factor of the repetitive test series of 10.7.3.1.5 shall conform to the requirements of Section _____.

10.7.4.1.6 Command Rate Scale Factor Sensitivities

10.7.4.1.6.1 Temperature

The change in command rate scale factor obtained from 10.7.4.1.1 divided by the change in temperature shall conform to the requirements of Section _____.

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10.7.4.1.6.2 Magnetic

The change in command rate scale factor obtained from 10.7.4.1.1 divided by the change in the magnetic flux density shall conform to the requirements of Section _____.

10.7.4.4 Torquer Time Constant

Using the data obtained in 10.7.3.4, compute the torquer time constant as follows:

$$\tau = \frac{L}{R}$$

where

τ = torquer time constant, seconds
L = torquer inductance, henrys
R = torquer resistance, ohms

The results shall conform to the requirements of Section _____.

10.10.3.1 Alignment of the IRA to the Projection of the IA on the IRA-SRA Plane

1) *Open-Loop Method.* Align the rate table rotational axis within_____arc seconds of vertical. Mount the gyro in the fixture on the rate table so that the SRA is parallel to the rate table rotational axis within _____ arc seconds. Connect the pickoff to the pickoff output measuring equipment. Operate the gyro in accordance with the standard test conditions of 9.1. Apply a table rate of _____±_____°/s in the same sense as the SRA. After _____ revolutions minimum, measure the average pickoff output voltage over a complete revolution.

> The rate about the SRA should be large enough to make the effects of gyro drift rates and the horizontal component of the earth's rate negligible.
>
> To eliminate test fixture errors, it may be desirable to rotate the gyro 180° about the ORA with respect to the fixture and repeat the test.

2) *Closed-Loop Method.* Align the rate table rotational axis within_____arc seconds of vertical. Mount the gyro in the fixture on the rate table so that the SRA is parallel to the rate table rotational axis within_____arc seconds. Operate the gyro in the rate-sensing mode (8.2) in accordance with the standard test conditions of 9.1. Connect the gyro to the torquer current measuring equipment. Apply an input rate of _____±_____°/s about the SRA for_____revolutions of the rate table. Measure the average torquer current. Reverse the direction of the table rotation and repeat the above test.

> To eliminate test fixture errors it may be desirable to rotate the gyro 180° about the ORA with respect to the fixture and repeat the test for both directions of the table rotation.
>
> If alignment stability is specified, a direction of table rotation and current polarity must be recorded.

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10.10.3.2 Alignment of the IA to the IRA-SRA Plane

A false measurement of the misalignment angle could result from this test because of the output axis rate error D_{ω} (ω_o) term. Refer to 10.13.3.9 for an alternate test procedure.

10.10.4.1 Alignment of the IRA to the Projection of the IA on the IRA-SRA Plane

1) *Open-Loop Method*. The misalignment is calculated from the data obtained in 10.10.3.1 (1) and the pickoff scale factor from 10.6.4.1, nominal scale factor, as follows:

$$\text{misalignment} = \frac{\text{average pickoff output (V)}}{\text{pickoff scale factor (V/°)}}$$

The results shall conform to the requirements of Section_____.

2) *Closed-Loop Method*. The misalignment is calculated from the data obtained in 10.10.3.1 (2) and the command rate scale factor from 10.7.4.1 as follows:
misalignment = $\sin^{-1}$

$$\times \frac{\left(\begin{array}{c}\text{difference between the} \\ \text{two average currents}\end{array}\right)\left(\begin{array}{c}\text{command rate} \\ \text{scale factor}\end{array}\right)}{2 \times \text{table rate}}$$

The results shall conform to the requirements of Section_____.

10.13.1 Purpose

The purpose of this test series is to measure the gyro anisoinertia drift rate, cross-coupling drift rate, torquer current rectification drift rate, rate hysteresis error, and output axis rate error.

10.13.2 Test Equipment

In addition to the standard operating equipment from 9.2.2, the following test equipment from 9.2.3 is required for these tests and shall be listed in this section:

1) Rate table
2) Oscillating rate table
3) Means of measuring rate table angular amplitude and frequency
4) Means to mechanically lock the rate table in a reference position
5) Voltage-controlled oscillator, current quantizer, or other means of converting the gyro current readout to a serial pulse train
6) Up- down counter or other means for measuring the total number of gyro readout pulses accumulated during a preselected, gated interval
7) Variable amplitude/frequency oscillator

10.13.3.5 Anisoinertia Drift Rate Coefficient

10.13.3.5.1 Constant Rate Method

Align the rate table axis to within _____ arc minutes of vertical. Mount the gyro in the fixture on the rate table with OA perpendicular to the rate table axis within _____ arc minutes and with the intersection of the major gyro axes within _____ cm of the rate table axis. Align IA during successive tests at an angle α of 45°, 135°, 225°, and 315° within _____ arc minutes with the plane of rotation, where $\alpha = 0°$ for SA pointing up and α increases when rotating the gyro in a positive direction about OA.

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Operate the gyro in the rate-sensing mode (8.2) with a nonspinning rotor in accordance with the standard test conditions of 9.1. Only one phase of the spin motor shall be energized with normal voltage and frequency to effect a locking of the rotor to the stator. Connect the gyro to the equipment for recording torquer [current, pulse rate].

Record the torquer [current, pulse rate] when the gyro is mounted in any of the four positions of IA as described above and while the rate table is rotating at a rate of ____ ± ____°/s in either clockwise or counterclockwise direction. Record polarities of torquer currents or torquer pulses and direction of table rotation.

> Table rates must be selected high enough so that anisoinertia terms can readily be distinguished from other drift terms. For greater accuracy in deriving the anisoinertia drift coefficients, it may be desirable to perform the test at more than one rate and to repeat the tests with the table rotating in the opposite direction.

10.13.3.5.2 Oscillatory Method

Align the rate table axis to within _____ arc minutes of vertical. Mount the gyro in the fixture on the rate rate table such that the IRA and SRA are each at 45° ± _____ arc minutes to the vertical. Operate the gyro in accordance with the standard test conditions of 9.1.

Connect the readout quantizer to the gyro and to the up-down counter. Gate the counter to accumulate pulses over a selected gating interval of_____ seconds. With the rate table locked, accumulate pulses over this interval. Designate the accumulated counts as C_1.

Begin a second accumulation of pulses. After _____ seconds, unlock the table and oscillate it at a frequency of____±____ Hz and a rate amplitude of____±____°/s. Continue to operate the table for a period of time so that the table rate can be brought to zero and the table relocked before the end of the gating interval. Designate counts accumulated during this gating interval as C_2

Record the rate table frequency, the zero-to-peak amplitude of the table rate, the time during which the rate table was ocillating, and the accumulated pulse counts C_1, C_2.

> Select the rate table frequency to be at least ____ octaves below the motor hunting frequency of the gyro, so that the actual rates coupled into the sensitive element will not be variable as a function of frequency.
>
> Select the time for rate table oscillation to be sufficiently long to minimize the transient effects of table startup and shutdown.
>
> If it is desired to determine the anisoinertia drift rate coefficient at a single input frequency, select the rate table frequency to be sufficiently below the motor hunting frequency of the gyro, so that the actual rates coupled into the sensitive element will not vary as a function of table frequency.
>
> If it is desired to determine the anisoinertia drift rate coefficient as a function of the frequency of the input, 10.13.3.5 may be repeated at various frequencies, taking enough observations in the region of the motor hunting frequency to ensure that a possibly sharp peak is adequately defined.

10.13.3.6 Cross-Coupling Drift Rate

Align the rate table axis to within _____ arc minutes of vertical. Mount the gyro in the fixture on the rate table such that the OA and SRA are each at 45° ± _____ arc minutes to the vertical. Operate the gyro in accordance with the standard test conditions of 9.1.

Connect the readout quantizer to the gyro and to the up- down counter. Gate the counter to accumulate pulses over a selected gating interval of _____ seconds. With the rate table locked, accumulate pulses over this interval. Designate the accumulated counts as C_1.

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Begin a second accumulation of pulses. After _____ seconds, unlock the table and oscillate it at a frequency of _____±_____Hz and a rate amplitude of_____± _____°/s. Continue to operate the table for a period of time so that the table rate can be brought to zero and the table relocked before the end of the gating interval. Designate counts accumulated during this gating interval as C_2.

Record the rate table frequency, the zero-to-peak amplitude of the table rate, the time during which the rate table was ocillating, and the accumulated pulse counts C_1, C_2.

> Select the lowest rate table frequency to at least _____ octaves above the motor hunting frequency of the gyro, so that the actual rates coupled into the sensitive element will not be variable as a function of frequency.
>
> Select the time for rate table oscillation to be sufficiently long to minimize the transient effects of table startup and shutdown.

10.13.3.7 Torquer Current Rectification Drift Rate

10.13.3.7.1 Angular Rate Sensing Mode, Method 1

Align the dividing head spindle axis to within _____ arc minutes of vertical. Mount the gyro in the fixture on the dividing head so that the gyro ORA is parallel to the spindle axis within _____ arc minutes and the IRA is east within _____ arc minutes. Operate the gyro in the rate-sensing mode (8.2) in accordance with the standard test conditions of 9.1.

Connect the gyro torquer to the torquer current measurement equipment. Connect the differential input of the torque amplifier to a variable oscillator capable of producing alternating torquer currents up to _____ mA peak at various frequencies from _____ to _____ kHz in _____ kHz steps.

Connect the readout quantizer to the gyro and to the up-down counter. Gate the counter to accumulate pulses over a selected gating interval of _____ s. With zero output of the oscillator, accumulate pulses over this interval. Designate the accumulated pulses as C_1.

Begin a second accumulation of pulses. After _____ seconds adjust or switch the oscillator so as to produce a torquer current of_____ ± ____ mA peak at a frequency of ____ ± ____ kHz. Continue to apply the alternating torquer current for a period of time so that the oscillator output can be brought to zero before the end of the gating interval. Designate counts accumulated during this gating interval as C_2.

Record the oscillator frequency, the amplitude of applied torquer current, the time during which the alternating torquer current was applied, and the accumulated pulse counts C_1, C_2.

Repeat the procedure at the following frequencies: _____ kHz.

10.13.3.7.2 Angular Displacement Sensing Mode (Rate-Integrating Mode), Method 2

Align the servo table rotational axis to within _____ arc minutes of vertical. Mount the gyro in the fixture on the servo table so that the IA is parallel to the table rotational axis within _____ arc minutes. Operate the gyro in the angular displacement sensing mode (rate-integrating mode, 8.1) in accordance with the standard test conditions of 9.1.

Connect the gyro torquer via a high impedance to a variable oscillator capable of producing alternating torquer currents up to _____ mA peak at various frequencies from _____ to _____ kHz in _____ kHz steps.

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Connect the table angular position output device to the servo-driven table position recording equipment. With zero output from the oscillator, measure the change in table angular displacement over a selected interval of _____ seconds. Designate this angular displacement change as θ_1.

Begin a second measurement of change in table angular displacement.

After _____ seconds adjust or switch the oscillator so as to produce a torquer current of _____ ± _____ mA peak at a frequency of _____ ± _____ kHz. Continue to apply the alterating torquer current for a period of time so that the oscillator output can be brought to zero before the end of the selected measurement interval. Designate this change of table angular position as θ_2.

Record the oscillator frequency, the amplitude of torquer current, the time during which the alternating torquer current was applied, and the measured changes of table displacement θ_1,θ_2.

Repeat the procedure at the following frequencies: _____ kHz.

> The selection of alternating torquer current amplitudes and frequencies should be based on a Fourier analysis of the waveform to be encountered in the application. Select the time for application of the current to be sufficiently long to minimize the transient effect of bringing up, turning down, or switching the oscillator amplitude. The rectification effect varies with tuning of the torquer, the applied frequencies, and the gain of the gyro capture loop.

10.13.3.8 Rate Hysteresis Error

Align the rate table rotational axis within _____ arc minutes of vertical. Mount the gyro in the fixture on the rate table with the IA aligned parallel with the rate table rotational axis within _____ arc minutes. Operate the gyro in the rate-sensing mode (8.2) in accordance with the standard test conditions of 9.1. Rotate the gyro at _____ ± _____ °/s counterclockwise. Disengage the rate table servo drive and let the table coast to a stop. With the rate table at rest, record the torquer [current, pulse rate]. Repeat the above procedure using clockwise rotation.

10.13.3.9 Output Axis Rate Error

Align the rate table rotational axis to within _____ arc minutes of vertical. Mount the gyro in the fixture on the rate table with the ORA aligned parallel with the rate table rotational axis within _____ arc minutes and the IRA east within _____ arc minutes. Operate the gyro in the rate-sensing mode (8.2) in accordance with the standard test conditions of 9.1.

Apply a table rate of _____ ± _____ °/s and record the mean torquer current for _____ full revolutions of the table. Repeat by increments to the specified rate limit, reverse the direction of table rotation, and repeat the above measurements so that data for both clockwise and counterclockwise rotations with reasonable symmetry have been obtained.

10.13.4 Test Results

10.13.4.5 Anisoinertia Drift Rate Coefficient

10.13.4.5.1 Constant Rate Method

The anisoinertia drift rate coefficient equals:

$$\frac{J_S - J_I}{H} = \frac{1}{2\omega^2} K_{TO} (i_{45} - i_{135} + i_{225} - i_{315})$$

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where i_{45}, i_{135}, i_{225}, and i_{315} is the recorded torquing current or pulse rate at test positions for $\alpha = 45°$, 135°, 225°, and 315°. The other terms of this equation are defined in 6.3.

Torques due to centrifugal acceleration must be taken into account when the product of gimbal unbalance and its distance from the table axis is large. Such torques may be determined by translating the gyro on the table perpendicular to OA by a known distance R and then repeating the tests. Their magnitudes are proportional to $\omega^2 R$ and the gimbal mass unbalances along the input and spin axes.

10.13.4.5.2 Oscillatory Method

Divide the difference between counts (C_2 — C_1) by the time during which the rate table was oscillating. Divide this quotient by the gyro quantizer scale factor, that is, pulses per arc second. Multiply this quotient by 4 and divide by the square of the peak table rate.

The results shall conform to the requirements of Section _____.

10.13.4.6 Cross-Coupling Drift Rate

10.13.4.6.1 Spin-Output Rectification

Divide the difference between counts (C_2 — C_1) by the time during which the rate table was ocillating. Divide this quotient by the gyro quantizer scale factor; that is, pulses per arc second.

The results shall conform to the requirements of Section _____.

10.13.4.6.2 Spin-Input Rectification

Multiply the result obtained in 10.13.4.6.1 by the following ratio:

$$\frac{G_1(f)\cos\phi_1(f)}{G_2(f)\cos\phi_2(f)}$$

where $G_1(f)$, $G_2(f)$, $\phi_2(f)$, and ϕ_2 (f) are as defined in the model equation 6.3.

The results so obtained shall conform to the requirements of Section _____.

10.13.4.7 Torquer Current Rectification Drift Rate

10.13.4.7.1 Angular Rate Sensing Mode, Method 1

Divide the difference between counts (C_1 — C_2) by the time during which the alternating torquer current was applied. Divide this quotient by the gyro quantizer scale factor, that is, pulses per arc second.

The results shall conform to the requirements of Section _____.

10.13.4.7.2 Angular Displacement Sensing Mode (Rate-Integrating Mode), Method 2

Divide the difference between table displacement changes (θ_1 — θ_2) by the time during which the alternating torquer current was applied.

The results shall conform to the requirements of Section _____.

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10.13.4.8 Rate Hysteresis Error

The rate hysteresis error is the absolute difference of the two readings in 10.13.3.8. This error shall not exceed the requirements of Section _____.

10.13.4.9 Output Axis Rate Error

Compute the indicated rate ω_{IR} for each data point (relating torquer current and rate) obtained in 10.3.3.9 using the command rate scale factor K_T (10.7.4.1) as follows:

$\omega_{IR} = K_T i$

Compute the indicated misalignment θ_{IM} for each data point using the equation $\theta_{IM} = \sin^{-1} (\omega_{IR}/\omega_O)$.

Plot the indicated misalignment versus table rate. Where the curve intersects the indicated misalignment axis at zero table rate is the actual IA to IRA- SRA plane misalignment angle α. (Refer to 10.10.3.2.)

Calculate the output axis rate error D_ω (ω_O for each data point as follows:

$D_\omega (\omega_O) = \omega_{IR} - \omega_O \sin \alpha$

The maximum value of $D\omega$ (ω_O) shall conform to the requirements of Section _____.

> A plot of D_ω (ω_O) versus table rate could be used in certain applications instead of the maximum value. An alternate method would be to model the indicated misalignment angle versus table rate.

10.14.2 Test Equipment

> In addition to the standard operating equipment from 9.2.2, the following test equipment from 9.2.3 is required for this test and shall be listed in this section:
>
> 1) Spectrum analysis equipment
> 2) Means of recording gyro torquer current
> 3) Means of integrating torquer current
> 4) Gyro torquer supply
> 5) Means of recording gyro pickoff out-put
> 6) Means of measuring elapsed time

10.14.3 Test Setup and Procedure

10.14.3.1 Method 1

Mount the gyro in the fixture on the dividing head so that the gyro ORA is vertical within _____ arc minutes and the gyro IRA is east within _____ arc minutes. Operate the gyro in the rate-sensing mode (8.2) in accordance with the standard test conditions of 9.1.

> The gyro IRA may be rotated about the ORA to a position which minimizes torquer current in order to improve resolution. Care must be exercised in the selection of a test pier that will not introduce noise that will mask or significantly add to the gyro output noise. Similarly, the capture loop should be equivalent in noise to the application's capture loop.

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Method 1A. Connect the gyro torquer to the spectrum analysis equipment and record the rms value between_____Hz and_____Hz.

Method 1B. Connect the gyro torquer to the torquer current recording equipment. Start the recorder and record the torquer current for_____[min, h].

> The recorder selected must have sufficient bandwidth to record noise over the bandpass of interest. A magnetic tape recorder is most commonly used in order to permit subsequent computer processing of the data.

Method 1C. Connect the gyro torquer to the current integrator and recording equipment. Start the recorder and record the output for_____[min, h].

> The recorder selected must have sufficient bandwidth to record noise over the bandpass of interest.

Method 1D. Connect the output lines to the pulse counters. Record_____[ms, s] samples of the pulse count for_____[min, h].

> The length of the sample interval and the number of intervals must be selected so as to permit noise determination over the desired bandpass.

10.14.3.2 Method 2

Mount the gyro in the fixture on the dividing head so that the gyro ORA is vertical within_____arc minutes and the gyro IRA is east within____arc minutes. Operate the gyro in accordance with the standard test conditions of 9.1. Connect the precision current source to the gyro torquer. Adjust the torquer current until the pickoff output remains at null. (The average output shall not change more than_____mV/min.)

Method 2A. Connect the gyro pickoff to the spectrum analysis equipment. Record the rms value between_____Hz and_____Hz.

Method 2B. Connect the gyro pickoff to the pickoff output recording equipment. Start the recorder and record the gyro pickoff output for_____[min, h].

> This method is applicable when the measurement of output noise unmodified by capture loop electronics is desired.

10.14.4 Test Results

> Power spectral density calculations are affected by aliasing and nonstationary processes such as trends and periodicities. Care should be taken that the data used for power spectral density calculations are not significantly affected by these error sources.

10.14.4.1

Method 1A. The torquer current measured in 10.14.3.1 multiplied by the command rate scale factor as determined in 10.7.4.1 is the gyro rate noise. The gyro rate noise shall conform to the requirements of Section_____.

Method 1B. From the data obtained in 10.14.3.1 and the command rate scale factor as determined in 10.7.4.1,

1) Calculate the noise power spectral density and/or

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2) Integrate the data and calculate the input angle noise power spectral density over the bandwidth from_____Hz to_____Hz. The gyro noise is then calculated as the square root of the integral of the power spectral density function over the bandwidth from_____Hz to_____Hz. The noise as calculated above shall conform to the requirements of Section _____.

Method 1C. From the data obtained in 10.14.3.1 and the gyro scale factor determined in 10.12.4.1 calculate the input angle noise power spectral density over the bandwidth from____Hz to____Hz. The gyro noise is then calculated as the square root of the integral of the power spectral density function over the bandwidth from_____Hz to_____Hz. The noise as calculated above shall conform to the requirements of Section_____.

Method 1D. Multiply the pulse count data samples determined in 10.14.3.1 by the gyro scale factor determined in 10.12.4.1 to obtain incremental angle samples. Calculate the input angle noise power spectral density over the bandwidth from_____Hz to____Hz. The gyro noise is then calculated as the square root of the integral of the power spectral density function over the bandwidth from____Hz to____Hz. The noise as calculated above shall conform to the requirements of Section_____.

10.14.4.2

Method 2A. The pickoff output voltage measured in 10.4.3 multiplied by the gyro scale factor determined in 10.12.4.1 is the gyro input angle noise. The results shall conform to the requirements of Section _____.

Method 2B. From the data recorded in 10.14.3.2 and the gyro scale factor determined in 10.12.4.1 calculate the input angle noise power spectral density over the bandwidth from_____Hz to_____Hz. The gyro noise is calculated as the square root of the integral of the power spectral density function over the bandwidth from_____Hz to_____Hz. The noise as calculated above shall conform to the requirements of Section_____.

10.18 Environmental Test Series

Separate linear and angular vibration tests shall be performed for gyros operating in a strapdown mode. Table 3 (Addendum) lists the tests for strapdown gyros beyond those shown in Table 3 of IEEE Std 517–1974 (R1980).

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Table 3 (Supplement)
Environmental Test Series

ENVIRONMENT / Gyro Parameter Description and Reference	10.1 Examination of Product Mechanical	10.2 Impedance Test	10.3 Dielectric Test	10.2 Insulation Resistance	10.3 Leak Test	10.4 Polarity	10.5 Temperature Sensor Characteristics	10.5 Warmup Time	10.5 Operating Temperature	10.6 Pickoff Scale Factor and Composite Error	10.6 Pickoff Phase Shift and Electrical Null	10.7 Torquer Scale Factor and Composite Error	10.7 Maximum Command Rate	10.7 Continuous Command Rate	10.8 Rotor Rotation Detector	10.9 Run-up Time	10.9 Run-down Time	10.9 Power Consumption	10.10 Axis Alignment	10.11 Input Angle	10.11 Limit Shops	10.12 Gyro Scale Factor	10.12 Characteristic Time	10.13 g Insensitivity, g Sensitivity and g^2 Sensitivity Drift Rate Coefficient	10.13 Elastic Restraint Drift Rate Coefficient	10.13 Gimbal Retardation	10.13 Random Drift Rate	10.14 Output Noise	10.15 Frequency Response	10.15 Closed Loop Step Response	10.15 Settling Time	10.16 Angular Acceleration Sensitivity about OA	10.17 Generated Fields	Monitor: Pickoff Output Voltage	Monitor: Torquer Current (Closed Loop)	Comments
1. Temperature																																			
2. Excitation Voltage and Frequency Variation																																			
3. Mechanical Shock																																			
4. Thermal Shock																																			
5.1 Vibration Linear	N	O N	O N	O N	O N	O N		O N		O N	O N	O N	O N	O N		O N M	D O N	O N	O N	O N		O N	O N		O N		O N	O N	O N					M	M	It may be desirable to monitor electrical circuits for anomalies.
5.2 Vibration Angular	N	O N	O N	O N	O N	O N		O N		O N	O N	O N	O N	O N		O N M	D O N	O N	O N	O N		O N	O N		O N		O N	O N	O N					M	M	It may be desirable to monitor electrical circuits for anomalies.
6. Acceleration																																			
7. Mechanical Overload																																			
8. Life, Storage																																			
8.1 Life, Operating																																			
9. Fungus																																			
10. Humidity																																			
11. Salt Spray																																			
12. Acoustical Noise																																			
13. Thermal Radiation																																			
14. Air Currents																																			
15. Pressure																																			
16. Nuclear Radiation																																			
17. Magnetic Fields																																			
18. Electromagnetic Fields																																			
19. Sand and Dust																																			
20. Sunshine																																			
21. Rain																																			

D = Gyro parametric test is to be conducted while the gyro is operating or nonoperating, as applicable, during the specified environment.
O = Gyro is to be operated during the specific environment and the parametric test performed before and after.
N = Gyro is to be nonoperating during the specified environment and the parametric test performed before and after.
S = Special test is recommended as described under "Comments."
M = Monitor output indicated in table; when monitor output is the requirement, further clarification is necessary as to how output variation is to be judged.

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