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IEEE Standard Specification Format Guide and Test Procedure for Coriolis Vibratory Gyros

IEEE Aerospace and Electronic Systems Society

Sponsored by the
Gyro and Accelerometer Panel

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Abstract: Specification and test requirements for a single-axis Coriolis vibratory gyro (CVG) for use as a sensor in attitude control systems, angular displacement measuring systems, and angular rate measuring systems are defined. A standard specification format guide for the preparation of a single-axis CVG is provided. A compilation of recommended procedures for testing a CVG, derived from those presently used in the industry, is also provided. Informative annexes cover CVG design features and theoretical principles of operation.
Keywords: Coriolis vibratory gyro, force-rebalance mode, gyro, gyroscope, inertial instrument, inertial sensor, MEMS, MEMS gyro, micro-electro-mechanical system, open loop mode, ratiometric output, whole angle mode

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Introduction

This introduction is not part of IEEE Std 1431-2004, IEEE Standard Specification Format Guide and Test Procedure for Coriolis Vibratory Gyros.

This new standard consists of two parts:

Part I is a specification format guide for the preparation of a Coriolis vibratory gyro specification. It provides a common meeting ground of terminology and practice for manufacturers and users. The user is cautioned not to over specify; only those parameters that are required to guarantee proper performance in the specific application should be controlled. In general, the specification should contain only those requirements that can be verified by test or inspection. Parameters in addition to those given in this standard are not precluded.

Part II is a compilation of recommended procedures for testing a Coriolis vibratory gyro. These procedures, including test conditions to be considered, are derived from those currently in use. For a specific application, the test procedure should reflect the requirements of the specification; therefore, not all tests outlined in this standard need be included, nor are additional tests precluded. In some cases, alternative methods for measuring performance characteristics have been included or indicated.

The intent is for the specification writer to extract the applicable test conditions and equipment requirements from clause 11 for inclusion in the appropriate clauses listed under 6.5 of this standard. Similarly, it is intended that the writer extract the applicable test procedures from clause 12 for inclusion in the appropriate clauses listed under 6.6. Part II can also be used as a guide in the preparation of a separate Coriolis vibratory gyro test specification with appropriate clause numbering. In general, the intent is for the specification writer to ensure consistency and traceability between Part II test procedures and Part I requirements for performance, mechanical, electrical, environmental, reliability, and quality assurance. To that end, a test procedure should not be listed in Part II unless a related requirement exists in Part I.

Blank spaces in the text of this document permit the specification writer to insert specific information such as parameter values and their tolerances, clause numbers, etc. Brackets are used to enclose alternative choices of dimensional units, signs, axes, etc. Boxed statements are included for information only and are not part of the specification or test procedures. The terminology used conforms to *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. The units used conform to ANSI/IEEE Std 268-1992, IEEE Standard for Metric Practice. The abbreviation of units conforms to ANSI/IEEE Std 260.1-1993, Standard Letter Symbols for Units of Measurement. The graphic symbols used conform to ANSI/IEEE Std 315-1975, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams and its supplement ANSI/IEEE Std 315A-1986.

This standard defines the requirements and test procedures for a Coriolis vibratory gyro in terms unique to the Coriolis vibratory gyro. The requirements contained herein cover applications where the Coriolis vibratory gyro is used as an angular motion sensor in navigation and control systems.

The term Coriolis vibratory gyro is accepted to include the electronics necessary to operate the gyro and to condition the output signal. The Coriolis vibratory gyro provides an output proportional to inertial angular rate about its input axis.

Annex A lists various Coriolis vibratory gyro design features for which this format is applicable. The list is not intended to make any suggestion regarding the selection of particular design features that might restrict the free choice of manufacturers.

Annex B is a description of the various types of Coriolis vibratory gyros and their functioning.

Annex C is a compliance matrix that lists requirements clauses and their corresponding test clauses.

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This publication represents a group effort on a large scale. A total of 98 individuals attended 48 meetings of the Gyro and Accelerometer Panel while this standard was in preparation. The major contributors to this standard were the following:

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IEEE Standard Specification Format Guide and Test Procedure for Coriolis Vibratory Gyros

1. Overview

1.1 Scope

Specification and test requirements for a single-axis Coriolis vibratory gyro (CVG) for use as a sensor in attitude control systems, angular displacement measuring systems, and angular rate measuring systems are defined. A standard specification format guide for the preparation of a single-axis CVG is provided. A compilation of recommended procedures for testing a CVG, derived from those presently used in the industry, is also provided. Informative annexes cover CVG design features and theoretical principles of operation.

1.2 Document structure

This standard consists of two parts: Part I is a specification format guide for the preparation of a CVG specification; Part II is a compilation of recommended procedures for testing a CVG.

1.3 Definitions

Except for the terms defined below, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition; IEEE Std 528™-2001[1]; and the model equation of 8.3 define terminology used in this standard.

1.3.1 Angle storage (Coriolis Vibratory Gyro): The angular information stored in a gyro as a result of its dynamics.

1.3.2 Coriolis Vibratory Gyro (CVG): A gyro based on the coupling of a structural, driven, vibrating mode into at least one other structural mode (pickoff) via Coriolis acceleration.

NOTE—CVGs may be designed to operate in open-loop, force-rebalance (i.e., closed-loop) and / or whole angle modes.[2]

1.3.3 Force-rebalance mode (Coriolis Vibratory Gyro): A mode in which the vibration amplitude of the pickoff is nulled by a signal whose amplitude is proportional to the rotation rate about the input axis (es).

[1]Information on references can be found in Clause 2.
[2]Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

1.3.4 Forcer (Coriolis Vibratory Gyro): A device that exerts a force on a resonator, in response to a command signal.

1.3.5 Open loop mode (Coriolis Vibratory Gyro): A mode in which the vibration amplitude of the pickoff is proportional to the rotation rate about the input axis (es).

1.3.6 Ratiometric output: An output method where the representation of the measured quantity (e.g., voltage, current, pulse rate, pulse width) varies in proportion to a reference quantity.

1.3.7 Whole angle mode (Coriolis Vibratory Gyro): A mode of single-axis operation in which the pickoff output is a measure of the net angle of rotation since initialization.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI Std 268-1992[3], American National Standard for Metric Practice.

IEEE Std 260.1™-2004[4], American National Standard Letter Symbols for Units of Measurement (SI Units, Customary Inch-Pound Units).

IEEE Std 280™-1985, IEEE Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering.

IEEE Std 315™-1975, IEEE Graphic Symbols for Electrical and Electronics Diagrams.

IEEE Std 315A™-1986, IEEE Graphic Symbols for Electrical and Electronics Diagrams (Supplement to ANSI / IEEE Std 315™-1975).

IEEE Std 528™-2001, IEEE Standard for Inertial Sensor Terminology.

IEEE Std 647-1995, IEEE Standard Specification Format Guide and Test Procedure for Single-Axis Laser Gyros.

IEEE Std 952™-1997, IEEE Standard Specification Format Guide and Test Procedure for Single-Axis Interferometric Fiber Optic Gyros.

[3]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

Part I—Specification format

3. Purpose

This specification defines requirements for a single-axis Coriolis vibratory gyro (CVG) to be used as a sensor in [an inertial measurement unit, _____].

A description of the design features of a single-axis CVG is presented in Annex A and principles of operation in Annex B. The CVG may include electronics necessary to operate the gyro and condition the output signal. A CVG can be either a macroscopic device or a micro-electro-mechanical system (MEMS).

4. Applicable documents

The following documents form a part of the specification to the extent specified herein. In the event of any conflict between the requirements of this specification and the listed documents, the requirements of this specification shall govern.

Give identification number, title, date of issue, and revision letter of each listed document.

4.1 Specifications

4.1.1 Government

MIL-P-116H	Methods of Preservation

4.1.2 Industry/technical

4.1.3 Company

4.2 Standards

4.2.1 Government

MIL-STD-105	Sampling Procedure and Tables for Inspection by Attributes.
MIL-STD-461	Electromagnetic Interference Characteristics, Emission, and Susceptibility Requirements for the Control of Electromagnetic Interference.
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of.
MIL-STD-704C	Aircraft Electrical Power Characteristics.
MIL-STD-781C	Reliability Design Qualification and Production Acceptance Tests: Exponential Distribution.
MIL-STD-785B Notice 2	Reliability Program for Systems and Equipment Development and Production.
MIL-STD-810	Environmental Test Methods and Engineering Guidelines.
MIL-STD-883	Test Method Standard Microcircuits

4.2.2 Industry/technical

IEEE Std 100-1996	IEEE Standard Dictionary of Electrical and Electronics Terms
IEEE Std 528-2001	IEEE Standard for Inertial Sensor Terminology
IEEE Std C62.38-1994	IEEE Guide on Electrostatic Discharge (ESD): ESD Withstand Capability Evaluation Methods (for Electronic Equipment Subassemblies)
CEI/IEC 61000-4-2, 2001-04	Electromagnetic Compatibility (EMC) – Testing and measurement techniques – Electrostatic discharge immunity test.
EMC Directive 89/336/EEC	Council Directive on the Approximation of the Laws of the Member States Relating to Electromagnetic Compatibility
CDF-AEF-Q100-003	Machine Model Electrostatic Discharge Test

4.2.3 Company

4.3 Drawings

4.3.1 Government

4.3.2 Industry/technical

4.3.3 Company

4.4 Bulletins

4.4.1 Government

4.4.2 Industry/technical

4.4.3 Company

4.5 Other publications

Other applicable documents should be listed under the appropriate paragraph.

5. Requirement

5.1 Description

The major components of the CVG herein specified are: a ______ resonant mode structure, a drive excitation mechanism, a pickoff mechanism, electronics, and a case. The CVG may also have the following additional major components: drive-pickoff, forcer, servo electronics, temperature sensor, damping means, vibration isolation, and over-range protection.

To fill in the blanks, refer to Annex A for examples.

5.2 General requirements

5.2.1 Precedence

In the event of conflict among the purchase agreement, this specification and other documents referred to herein, the order of precedence shall be as follows:

a) Purchase agreement

b) This specification and its applicable drawings (see 5.4.2 and 5.5.1)

c) Other applicable documents (see 4).

5.2.2 Deliverables

The deliverables include the gyro plus its numerical data, such as bias, scale factor, and input axis misalignment.

5.2.3 Other

List other applicable general requirements.

5.3 Performance

Performance characteristics shall be as specified in this subclause.

The tolerances include a summation of manufacturing and test errors, and environmental effects. Any exception due to environmental effects will be listed in _____.

When required by the application, the sensitivity of a gyro characteristic to variations in voltage, frequency, temperature, or other variables should be included in the paragraph specifying that characteristic. Where applicable, the operating conditions under which each requirement applies should be stated.

5.3.1 Input rate limits

The input rate limits about the gyro input axis shall be ± ______[°/s, rad/s].

The positive and negative input rate limits need not be equal. Multiple rate limits may be specified. It may be important to specify the maximum input rate or angular acceleration that can be applied to the gyro without damage.

5.3.2 Gyro scale factor

_________[(°/s)/V, (°/s)/Hz, _____] ± _________ [ppm, %,______] .

In some applications it may be more appropriate to express the scale factor as the inverse of that stated above. For gyros operating in the ratiometric output mode, the nominal scale factor should be measured at a specified reference voltage. The output scale factor is then inversely proportional to the ratio of the reference voltage to the power supply voltage. In the whole angle mode, the scale factor is specified in units of angular change per LSB. Different values and tolerances may be specified for different input ranges. The scale factor range includes the manufacturing tolerance. The test procedure will result in a nominal scale factor that is defined in the model equation in 8.3.

5.3.2.1 Gyro scale factor errors

5.3.2.1.1 Linearity error

________[ppm, %] of full scale and/or _______[ppm, %] of output, [maximum, 1σ, _____].

Linearity error is the residual error remaining after a linear fit. This includes both systematic and nonsystematic errors. In some applications, nonlinearity may be specified. Nonlinearity involves only systematic deviations from a straight line.

5.3.2.1.2 Asymmetry error

The difference between the scale factor measured with positive input rates and negative input rates shall not exceed _______[ppm, %] of half the sum of the magnitudes of the scale factor determined for positive and negative inputs.

5.3.2.1.3 Repeatability

________ [ppm, %], [maximum spread, 1σ,______].

Repeatability involves changes in scale factor measurements made under the same operating conditions that occur between periods of operation. Thermal cycles and other environmental exposures, shut downs, time between runs, remounting, and additional factors pertinent to the particular application should be specified.

5.3.2.1.4 Stability

________[ppm, %], [maximum spread, 1σ, ______] for ______[hours, days,______].

Stability is the variation in scale factor over a specified time of continuous operation. Ambient temperature, power supply and additional factors pertinent to the particular application should be specified.

5.3.2.1.5 Hysteresis

a) *Temperature* ______ ppm maximum over the range ______ °C to ______ °C.

b) *Rate* ______ ppm maximum over an input range of ______ [°/s , rad/s].

5.3.2.1.6 Other errors

Gyros operating in the ratiometric output mode may exhibit an error associated with deviations from the expected ratiometric relationship. Gyros operating in whole angle mode may exhibit modelable periodic scale factor errors associated with the internal device geometry. This effect can be observed as a variation in scale factor associated with the net angular rotation since turn on.

5.3.2.2 Gyro scale factor sensitivities

5.3.2.2.1 Temperature

The change in gyro scale factor resulting from a change in steady state operating temperature shall not exceed______ppm from that measured at ______°C over the range___°C to___°C.

5.3.2.2.2 Acceleration, S_a

The change in gyro scale factor shall not exceed _____ ppm when subjected to a constant acceleration of _____m/s^2 along any axis.

5.3.2.2.3 Other sensitivities

Additional sensitivities may be specified such as those due to variations in supply voltage (including frequency, voltage, ripple, starting and operating current), rate of temperature change, temperature gradient, orientation, acceleration, vibration, magnetic field, radiation, and other environments pertinent to the particular application.

5.3.3 Drift rate, D

5.3.3.1 Systematic drift rate

Gyros can be specified in three ways: (1) not intended to be compensated, (2) compensated internally by the manufacturer, (3) compensated externally. For (3), the specification limits reflect performance after implementing a specific model and/or coefficients provided by either the manufacturer or the user.

5.3.3.1.1 Bias, D_F

_____ [±, _____], [°/h, °/s, rad/s]

a) Trend: _____ [(°/h)/h, _____] over _____ [h, _____] If trend is not specified, then bias represents the performance expected between calibrations or during the lifetime. Trend represents a predictable, linear, long-term change from the bias measured at the time of acceptance.

b) Repeatability: _____ [°/h, _____] [peak-to-peak, 1σ, _____]

Repeatability involves changes in bias measurements made under the same operating conditions that occur between periods of operation. Thermal cycles and other environmental exposures, shut downs, time between runs, remounting, and additional factors pertinent to the particular application should be specified.

5.3.3.1.2 Environmentally sensitive drift rate, E

a) Drift Rate Acceleration Sensitivity, D_a

The change in drift rate shall not exceed _____ [°/h, _____] when subject to a constant acceleration of _____ m/s^2 along any axis.

b) Drift Rate Temperature Sensitivity, D_T

The drift rate sensitivity to temperature change shall not exceed ______ [(°/h)/ °C, _____].

c) Drift Rate Temperature Gradient Sensitivity, $\vec{D}_{\nabla T}$

The drift rate sensitivity to a temperature gradient in any axis shall not exceed ______ [(°/h)/(°C/m), _____].

d) Drift Rate Temperature Ramp Sensitivity, $D_{\dot{T}}$

The drift rate sensitivity to a temperature ramp shall not exceed ______ [(°/h)/(°C/s), _____].

e) Temperature Hysteresis

The drift rate sensitivity to thermal loop over the range _____ °C to _____ °C shall not exceed ____ [°/h, _____].

f) Vibration Induced Coning, $D_c a_{VR}$

The drift rate sensitivity shall not exceed ______ [(°/h)/((m/s^2)^2/Hz), (°/h)/(g^2/Hz), _____] when subject to a random vibration input in any axis around any CVG eigenfrequency.

g) Vibration Induced Electronics Saturation (Open Loop Mode), $D_{\Delta F} a_{V\Delta F}$

The drift rate sensitivity shall not exceed ______ [(°/h)/((m/s^2)^2/Hz), (°/h)/(g^2/Hz), _____] when subject to a random vibration input in any axis around the difference frequency between CVG eigenfrequencies.

h) Vibration Sensitivity at Drive Frequency (Open Loop Mode), $D_D a_{VD}$
The drift rate sensitivity shall not exceed ______ [(°/h)/((m/s^2)^2/Hz), (°/h)/(g^2/Hz), _____] when subject to a random vibration input in any axis around the CVG drive frequency.

i) Vibration Sensitivity at Pickoff Frequency (Open Loop Mode), $D_P a_{VP}$

The drift rate sensitivity shall not exceed ______ [(°/h)/((m/s^2)^2/Hz), (°/h)/(g^2/Hz), _____] when subject to a random vibration input in any axis around the CVG pickoff frequency.

j) Vibration Sensitivity at Eigenfreqencies $D_{SR}a_{VSR}$

The drift rate sensitivity shall not exceed ______ [(°/h)/((m/s^2)^2/Hz), (°/h)/(g^2/Hz), _____] when subject to a random vibration input in any axis around any CVG eigenfrequency.

k) Vibration Sensitivity at Operating Frequency with Cross Axis Input, $D_{RI}a_{VOF}$ ($\omega_{XRA} + \omega_{YRA}$)

The drift rate sensitivity shall not exceed ______ [(°/h)/((m/s^2)^2/Hz), (°/h)/(g^2/Hz), _____] when subject to a random vibration input in any axis around the pickoff frequency and the angular rate about any axis orthogonal to the input axis.

l) Vibration Sensitivity with Pickoff Asymmetry, $D_{RBB}a_{VBB}$

(Open Loop Mode) The angle random walk sensitivity shall not exceed ______ [(°/$\sqrt{\text{h}}$)/((m/s^2)/$\sqrt{\text{Hz}}$), (°/$\sqrt{\text{h}}$)/(g/$\sqrt{\text{Hz}}$), _____] when subject to a broadband noise input in any axis in the frequency range _____ to _____ Hz.

$D_{RBB}a_{VBB}$ must be multiplied by the square root of the mission time to get a drift rate result.

(Whole Angle Mode) The angle white noise sensitivity shall not exceed ______ [(°/$\sqrt{\text{Hz}}$)/((m/s^2)/$\sqrt{\text{Hz}}$), (°/$\sqrt{\text{Hz}}$)/(g/$\sqrt{\text{Hz}}$), _____] when subject to a broadband noise input in any axis in the frequency range _____ to _____ Hz.

$D_{RBB}a_{VBB}$ must be multiplied by the square root of the vibration input bandwidth to get a drift rate result.

m) Other Sensitivities

These sensitivities include, but are not limited to, effects due to input power variations including frequency, voltage, ripple, starting and operating current.

5.3.3.2 Random drift rate, D_R

Random drift rate is usually defined in terms of the Allan variance components. See 8.3 and Annex C of either IEEE Standard 647 or IEEE Standard 952. PSD analysis can also be used to determine the random components of gyro drift.

a) *Angle Random Walk*, (rate white noise) coefficient, N. _______ °/$\sqrt{\text{h}}$ maximum.
b) *Bias Instability*, coefficient, B. _______ °/h maximum.
c) *Rate Random Walk*, coefficient, K. _______ (°/h)/$\sqrt{\text{h}}$ maximum.
d) *Ramp*, coefficient, R. _______ (°/h)/h maximum.
e) *Quantization noise*, coefficient, Q. _______ [“, μrad] maximum
f) *Markov noise*, amplitude coefficient, q_c, _______ (°/h)/$\sqrt{\text{h}}$ maximum and time constant T_c, _______ h.

For some applications it may be sufficient to specify random drift as the standard deviation of the output in a specified frequency band.

Quantization noise is not present in the analog output CVG.

5.3.4 Input axis alignment

5.3.4.1 IA Misalignment

______ [″, μrad], maximum with respect to the input reference axis (IRA).

The specific direction of IA misalignment may be important in some applications and should be specified with respect to XRA and YRA gyro case reference axes. Note that these axes are defined in 5.4.3

5.3.4.2 IA Misalignment repeatability

______ [″, μrad], [maximum spread, 1σ, _____]

Thermal cycles and other environmental exposures, shutdowns, time between runs, remounting, and additional factors pertinent to the particular application should be specified.

5.3.4.3 IA Alignment sensitivities

IA alignment sensitivities may be specified, such as those due to temperature, thermal gradients, rate of temperature change, acceleration, vibration, and additional environments pertinent to the particular application.

5.3.5 Operating temperature

____ ± _____ °C

The operating temperature above applies only to temperature-controlled gyros. For gyros intended to operate without temperature controls, see 5.6.4.4.

5.3.6 Activation time

5.3.6.1 Turn-on time

The gyro output rate shall be within _____ [°/s, %, ____] of the input rate, at an input rate of _____ °/s within _____ [s, ____] after the application of power.

5.3.6.2 Warm-up time

_________[s, ________], maximum.

The limits of gyro performance during that portion of warm-up time following the turn-on time should be specified for certain applications. These limits could be fixed bounds or functions of time. More than one function may be specified for different temperatures at the time of turn-on, or different functions may be specified for each performance parameter (i.e., scale factor, bias, etc.)

5.3.7 Angle storage

5.3.7.1 Normal operation

The maximum angle stored in the gyro during normal operation shall not exceed ____°.

This requirement typically applies to force-rebalance modes of operation.

5.3.7.2 Over-range operation

The minimum angle storage for an over-range angle rate pulse shall exceed ____°.

This requirement typically applies to force-rebalance modes of operation.

5.3.7.3 Across power interrupt

The magnitude of angular error resulting from an interruption of power of ____ ms shall be less than ____ [°,___].

This requirement typically applies to force-rebalance and whole angle modes of operation.

5.3.8 Run-down time

The gyro run-down time shall be greater than _______s.

Run-down time can be used as a measure of hermeticity at manufacture and as part of built-in test capabilities. This characteristic may not be appropriate for all designs or applications.

5.3.9 Output signal polarities

5.3.9.1 Input axis

The positive input axis shall conform to [drawing number ____, Figure ____]

5.3.9.2 Output signals

The output signals representing gyro rotation shall conform to [drawing number ____, Figure ____]

5.3.10 Mechanical isolation

Mechanical isolation may be required to reduce errors caused by vibration sensitivities and to reduce transmission of emitted vibrations.

5.3.11 Transfer function

The transfer function dynamic response shall be within the limits defined by Figure ______.

The transfer function should be described in the form of a phase and gain plot versus rate input frequency. In some applications it may be more appropriate to specify a bandwidth. Two common ways to specify bandwidth are the frequency at: 1) –3dB gain and 2) –90º phase. Both of these are specified in some applications.

5.3.12 Reference constants

These constants are for reference only. They are not specified independently, because they may vary within the framework of the specification, or because they are difficult or impossible to measure independently in a completed gyro. Nominal values are to be listed.

5.3.12.1 Drive frequency

5.3.12.2 Sense frequency

5.3.12.3 Other resonances

5.3.12.4 Pickoff orientation

The angular separation between the drive and pickoff axes is ______ °.

5.4 Mechanical requirements

Mechanical characteristics shall be as specified hereinafter.

5.4.1 Exterior surface

Requirements controlling surface finish, workmanship, processing, etc., should be specified.

5.4.2 Outline and mounting dimensions

Outline and mounting dimensions, and accuracy requirements of mounting surface shall conform to [drawing number _____, Figure _____].

Specify center of gravity if required.

5.4.3 Gyro axes

The X and Y gyro case reference axes (XRA and YRA) are mutually perpendicular and are located by means of the gyro mounting surface and the reference index on the gyro case [notch, pin, scribe line, _____]. The IRA, XRA and YRA are reference axes defined with respect to the mounting provisions. These axes are nominally parallel to IA, XA and YA respectively, and define a right-handed coordinate system. The IRA is defined relative to the gyro mounting surface and shall conform to [drawing number __________, Figure __________] (see Figure 1).

In some applications for the purpose of measuring environmental sensitivities, it may be important to identify the angle between the XRA and the driven axis.

5.4.4 Weight

__________ ± __________ [g, _____].

Specify those components such as cables, connectors, and electronics which are to be included in the weight.

5.4.5 Seal

The gyro shall be sealed so that the equivalent helium leak rate is less than __________ [cm^3/s, _____] when subjected to a pressure of __________ ± __________ Pa and gyro temperature of __________ ± __________ °C for a minimum of __________ minutes.

CVGs may be sealed using vacuum, gas or ambient environment. An appropriate requirement should be inserted depending upon the construction type. In establishing this requirement, consideration should be given to the lifetime.

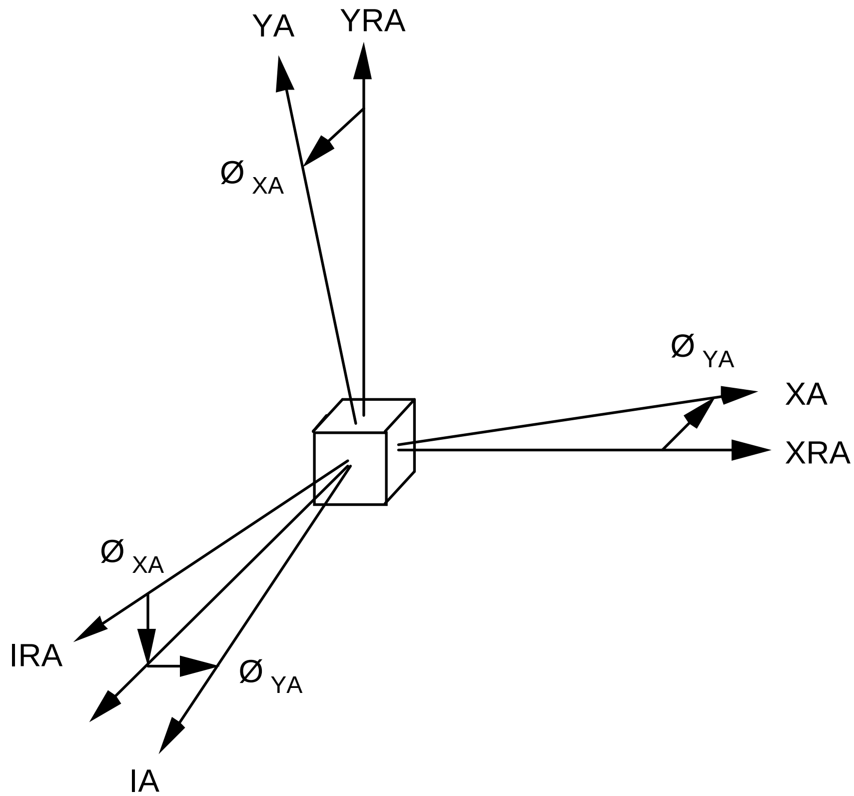


Figure 1—Gyro axes and misalignment angles

5.4.6 Identification of product

The gyro shall be identified on the surface and in the manner indicated in drawing number __________. Identification shall include:

a) Coriolis vibratory gyro or CVG

b) Specification number

c) Unit serial number.

d) Axes identification marking as shown in [drawing number __________, Figure __________].

e) Manufacturer's name or symbol.

The purchase agreement may require additional identification such as date of manufacture and safety warnings.

5.4.7 Acoustic noise

The acoustic noise emissions shall conform to _________.

5.5 Electrical interface requirements

Electrical characteristics shall be as specified in this subclause.

5.5.1 Schematic

An interface control drawing should be provided which specifies the test points and pin connections by function and includes appropriate voltage, polarity and other electrical information.

5.5.2 Impedances

The gyro impedances shall be __________ Ω.

Load impedances and impedances of excitation, monitoring, temperature sensing and test circuits should be individually specified.

5.5.3 Input power

The input power shall not exceed __________ W.

Requirements, including tolerances, for such parameters as frequency, voltage, ripple, starting and operating current should be specified. Transient conditions may need to be specified.

Gyros with thermal controls may exhibit substantial changes in input power requirements during warm up and over the operating temperature range.

5.5.4 Test points

Test points required for monitoring and testing of the gyro should be specified. These may include excitation voltages, pickoff, forcer or control signals, or temperature sensor(s). Any special buffering or scaling requirements should be specified.

5.5.5 Grounding

Electrical grounding requirements (for example, requirements for isolation between input, output power returns and the grounding requirements for shields, chassis and critical components) should be specified.

5.5.6 Output signals

The type and characteristics of output signal(s) required, such as analog voltage or current, parallel or serial digital, or incremental angle pulses should be specified. For example:

a) Type: Pulses indicating positive angular increments on one signal line and pulses indicating negative angular increments on a second line.
b) Characteristics:
    1) Source impedance
    2) Load impedance
    3) Wave shape (see Figure 2)
    4) Maximum pulse rate

5.5.7 Temperature sensors

The output of the temperature sensor(s) shall be __________ ± __________ [V, _____] in the operating temperature range specified in 5.6.4.4 of this standard. The temperature rise of the sensor due to self-heating shall not exceed __________ °C. The scale factor of the temperature sensor(s) shall be [±] __________ ± __________ [V/°C, _____].

Thermistors and resistors (ohms), thermocouples (V), resonators (Hz), integrated circuits (μA) or other temperature sensors may be specified. Temperature sensors may be built into the gyro for use in characterizing its temperature sensitivity. If sensors are required, specify quantity, locations and characteristics. The temperature range over which the scale factor should be specified is given by 5.3.5 for temperature-controlled gyros and 5.6.4.4 for all other gyros. Other characteristics of the temperature sensor may be specified, such as offset.

5.5.8 Insulation resistance

The insulation resistance between isolated interface circuits and between the case(s) and circuits isolated from the case(s) shall not be less than __________ MΩ measured at __________ ±__________ V dc, applied for __________ ± __________ s.

Different voltages may be specified for different circuits.

5.5.9 Dielectric strength

The leakage current shall not exceed __________ nA when __________ ± __________ V rms, at __________ Hz, are applied between isolated interface circuits, and between the case(s) and circuits isolated from the case(s) for __________ ± __________ s.

Different voltages may be specified for different circuits. In some instances, lower voltages may be specified for subsequent tests.

5.5.10 Electromagnetic interference

The electromagnetic emissions and susceptibilities shall conform to __________.

In the U.S., a common standard is MIL-STD-461 or for the EC a common standard is EMC Directive 89/336/EEC.

5.5.11 Electrostatic Discharge (ESD)

The electrostatic discharge immunity shall conform to _____ when subjected to ____ [discharge level, human body model, machine model] applied to any surface.

Common standards in the U.S. are MIL-STD-883 and IEEE Std. C62.38-1994 and for automotive application AEC Q100-003 issued by the Automotive Electronics Council. A common standard in the European Community is CEI/IEC 61000-4-2.

If the supplier requires and supplies ESD protection, it may be necessary to specify that the ESD limits apply only when the protection is in place. The requirement should include the description of the parameters to be monitored during test.

5.6 Environmental requirements

This subclause contains environmental requirements only. Test procedures that are to be used, including required combinations of environments, are covered in 6.6 of this standard.

5.6.1 Storage

The gyro shall conform to all requirements of this specification after exposure to the following environments or specified combinations thereof.

The procuring organization should list the applicable environments from 5.6.4 of this standard and specify the limits for each based on the storage and packaging conditions expected.

5.6.2 Transport

The gyro shall conform to all requirements of this specification after exposure to the following environments or specified combinations thereof, while packaged as specified in clause 7.

The procuring organization should list the applicable environments from 5.6.4 of this standard and specify the limits for each based on the transportation conditions expected.

5.6.3 Operation

In order to properly specify the environmental requirements for a gyro, three different sets of environments or environmental limits, or both, as defined in 5.6.3.1, 5.6.3.2 and 5.6.3.3 of this standard may need to be described.

5.6.3.1 Operating environment

The gyro shall conform to all requirements of this specification during exposure to the following environments or specified combinations thereof (except during exposure to __________ where the deviations of this specification are given in the following subclauses).

Where degraded performance is to be allowed, include the parenthetical phrase in 5.6.3.1 of this standard and list in the blank space those environments for which degraded performance is allowed. The procuring organization should list the applicable environments from 5.6.4 of this standard and specify the limits for each based on the conditions expected when the gyro is in use. For those environments where degraded performance is allowed, specify the performance deviation in the subclause that specifies the environment.

5.6.3.2 Survival environment, operating

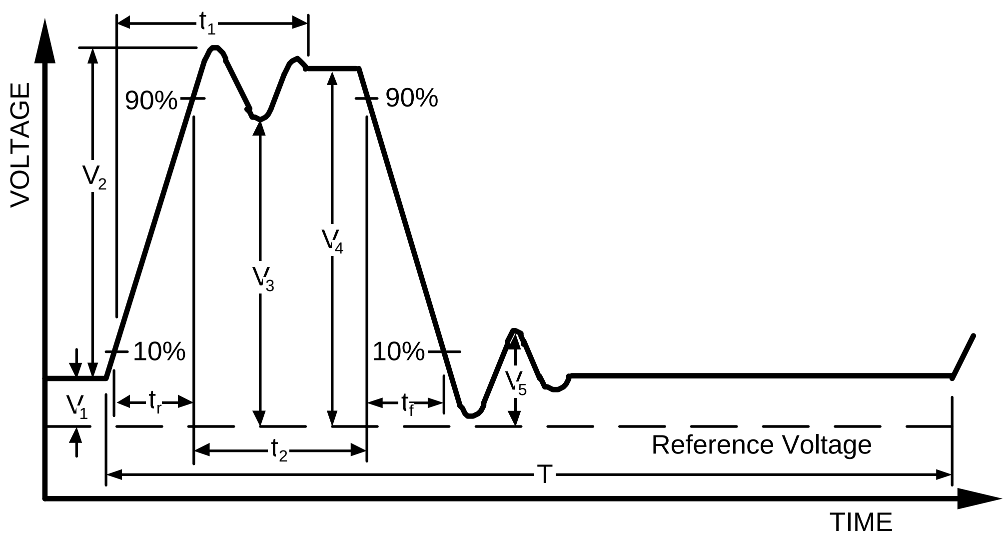
The gyro shall conform to all requirements of this specification after the operating gyro has been exposed to the following environments or specified combinations thereof.

The procuring organization should list the applicable environments from 5.6.4 of this standard and specify the limits for each based on the conditions expected when the gyro is operating, but not in use.

5.6.3.3 Survival environment, non-operating

The gyro shall conform to all requirements of this specification after the non-operating gyro has been exposed to the following environments or specified combinations thereof.

The procuring organization should list the applicable environments from 5.6.4 of this standard and specify the limits for each based on the conditions expected when the gyro is not operating. Such conditions are expected to occur when the gyro is mounted in the system and the system is stored or transported in severe environments.



	UNITS	MAXIMUM	MINIMUM	REMARKS
V_1	Volts	________	________	steady state low voltage
V_2	Volts	________	N/A	overshoot voltage
V_3	Volts	N/A	________	undershoot voltage
V_4	Volts	________	________	steady state high voltage
V_5	Volts	________	N/A	maximum low voltage transient
t_r	seconds	________	________	rise time
t_f	seconds	________	________	fall time
t_1	seconds	________	________	turn-on transient time
t_2	seconds	________	________	high voltage on time
t_1/t_2	________	________	N/A	ratio of turn-on transient to high voltage on time
T	seconds	________	________	waveform period
t_2/T	________	________	________	duty cycle

Figure 2—Wave shape requirements for direct coupled pulse-type signals

5.6.4 Environments

Environmental characteristics shall be as specified in this subclause.

This list is intended as an aid to the selection of the applicable environments under 5.6.1, 5.6.2 and 5.6.3 of this standard. 5.6.4 in this form would not be included in a final specification.

5.6.4.1 Vibration

Gyro axes and direction of vibration should 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 and duration should be specified.

5.6.4.1.1 Linear vibration

Sinusoidal: __________ [cm, ____] DA (double amplitude) __________ to __________ Hz; __________ [m/s^2, *g*] peak, __________ to __________ Hz. Sweep rate: __________ min/octave (continuous). Exposure time: __________ [min, _____].

5.6.4.1.2 Angular vibration

Sinusoidal: __________ [rad/s^2, _____] peak, __________ to __________ Hz. Sweep rate: __________ min/octave (continuous). Exposure time: __________ [min, ___].

5.6.4.2 Mechanical shock

__________ [m/s^2, *g*] peak, __________ wave shape, __________ ms, __________ shock(s).

Gyro axes and direction of shock should be defined. A figure may be included to describe more complex waveforms. A shock spectrum may be specified.

5.6.4.3 Acceleration

Gyro axes and direction of acceleration should be defined.

5.6.4.3.1 Linear acceleration

__________ [m/s^2, *g*], exposure time __________ [min, _____].

5.6.4.3.2 Angular acceleration

__________ [rad/s^2, _____], exposure time __________ [min, _____].

5.6.4.4 Temperature

__________ °C to __________ °C.

5.6.4.5 Thermal shock

__________ °C to __________ °C within __________ [s, _____].

If exposure to cyclic conditions is required, temperature limits for each level, dwell times and sequence should be specified. A figure may be included to describe more complex profiles.

5.6.4.6 Thermal radiation

__________ [W/m^2, _____] of radiation of wavelength from __________ to __________ µm; exposure time: __________ [min, _____].

Power density distribution versus wavelength should be specified.

5.6.4.7 Ambient air pressure

__________ to __________ [Pa, _____].

If exposure to cyclic conditions is required, pressure limits for each level, dwell times and sequence should be specified. A figure may be included to describe more complex profiles.

5.6.4.8 Acoustic noise

__________ dB referenced to 2 • 10^{-5} Pa, __________ to __________ Hz; exposure time: __________ [s, _____].

When available, the specific sound pressure versus frequency for the application should be specified. Sweep rate may be specified if applying sinusoidal acoustic noise.

5.6.4.9 Humidity

__________ % relative humidity at __________ °C for __________ h.

5.6.4.10 Air currents

__________ [m/s, ____].

Gyro axes and direction of airflow should be defined.

5.6.4.11 Fungus

Types of fungi, length of exposure, temperature and humidity conditions during exposure should be specified.

5.6.4.12 Salt spray

__________ % salt solution; exposure time: __________ [h, _____].

5.6.4.13 Nuclear radiation

__________ [J/kg, rd(Si)] with an exposure of __________ [(J/kg)/s, rd(Si)/s] and/or combinations of __________ particles at a fluence of __________ /cm^2 with energy greater than __________ MeV.

Radiation field characteristics and direction with respect to gyro axes should be defined. If exposure to varying fields is required, the nature of the variation should be described.

5.6.4.14 Magnetic fields

__________ [mT, ___]; exposure time: __________ [s, _____].

Gyro axes and direction of field should be defined. If exposure to varying fields is required, the nature of the variation should be described.

5.6.4.15 Electromagnetic fields

Electromagnetic fields shall conform to __________.

In the U.S., a common standard is MIL-STD-461 or for the EC a common standard is EMC Directive 89/336/EEC.

5.6.4.16 Sand and dust

__________ [kg/m^3, _____] at a velocity of __________ $\pm$ __________ [m/s, _____]; exposure time: __________ [s, _____].

Particle size, shape and chemical composition should be specified.

5.6.4.17 Solar radiation

__________ ± __________ [W/m^2, _____] of wavelength __________ to __________ nm; exposure time: __________ [min, ___].

Power density distribution versus wavelength should be specified.

5.6.4.18 Rain

__________ ± __________ [mm/h, _____] consisting of droplets having a minimum diameter of __________ mm; exposure time: __________ [s, _____].

5.7 Life

5.7.1 Non-operating

Storage: __________ [years, _____].
Dormant: __________ [years, _____].

5.7.2 Operating

__________ [h, _____] with a minimum of ________ start cycles.

Life may need to be specified under varying environmental conditions.

5.8 Reliability

5.8.1 Reliability program

The reliability program required shall conform to __________.

In the United States, a common standard is MIL-STD-785B.

5.8.2 Mean Time Between Failure (MTBF)

The MTBF shall be __________ h minimum.

Conditions, methods of analysis, and failure criteria should be specified.

6. Quality assurance provisions

6.1 Classification of tests

Inspection and testing shall be classified as follows:

a) *Acceptance tests*. Acceptance tests are those tests accomplished on gyros submitted for acceptance under contract.

b) *Qualification tests*. Qualification tests are those tests accomplished on gyros submitted for qualification as a satisfactory product.

c) *Reliability tests*. Reliability tests are those tests performed to demonstrate the gyro reliability specified in 5.8 of this standard.

6.2 Acceptance tests

6.2.1 Individual tests

Each gyro shall be subjected to the following tests described in 6.6.

The list and sequence of individual tests should be specified by the procuring organization based on individual requirements. Those tests that are usually specified are listed below. A burn-in period under specified conditions may be required before beginning individual tests.

6.6.1	Examination of Product (Mechanical)
6.6.2.1	Insulation Resistances
6.6.2.2	Impedances
6.6.4	Input Power
6.6.5	Turn-on Time
6.6.6	Warm-up Time
6.6.7	Polarity
6.6.9.1	Gyro Scale Factor
6.6.9.2	Gyro Scale Factor Errors
6.6.10	Input Rate Test Series
6.6.11.1	Bias
6.6.11.3	Random Drift
6.6.12.1	Input Axis Misalignment (Nominal)

Other individual tests, not generally specified, may be required for a specific application.

6.2.2 Sampling plans and tests

6.2.2.1 Sampling plans

This clause is intended to designate a sampling plan if required. Sampling plans are up to the discretion of the procuring organization based upon usage, size of contract, individual requirements, etc.

Gyros selected shall be subject to the tests specified in 6.2.2.2, which are described in 6.6.

In the U.S., selection according to MIL-STD-105 is common.

6.2.2.2 Sample tests

In addition to the individual tests listed in 6.2.1 of this standard, the procuring organization should specify from 6.6 those tests that should be performed on gyros selected by 6.2.2.1. Sampling plan units may be used for delivery unless the procuring agency specifies life tests or other destructive type tests under the sampling plan.

6.2.2.3 Rejection and retest

When one item selected from a production run fails to meet the specification, the procuring organization shall be immediately notified of the failure, and at the discretion of the procuring organization no items still on hand or later produced shall be accepted until the extent and cause of failure are determined. After corrections have been made, all necessary tests shall be repeated. For operational and production reasons, individual tests may be continued pending the investigation of a sampling plan failure.

Other requirements suitable to an individual contract may be substituted for this subclause.

6.2.2.4 Defects in items already accepted

The investigation of a test failure could indicate that defects may exist in items already accepted. If so, the manufacturer shall fully advise the procuring organization of defects likely to be found and of methods for correcting them.

6.3 Qualification tests

6.3.1 Qualification test samples

A sample of __________ gyros manufactured in accordance with the requirements of this subclause shall be subjected to qualification tests specified herein at an activity designated by the procuring organization.
If the gyro is later modified in any way, the modified gyro shall be subjected to and pass those qualification tests designated by the procuring organization.
The qualification test samples shall be identified with the manufacturer’s part number and/or any other information required by the procuring organization.

6.3.2 Qualification tests

The procuring organization should specify from 6.6, those tests, or combinations of tests, that should be performed on gyros submitted for qualification.

6.4 Reliability tests

The reliability tests may be performed at the gyro or higher assembly level, or both. Field data are typically combined with laboratory test data to estimate reliability.

6.4.1 Burn-in

Each gyro shall be subjected to a __________ h burn-in period under the following conditions.

Environmental and operating conditions should be specified. Avoid compromising useful operating life with excessive burn-in time.

6.4.2 Demonstration testing

The mean-time-between-failure requirements of 5.8.2 shall be demonstrated by testing __________ units for a minimum of __________ h each, for a combined total of __________ h minimum.

In the U.S., testing in accordance with MIL-STD-781 is common.
Other methods of demonstration testing may be selected. A demonstration test plan should be prepared to define test conditions, stress levels, failures, types of tests, etc.

6.5 Test conditions and equipment

The procuring organization should specify from Part II, clause 11, the nominal test conditions and test equipment required. The conditions should apply to all tests unless otherwise specified. When a test condition is specified, the complete test condition should be detailed in this specification. The test equipment required should also be listed by name and model, part number, or performance requirement.

6.6 Test methods

Instructions for performing specified tests in this subclause are detailed in Part II, clause 12. When a test is specified, the complete test method should be detailed in this specification, including requirements to be met to determine satisfactory performance. A test method should not be listed in 6.6 unless a requirement exists in clause 5 of this specification. The corresponding test methods are shown in Annex C for each requirement.

6.6.1 Examination of product (mechanical)

6.6.2 Examination of product (electrical)

6.6.2.1 Insulation resistances

6.6.2.2 Impedances

6.6.2.3 Dielectric strength

6.6.3 Leak test

6.6.4 Input power

6.6.5 Turn-on time

6.6.6 Warm-up time

6.6.7 Polarity

6.6.8 Operating temperature test series

6.6.8.1 Temperature sensor characteristics

6.6.8.2 Operating temperature

6.6.9 Gyro scale factor test series

6.6.9.1 Gyro scale factor

6.6.9.2 Gyro scale factor errors

6.6.9.2.1 Asymmetry

6.6.9.2.2 Linearity

6.6.9.2.3 Repeatability

6.6.9.2.4 Stability

6.6.9.2.5 Hysteresis

6.6.9.3 Gyro scale factor sensitivities

6.6.9.3.1 Temperature

6.6.9.3.2 Acceleration

6.6.9.3.3 Other sensitivities

6.6.10 Input rate limits test

6.6.11 Drift rate test series

6.6.11.1 Bias

6.6.11.1.1 Repeatability

6.6.11.1.2 Sensitivities

6.6.11.2 Measurement noise

6.6.11.3 Random drift

6.6.11.3.1 Angle random walk

6.6.11.3.2 Bias instability

6.6.11.3.3 Rate random walk

6.6.11.3.4 Ramp

6.6.12 Input axis alignment test series

6.6.12.1 Misalignment (nominal)

6.6.12.2 Alignment repeatability

6.6.12.3 Alignment sensitivities

6.6.13 Angle storage

6.6.13.1 Normal operation angle storage

6.6.13.2 Over-range operation angle storage

6.6.13.3 Across power interrupt operation angle storage

6.6.14 Run down time

6.6.15 Transfer function

6.6.16 Generated fields

6.6.16.1 Electromagnetic interference

6.6.16.2 Acoustic noise

6.6.17 Environmental test series

6.6.17.1 Temperature

6.6.17.2 Mechanical shock

6.6.17.3 Thermal shock

6.6.17.4 Vibration

6.6.17.4.1 Linear

6.6.17.4.2 Angular

6.6.17.5 Acceleration

6.6.17.5.1 Linear

6.6.17.5.2 Angular

6.6.17.6 Fungus

6.6.17.7 Humidity

6.6.17.8 Salt spray

6.6.17.9 Acoustic noise

6.6.17.10 Thermal radiation

6.6.17.11 Air currents

6.6.17.12 Nuclear radiation

6.6.17.13 Pressure

6.6.17.14 Magnetic fields

6.6.17.15 Electromagnetic fields

6.6.17.16 Sand and dust

6.6.17.17 Solar radiation

6.6.17.18 Rain

6.6.17.19 Other

Specific applications may require combined environmental tests, such as:

a) Temperature (6.6.17.1) and Thermal Shock (6.6.17.3)
b) Fungus (6.6.17.6), Humidity (6.6.17.7) and Sand and Dust (6.6.17.16)
c) Air Currents (6.6.17.11) and Pressure (6.6.17.13)

6.6.18 Life test

6.6.18.1 Non-operating

6.6.18.2 Operating

6.6.19 Reliability test

7. Preparation for delivery

Detailed procedures for:

a) Preservation and packaging
b) Packing
c) Marking of shipping containers should be specified. A common U.S. specification covering preservation and packaging is MIL-P-116.

8. Notes

8.1 Intended use

Description of application if it is considered necessary or helpful.

8.2 Ordering data

Procuring documents should specify the following:

a) Title, number, and date of this specification.
b) Level of packaging and packing desired.
c) Mode of shipment required.

d) Whether sampling plan tests are to be conducted.
e) Number of preproduction samples to be submitted for qualification testing.
f) Data package.

8.3 Model equation

The model equation for a single-axis CVG expresses the relationship between the input rotation rate and the gyro output in terms of parameters whose coefficients are necessary to specify the performance of the gyro.

The use of the coefficients defined in this subclause to simulate gyro performance is discussed in Annex B.

Pick the appropriate model equation based upon the CVG output type.

For analog output, in either force-rebalance or open loop mode,

$$S_0 V_o = [I + D]\,[1 + 10^{-6}\,\varepsilon_K]^{-1}$$

S_0 = nominal scale factor ((°/h)/V)
V_o = analog output (volts)

For digital output, in either force-rebalance or open loop mode,

$$S_0 V_d = [I + D]\,[1 + 10^{-6}\,\varepsilon_K]^{-1}$$

S_0 = nominal scale factor ((°/h)/LSB)
V_d = digital output (LSBs)

For frequency output,

$$S_0 F = [I + D]\,[1 + 10^{-6}\,\varepsilon_K]^{-1}$$

S_0 = nominal scale factor ((°/h)/Hz)
F = frequency output (Hz)

For ratiometric output,

$$S_0 (V_{ref}/V_p) V_o = [I + D]\,[1 + 10^{-6}\,\varepsilon_K]^{-1}[1 + K_r(V_{ref}/V_p)]$$

S_0 = nominal scale factor ((°/h)/V)
V_{ref} = voltage at which the nominal scale factor is determined
V_p = power supply voltage
K_r = ratiometric error coefficient

For whole angle mode,

$$S_0 (\Delta\theta_{pickoff}/\Delta t) = [I + D]\,[1 + 10^{-6}\,\varepsilon_K]^{-1}$$

where the pickoff angle, $\Delta\theta_{pickoff}$ and the D_F component of D have harmonic errors as a function of pickoff angle.

S_0 = nominal scale factor (°/LSB)
$\Delta\theta_{pickoff}$ = angle rotated in time interval Δt
Δt = time between output data words (s)

where LSB represents the least significant bit of the digital word representing the angle change.

I = Inertial input (°/h)
$= \omega_{IRA} + \omega_{XRA} \sin\Theta_Y - \omega_{YRA} \sin\Theta_X$
D = Drift rate (°/h)
$= D_F + D_R + E$
ε_K = Scale factor error (ppm)
$= \varepsilon_{K0} + \varepsilon_T \Delta T + S_a a$

where

ω_{IRA}, ω_{XRA}, ω_{YRA} = Components of the inertial input rate resolved into the gyro reference coordinate frame.

Θ_X = Misalignment of the IA about the XRA.

Θ_Y = Misalignment of the IA about the YRA.

E = Environmentally sensitive drift rate (°/h)

$$= D_T \Delta T + \vec{D}_{\nabla T} \bullet \nabla T + D_{\dot{T}} \dot{T} + D_c a_{VR} + D_{\Delta F} a_{V\Delta F} + D_D a_{VD} + D_P a_{VP} + D_{SR} a_{VSR} + D_a a + D_{RI} a_{VOF} (\omega_{XRA} + \omega_{YRA}) + D_{RBB} a_{VBB}$$

$D_T \Delta T$ = Drift rate attributable to a change in temperature, ΔT, where D_T is the drift rate temperature sensitivity coefficient.

$\vec{D}_{\nabla T} \bullet \nabla T$ = Drift rate attributable to the temperature gradient, ∇T, where $\vec{D}_{\nabla T}$ is the drift rate temperature gradient sensitivity.

$D_{\dot{T}} \dot{T}$ = Drift rate attributable to the time rate of change of temperature, $\dot{T}$, where $D_{\dot{T}}$ is the drift rate time rate of change of temperature sensitivity.

$D_c a_{VR}$ = Drift rate attributable to coning error caused by a random vibration input around a resonance, a_{VR}, where D_c is the drift rate vibration induced coning sensitivity coefficient.

$D_{\Delta F} a_{V\Delta F}$ = (Open loop mode) Drift rate attributable to random vibration input around the difference frequency, $a_{V\Delta F}$, where $D_{\Delta F}$ is the drift rate sensitivity coefficient.

$D_D a_{VD}$ = (Open loop mode) Drift rate attributable to random vibration input around the drive frequency, a_{VD}, where D_D is the drift rate sensitivity coefficient.

$D_P a_{VP}$ = (Open loop mode) Drift rate attributable to random vibration input around the pickoff frequency, a_{VP}, where D_p is the sensitivity coefficient.

$D_{SR} a_{VSR}$ = Drift rate attributable to random vibration input around a structural resonance, a_{VSR}, where D_{SR} is the drift rate structural resonance sensitivity coefficient.

$D_a a$ = Drift rate due to acceleration, a, applied along any given axis, where D_a is the drift rate acceleration sensitivity coefficient for that axis.

$D_{RI} a_{VOF} (\omega_{XRA} + \omega_{YRA})$ = Drift rate attributable to random vibration, a_{VOF}, around the operating frequency and a constant input rate about an axis orthogonal to the input axis, where D_{RI} is the drift cross-axis vibration sensitivity coefficient.

$D_{RBB} a_{VBB}$ = Drift rate attributable to broadband input vibration, a_{VBB}, coupled with pickoff asymmetry, where D_{RBB} is the noise sensitivity coefficient.

> The noise generated adds to ARW in an open loop mode and to angle white noise in the whole angle mode. $D_{RBB}a_{VBB}$ must be multiplied by the square root of the mission time in the open loop mode or by the square root of the vibration input bandwidth in the whole angle mode prior to adding this term to E.

D_F = Bias

D_R = $D_{RN} + D_{RB} + D_{RK} + D_{RR} + D_{RM} + D_{RQ}$

D_{RN} = Random drift rate attributable to Angle Random Walk, where N is the coefficient.

D_{RB} = Random drift rate attributable to Bias Instability, where B is the coefficient.

D_{RK} = Random drift rate attributable to Rate Random Walk, where K is the coefficient.

D_{RR} = Random drift rate attributable to Ramp, where R is the coefficient.

D_{RM} = Random drift rate attributable to Markov noise.

D_{RQ} = Random drift rate attributable to Output Quantization, where Q is the coefficient.

ε_{K0} = Scale factor error at nominal conditions (difference between actual scale factor and nominal scale factor, ppm)

$\varepsilon_T \Delta T$ = Scale factor error attributable to a change in temperature, ΔT, where ε_T is the scale factor temperature sensitivity coefficient.

$S_a a$ = Scale factor error due to acceleration, a, applied along any given axis, where S_a is the scale factor acceleration sensitivity coefficient for that axis.

Other sensitivities may be added to the model equation, such as those due to variations in supply voltage, magnetic fields, and other environments pertinent to the particular application.

Part II—Test procedure

9. Test procedure overview

This test procedure describes the test requirements for __________ (model number, part number, change letter (if any), other identification), gyro specification number __________, manufactured by __________.

10. Description

The gyro considered in this standard is a single-axis Coriolis vibratory gyro. The gyro output may be either angular rate or angular displacement. The performance characteristics of the gyro are described by the model equation given in 8.3.

11. Test conditions and test equipment

11.1 Standard test conditions

Unless otherwise stated, the following conditions apply.

11.1.1 Ambient environment

Ambient environment may apply to general test area and to specific instrument test conditions.

11.1.1.1 Atmospheric conditions

11.1.1.1.1 Pressure

__________ ± __________ [Pa, _____]

11.1.1.1.2 Ambient temperature

__________ ± __________ °C

11.1.1.1.3 Relative humidity

__________ to __________ %

11.1.1.2 Magnetic field

The magnetic field magnitude shall be _________ [mT, G] maximum.

In some applications the magnetic field direction may be specified.

11.1.1.3 Radiation

List type of radiation and application intensity limits.

11.1.1.4 Seismic conditions

11.1.1.4.1 Tilt

Stable within __________ [µrad, ____] with respect to the local vertical.

11.1.1.4.2 Linear vibration

Vibration magnitude is not to exceed _________ [m/s^2, *g*, _____] rms in a frequency range from ________ Hz to ________ Hz.

The preceding limits apply to each of the three axes of a coordinate system.

11.1.1.4.3 Angular vibration

Oscillation magnitude is not to exceed __________ [rad/s^2, _____] rms in a frequency range from __________ Hz to __________ Hz.

The preceding limits apply to rotation about each of the three axes of a coordinate system.

11.1.2 Installation conditions

11.1.2.1 Thermal conditions

All tests requiring stable temperatures shall be performed with the gyro at thermal equilibrium as evidenced by its thermal rate of change. The gyro thermal rate of change shall be within ± __________ °C/min .

The method of determining the temperature should be specified if required.

11.1.2.2 Mechanical conditions

The gyro shall be mounted in such a way that the alignment of the IRA with respect to the test fixture is maintained within __________ [", µrad] under all specified test conditions.

11.1.3 Electrical excitation and load conditions

Excitation and load conditions shall be as specified hereinafter.

11.1.3.1 Input excitation

The gyro may require more than one input voltage. For each circuit, the source impedance, voltage, frequency, ripple, warm-up and operating current should be specified.

11.1.3.2 Output signals

Typical output signals are either analog signals proportional to angular rate or digital signals proportional to angular displacement. The output load or the type of logic devices and the number of unit loads to be driven should be specified.

11.1.3.3 Electrical connections and phasing

Electrical connections and phasing shall be specified on schematic diagram __________.

Grounding, shielding, test points, load requirements, etc. should be specified as needed.

11.1.4 Turn-on procedure

The sequence of operations required to bring the gyro to operating condition shall be __________.

11.1.5 Turn-off procedure

The sequence of operations required to turn off the gyro shall be __________.

11.2 Standard operating and test equipment

11.2.1 General requirements

The accuracy and response characteristics of the test equipment should be compatible with the requirements of the gyro performance specification. Provisions should be made for adequate stabilization of the test equipment. Adequate limitations should be placed on the test equipment to prevent the gyro from excessive inputs and loads, such as electrical, mechanical, thermal, etc.

In designing the mounting fixture, consideration should be given to the installation conditions of the application. Reference to a specific mounting block thermal and mechanical design, etc. may be necessary if deemed important to meet performance requirements. If temperature control is required, the following should be specified:

a) The unit operating temperature
b) The means of temperature determination
c) The criteria for establishing thermal equilibrium

Where necessary, the test installation should provide means to measure and/or control the temperature gradients.

11.2.2 Standard operating equipment

Standard operating equipment is the equipment, including software, used to provide standard gyro operation and should be listed here by name, manufacturer, model, part number, configuration control number, or by performance requirements.

11.2.3 Test equipment

Test equipment is the equipment used to provide a stimulus or measurement capability and should be listed here by name, manufacturer, model, part number, or by performance requirements.

11.2.4 Test software

Test software is the software used to control test equipment for specific tests and should be listed here by configuration control number or by performance requirements.

12. Test procedures

12.1 Examination of product—mechanical

The gyro shall be inspected visually and dimensionally for proper identification, surface finish and for defects in workmanship to determine that it conforms to the requirements of clause __________.

12.2 Examination of product—electrical

The gyro shall be inspected electrically according to the following subclauses to measure insulation resistances, impedances and dielectric strength.

For gyros where preamplifiers or other sensitive devices are included within the gyro case, care should be taken to avoid the application of voltages that could damage those devices.

12.2.1 Insulation resistance

12.2.1.1 Purpose of insulation resistance test

The purpose of this test is to measure the insulation resistance between the isolated circuits and between the gyro case and the circuits isolated from the gyro case.

12.2.1.2 Insulation resistance test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Megohmmeter.

12.2.1.3 Insulation resistance test—setup and procedure

Apply __________ ± __________ V dc for a period of __________ ± __________ s between the indicated circuits and between the circuits and the gyro case. Record the resistance reading.

12.2.1.4 Insulation resistance test—results

The results shall conform to the requirements of clause __________.

12.2.2 Impedance

12.2.2.1 Purpose of impedance test

The purpose of this test is to measure the impedance of the specified gyro circuits.

12.2.2.2 Impedance test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Impedance bridge with frequency generator adjustable to the specified frequency
b) DC resistance bridge or other suitable resistance measuring system

12.2.2.3 Impedance test—setup and procedure

The gyro shall be allowed to reach thermal equilibrium at the temperature specified in clause __________ in order that the final value will not be affected by changing temperature.
Measure all gyro impedances specified in clause __________. To protect the gyro, the test current through the circuit shall be as small as practical considering the sensitivity of the measuring instruments.
The test current shall be uninterrupted for __________ ± __________ s.

12.2.2.4 Impedance test—results

The impedance measured shall be recorded and shall conform to the requirements of clause __________.

12.2.3 Dielectric strength

12.2.3.1 Purpose of dielectric strength test

The purpose of this test is to ascertain that a circuit element or component part of the gyro can operate safely at its rated voltage and withstand momentary over voltage due to switching, surges, etc., between isolated circuits and between the gyro case and the circuits isolated from the gyro case.

12.2.3.2 Dielectric strength test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) AC high-voltage source equipped with voltage and current-measuring devices.

12.2.3.3 Dielectric strength test—setup and procedure

Apply __________ ± __________ V RMS at __________ Hz between the insulated portion and the case ground. The test voltage shall be raised from zero to the specified value as uniformly as possible, at a rate of approximately _____ V RMS/s. The specified value of the test voltage shall be maintained for a period of __________ s. The voltage shall then be gradually reduced to avoid surges. During each test, the leakage current shall be measured.

12.2.3.4 Dielectric strength—test results

The results shall conform to the requirements of clause __________.

12.2.4 ESD Withstand capability

12.2.4.1 Purpose of ESD withstand capability test

The purpose of this test is to evaluate the ability of the gyro to operate properly during and after an electrostatic discharge.

12.2.4.2 ESD Withstand capability test—equipment

In addition to the standard operating equipment from 11.2.2, test equipment from 11.2.3 is required for this test and should be listed in this subclause. Test equipment requirements can be found in IEEE Std C62.38-1994 or IEC 1000-4-2.

12.2.4.3 ESD Withstand capability test—set-up and procedure

Standard methods of performing this test are accepted in the industry as described in IEEE Std C62.38-1994 and IEC 1000-4-2. Since both the test equipment and procedures are specifically described and well documented, it is recommended that one of those standard be chosen as the test vehicle. It may be necessary to delineate the test method (such as direct contact), model to use (such as human body model), voltage, the test points, and any other criteria specific to the gyro under test.

12.2.4.4 ESD Withstand capability test—test results

The results shall conform to the requirements of clause ______.

12.3 Leak test

12.3.1 Purpose of leak test

The purpose of this test is to determine if leakage through the gyro case is occurring.

12.3.2 Leak test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 may be required for this test and if so should be listed in this subclause. Examples are:

a) Helium leak detector
b) Vacuum enclosure

12.3.3 Leak test—setup and procedure

CVGs may be sealed using vacuum, gas or ambient environment. For each construction type an appropriate test procedure should be inserted. For gas filled CVGs with a helium trace an appropriate test would be:

The gyro case should be cleaned of dirt and grease and placed in a vacuum enclosure at __________ ± __________ [Pa, _____] and stabilized at __________ ± __________ °C gyro temperature. Gas leakage should then be measured using a helium leak detector.

In a vacuum sealed CVG, specific performance parameters, such as run down time, may be acceptable measures of seal.

12.3.4 Leak test—results

The measured gas leakage rate shall conform to the requirements of clause _________.

12.4 Input power

12.4.1 Purpose of input power test

The purpose of this test is to measure the input power (current) required from each source.

12.4.2 Input power test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Power (current) measuring equipment

12.4.3 Input power test—setup and procedure

Connect the power (current) measuring devices and apply power as specified in clause __________. Record the input power (current) from each source.

12.4.4 Input power test—results

The results shall conform to the requirements of clause __________.

12.5 Turn-on time

12.5.1 Purpose of turn-on time test

The purpose of this test is to determine the time interval between the application of power and the presence of a usable output of the gyro.

12.5.2 Turn-on time test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause: a) Rate table with angle or rate output, depending on gyro output data format b) Gyro output measuring and recording equipment c) Timing device

12.5.3 Turn-on time test—setup and procedure

Mount the gyro in the fixture on the rate table so that the Input Reference Axis (IRA) is parallel to the table rotational axis within __________ [mrad, ___]. Connect the gyro to the output measuring equipment. Turn the rate table on and set the rate at __________ [rad/s, ___]. Apply power to the gyro and record elapsed time and the gyro output.

12.5.4 Turn-on time test — results

From the recorded data, determine the time interval from the application of power until the indicated rate from the gyro is within __________ [rad/s, ___] of the table rate after correcting for earth rate and bias. This time shall conform to the requirements of clause __________.

12.6 Warm-up time

12.6.1 Purpose of warm-up time test

The purpose of this test is to determine the time interval required for the gyro to reach the performance specified in 5.3 from the instant it is energized under specified operating conditions.

12.6.2 Warm-up time test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause: a) Rate table b) Gyro output measuring and recording equipment c) Timing device

12.6.3 Warm-up time test—setup and procedure

Operate the gyro in accordance with the standard test conditions of 11.1, except that the starting conditions shall be __________ and the starting sequence shall be __________.
Energize the gyro and record the specified performance characteristics as a function of time for __________ [s, _____].

12.6.4 Warm-up time test—results

The time for the gyro to meet the specified performance characteristics shall conform to the requirements of clause __________.

12.7 Polarity

12.7.1 Purpose of polarity test

The purpose of the polarity test is to determine the gyro output polarity with reference to the IRA defined in clause __________ of the specification.

12.7.2 Polarity test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:
a) Rate table
b) Means of measuring the gyro output

12.7.3 Polarity test—setup and procedure

Mount the gyro on the rate table with the gyro IRA nominally parallel to the rotation axis. Connect the gyro to the output measuring equipment. Prepare the gyro for test in accordance with the standard test conditions of 11.1. Accelerate the table to __________ [rad/s, ___] with the table rate vector in the same direction as the positive IRA and record the gyro output polarity. Rotate the table in a similar manner in the opposite direction and again record the gyro output polarity.

12.7.4 Polarity test — results

The results obtained shall conform to the requirements of clause __________.

12.8 Operating temperature test series

12.8.1 Temperature sensor characteristics

This test applies only when the gyro has externally available terminals for temperature sensor readout.

12.8.1.1 Purpose of temperature sensor characteristics test

The purpose of this test is to determine the output of the temperature sensor and its variation with temperature.

12.8.1.2 Temperature sensor characteristics test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:
a) Temperature control chamber

b) Temperature sensor output measuring equipment

12.8.1.3 Temperature sensor characteristics test—setup and procedure

Mount the gyro in a temperature-controlled chamber in accordance with the standard test conditions of 11.1. Stabilize the non-operating gyro temperature for __________ [h, ___] with the temperature-controlled chamber set at __________ ± __________ °C. Measure and record the temperature sensor output. Repeat these measurements with the temperature-controlled chamber set at the following temperatures: __________ and __________ ± __________ °C.

For temperature controlled gyros, one of the temperatures should be above and one below the operating temperature (see 5.3.5).

During this test, the power to the sensor shall not exceed __________ W. Record chamber temperature and sensor output.

12.8.1.4 Temperature sensor characteristics test—results

The output of the sensor within the specified temperature range shall conform to the requirements of clause _______.

From the data recorded in 12.8.1.3, compute the temperature sensor scale factor. The results shall conform to the requirements of clause _______.

12.8.2 Operating temperature

This test applies only to temperature controlled gyros.

12.8.2.1 Purpose of operating temperature test

The purpose of this test is to ensure that the gyro operating temperature is within the operating temperature range as indicated by the temperature sensor output.

12.8.2.2 Operating temperature test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause: a) Temperature measuring equipment b) Temperature chambers (if required) c) Temperature sensor output measuring equipment

12.8.2.3 Operating temperature test—setup and procedure

Allow the operating gyro to stabilize for _______[h, ___] in accordance with the standard test conditions of 11.1. Vary chamber temperature at _____°C/min within the range specified in 5.6.4.4 while measuring and recording the gyro temperature sensor output.

12.8.2.4 Operating temperature test—results

The gyro operating temperature shall be within the operating temperature range specified in clause __________.

12.9 Gyro scale factor test series

12.9.1 Purpose of gyro scale factor test series

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

12.9.2 Gyro scale factor test series—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Rate table with angle or rate output, depending on gyro output data format
b) Gyro output measuring and recording equipment
c) Gyro electronics and power supplies
e) Timing device
f) Environmental temperature control equipment

12.9.3 Gyro scale factor test series—setup and procedure

12.9.3.1 Gyro scale factor and gyro scale factor errors

Align the rate table rotation axis to within __________ [mrad, ___] of vertical. Mount the gyro in the fixture on the table so that the IRA is parallel to the table rotational axis within __________ [mrad, ___]. Connect the gyro to the output measuring equipment. Set the instrumentation to record the elapsed time and gyro output. With the table rotating, operate the gyro in accordance with the standard test conditions of 11.1. The tests shall be performed and the output data recorded in accordance with the following tabulation.

Normal input rate	Direction: positive, negative	Total number of revolutions	Number of measurements at each rate	Output data
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
• • •	• • •	• • •	• • •	• • •
—	—	—	—	—

In whole angle mode, it is sometimes important to sample data at angles different than one table revolution, so that errors periodic with one revolution or periodic over several revolutions are observable.

The output for whole angle mode devices is the delta angle recorded over one sample interval; for force-rebalance mode devices, it is the indicated rate output.

A warm-up test should be performed first. The warm-up test duration should be long enough to determine the warm-up effects on scale factor. The number of table revolutions per measurement for the warm-up test is a compromise between a large number of revolutions (so as to reduce noise due to table angle resolution, gyro output quantization and gyro output noise) and a small number of revolutions (to increase time resolution).

Sufficient measurements and conditions for repeatability measurements should be specified to provide for determination of the scale factor and scale factor errors. A zero table rate measurement at one or more table positions is required to remove the effects of earth's rate and uncompensated drift rate from the scale factor data. In selecting the zero table rate test time and the number of table revolutions consideration should be given to the error contributions of the table angle uncertainty, gyro output quantization, IA misalignment and gyro output noise. For scale factor measurements at extremely low input rates, a procedure of orienting the gyro to measure various components of earth's rate, instead of table rotation may be necessary.

12.9.3.2 Gyro scale factor sensitivities

12.9.3.2.1 Temperature

Using the environmental temperature control equipment, repeat 12.9.3.1 at temperatures __________ ± __________°C, after a minimum of __________ [h, _____] dwell at the specified temperatures.

Measurements need not be taken at all of the rates of 12.9.3.1.

12.9.3.2.2 Acceleration

Repeat the test procedure of 12.9.3.1 at the following table-rotation-axis angles to the vertical: ___, ___, … degrees within ______mrad.

12.9.3.2.3 Other sensitivities

These sensitivities include, but are not limited to, effects due to input power variations including frequency, voltage, ripple, starting and operating current.

12.9.4 Gyro scale factor test series—results

12.9.4.1 Gyro scale factor

From the test data taken in 12.9.3.1, compute the nominal gyro scale factor by computing the slope of the straight line that can be fitted by the method of least squares to the input-output data, after correction for the zero table rate. The gyro scale factor shall conform to the requirements of clause ________.

Alternatively, the gyro scale factor can be determined as the value obtained at a specified rate, the mean value over several rates, or the result of some other algorithm.

12.9.4.2 Gyro scale factor errors

12.9.4.2.1 Linearity error

From the test data taken in 12.9.3.1, compute the deviation of the output data at each input (rate, angle) from the least squares fit of the data calculated in 12.9.4.1. The linearity error shall conform to the requirements of clause __________.

Alternate methods include weighting, calculation over a limited range, and computing linearity error after compensation.

12.9.4.2.2 Asymmetry

Compute the asymmetry at specified rates as the ratio of the difference in magnitudes of scale factor measured for positive and negative inputs to one-half the sum of the magnitudes. Asymmetry shall conform to the requirements of clause __________.

12.9.4.2.3 Repeatability

From the test data in 12.9.3.1, compute the scale factor repeatability. The results of the gyro scale factor repeatability shall conform to the requirements of clause __________.

12.9.4.2.4 Stability

The variation in scale factor obtained from the test series of 12.9.3.1 shall conform to the requirements of clause __________.

12.9.4.2.5 Hysteresis

Scale factor hysteresis in temperature and/or rate obtained from the test series of 12.9.3.1 shall conform to the requirements of clause __________.

12.9.4.3 Gyro scale factor sensitivities

It is assumed that the data from gyros with a supplied scale factor model (thermal, acceleration, etc.) are compensated with that model prior to the above analysis.

12.9.4.3.1 Temperature

From the test data taken in 12.9.3.2.1, compute the temperature sensitivity as the maximum scale factor change over the specified temperature range, divided by the temperature range. The temperature sensitivity of the gyro scale factor shall conform to the requirements of clause __________.

12.9.4.3.2 Acceleration

From the test data taken in 12.9.3.2.2, compute the acceleration sensitivity as the maximum scale factor change over the specified acceleration range, divided by the acceleration range. The acceleration sensitivity of the gyro scale factor shall conform to the requirements of clause __________.

12.9.4.3.3 Other sensitivities

12.10 Input rate limits test

12.10.1 Purpose of input rate limits test

The purpose of this test is to measure the input rate limits.

12.10.2 Input rate limits test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Rate table with angle or rate output, depending on gyro output data format
b) Gyro mounting fixture
c) Gyro output measuring and recording equipment
d) Timing device

12.10.3 Input rate limits test—setup and procedure

Install and operate the gyro in accordance with the procedure of 12.9.3. The data points selected shall include the input rate limits of clause ____.

12.10.4 Input rate limit test—results

From the test data taken in 12.10.3, compute the linearity error of the gyro scale factor with the maximum input rate of clause _____ included in the set of data, using the same method described in 12.9.4.1 and 12.9.4.2.1. The gyro scale factor linearity error shall conform to the requirements of clause _____.

12.11 Drift rate test series

12.11.1 Purpose of drift rate test series

The purpose of this test series is to measure the bias, random drift rate, measurement noise, environmentally sensitive terms, their repeatabilities and sensitivities.

12.11.2 Drift rate test series—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Precision positioning means
b) Gyro output measuring and recording equipment (optional digitizer for analog output)
c) Timing device
d) Environmental temperature control equipment
e) Magnetic field generating equipment
f) Spectrum analyzer (for analog output)

12.11.3 Drift rate test series—setup and procedure

12.11.3.1 Bias, random and measurement noise

Mount the gyro so that the [IRA, XRA, YRA] is [vertical, horizontal, polar, __________] within __________ [mrad, _____]. Connect the gyro to the output measuring equipment and energize the gyro in accordance with the standard test conditions of 11.1. Record the gyro output for a period of __________ [h, __________] with data accumulated over __________ [s, __________] sample intervals.

In general, the data record length (test duration) should be sufficient to determine performance characteristics at desired confidence levels. The data sample rate should be at least twice the highest frequency of interest.
Care should be taken in mounting the gyro so that the effects of earth's rotation rate and the ambient magnetic field may be taken into account.

12.11.3.2 Repeatability

Repeat the procedure of 12.11.3.1 __________ times for the conditions specified in clause __________.

12.11.3.3 Environmentally sensitive drift

12.11.3.3.1 Temperature

Using the environmental temperature control equipment, stabilize the gyro at __________ ± __________ °C. Perform the procedure of 12.11.3.1. Repeat the procedure at additional temperature(s) of __________ ± __________ °C.

12.11.3.3.2 Temperature ramp

Mount the gyro in a temperature controlled chamber in accordance with the standard test conditions of 11.1. Stabilize the gyro temperature for _______ minutes at ______ ± ______ °C. Measure and record the gyro output as specified in 12.11.3.1 and the gyro temperature sensor output. Continue these measurements as the environmental chamber is ramped to ______°C at a rate of ______ °C per minute.

The locations of the sensors for the temperature to be measured and the temperature to be controlled should be specified. The temperature profile may also include several periods of stabilization followed by ramping, with a period of stabilization following the last ramp.

12.11.3.3.3 Other sensitivities

These sensitivities include, but are not limited to, effects due to input power variations including frequency, voltage, ripple, starting and operating current.

12.11.4 Drift rate test series—results

The data processing applied to the drift rate test series data from 12.11.3 includes least squares estimation and Allan variance computation methods for the purpose of determining bias and random drift coefficients.

The Allan variance method is discussed in detail in Annex C of IEEE Std 647 or IEEE Std 952. Annex B of these same documents presents an overview of dynamic error modeling.

PSDs may also be used to determine gyro noise terms. In addition, PSDs are useful to isolate and identify specific frequency components, which may be present in the gyro output.

Agreement between the supplier and the user concerning the modeling method and the data reduction and analysis process is recommended.

12.11.4.1 Bias and random

12.11.4.1.1 Bias, D_F

From the test data taken in 12.11.3.1 after warm-up, compute the drift rate as the average angular rate output for each sample interval multiplied by the gyro scale factor with the component of earth rate along the input axis removed. Compute D_F by calculating the average of all the drift rate data. The results shall conform to the requirements of clause __________.

12.11.4.1.2 Random, D_R

a) PSD — From the test data taken in 12.11.3.1, after warm-up, determine the noise characteristics from the PSD.

The PSD may be obtained by either a) using a spectrum analyzer (analog output), or b) by using any one of a number of discrete Fourier transform techniques (digitized output).

b) Allan variance — From the test data taken in 12.11.3.1 after warm-up compute the random drift coefficients R, K, B, N, and Q by forming the Allan variance estimates

$$\sigma_{\Omega}^2(nT_0) = \frac{1}{2(M-2n)(nT_0)^2} \sum_{m=1}^{M-2n} (\theta_{m+2n} - 2\theta_{m+n} + \theta_m)^2$$

for n=1,2,3,...,$n_{max} \leq (M-1)/2$ and fitting the results to the expression

$$\sigma_{\Omega}^{2} = \frac{R^2 n^2 T_0^2}{2} + \frac{K^2 n T_0}{3} + B^2\left[\frac{2}{\pi}\right]\ln(2) + \frac{N^2}{nT_0} + \frac{3Q^2}{n^2 T_0^2}$$

in the least squares sense where:

θ_m = integrated angular rate through the m[th] sample. $\theta_m = \int_0^{mT_0} \Omega(t)dt$

$1/T_0$ = data sample rate
MT_0 = data record length
The results shall conform to the requirements of clause ________.

> Annex C of IEEE Std 647 or IEEE Std 952 presents a detailed explanation of the random drift coefficients and their relationship to the Allan variance technique. In some cases additional noise terms such as those due to Markov (correlated) noise or sinusoidal noise should be added to the expression for σ_{Ω}^2.

12.11.4.2 Repeatability

From the test data in 12.11.3.2, compute the bias repeatability. The results of the bias repeatability shall conform to the requirements of clause __________.

12.11.4.3 Environmentally sensitive drift

> It is assumed that the data from gyros with a supplied bias model (thermal, acceleration, etc) are compensated with that model prior to the following analyses.

12.11.4.3.1 Temperature

From the test data taken in 12.11.3.3.1 after warm-up, calculate the gyro bias as in 12.11.4.1.1. Compute the bias temperature sensitivity as the slope of a least squares fit of bias over the test temperature range. The bias temperature sensitivity shall conform to the requirements of clause __________.

12.11.4.3.2 Temperature ramp

From the data taken in 12.11.3.3.2 after warm-up, calculate the maximum change in gyro bias and divide this by the temperature ramp rate. The temperature ramp drift rate shall conform to the requirements of clause _____.

12.11.4.3.3 Other sensitivities

12.12 Input axis alignment

12.12.1 Purpose of input axis alignment test

The purpose of this test is to measure the misalignment of the IA to the IRA.

12.12.2 Input axis alignment test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Rate table with angular readout
b) Gyro output measuring equipment
c) Gyro output recording equipment
d) Right angle test fixture

12.12.3 Input axis alignment test—setup and procedure

12.12.3.1 Input axis alignment

Mount the gyro in the fixture on the rate table so that the IRA is perpendicular to the rate table rotational axis within __________ [mrad, ___]. Operate the gyro in accordance with the standard test conditions of 11.1. Apply a positive table rate of __________ ± __________ [rad/s, ___] and record the gyro output over __________ revolutions. Repeat the test with a negative table rate whose magnitude is within ± __________ [rad/s, ___] of the positive rate. Rotate the gyro +90° about the IRA and repeat the test for positive and negative table rates.

If the direction of the IA misalignment is important, the XRA should be aligned to the positive rate table rotational axis (right hand rule) for the initial position. For the second position (gyro rotated by 90°) the YRA should be aligned to the positive rate table rotational axis.
If it is desirable to eliminate the test fixture error, rotate the gyro 180° about the IRA with respect to the fixture and repeat the test.

12.12.3.2 Repeatability

Repeat the procedure of 12.12.3.1 __________ times for the condition specified in clause __________.

12.12.4 Input axis alignment test—results

12.12.4.1 Alignment of the IA to the IRA

The misalignment, α, is calculated from the data obtained in 12.12.3.1 using the gyro scale factor obtained from 12.9.4.1 as follows:

$$\delta_{1,2} = \frac{\left(\Omega_{pos} - \Omega_{neg}\right)S}{2\dot{\theta}}$$

$$\alpha = \sin^{-1}(\delta_1^2 + \delta_2^2)^{1/2}$$

δ_1 = misalignment in initial gyro orientation in fixture
δ_2 = misalignment in 90° gyro orientation in fixture
Ω_{pos} = Gyro output from positive rotation
Ω_{neg} = Gyro output from negative rotation
S = gyro scale factor
$\dot{\theta}$ = table rotation rate

The misalignment shall conform to the requirements of clause __________.

When the XRA and YRA are used in performing the procedure of 12.12.3.1, δ_1 and δ_2 correspond to Θ_y and $-\Theta_x$ respectively in the model equation 8.3.

12.12.4.2 Repeatability

Repeat the test result calculations of 12.12.4.1 using the data from 12.12.3.2. The misalignment angles shall agree with those obtained in 12.12.4.1 within the requirements of clause __________.

12.13 Angle storage

12.13.1 Normal operation angle storage

This test applies only to force-rebalance mode and requires the gyro to have an externally available pickoff signal.

12.13.1.1 Purpose of normal operation angle storage test

The purpose of this test is to determine the amount of angle stored in the CVG when subjected to angular rates and angular accelerations that are within the operating environment.

12.13.1.2 Normal operation angle storage test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Means of recording the pickoff signal
b) Rate table

12.13.1.3 Normal operation angle storage test—setup and procedure

Mount the CVG with IA parallel to the test table rotation axis. While recording the CVG pickoff signal, impart angular rates and angular accelerations within the operating environmental limits of clause __________.

12.13.1.4 Normal operation angle storage test—results

Determine that the angle storage indicated by the maximum excursion of the CVG pickoff signal meets the requirements of clause __________.

12.13.2 Over-range operation angle storage

This test applies only to force-rebalance mode and requires the gyro to have an externally available pickoff signal.

12.13.2.1 Purpose of over-range operation angle storage test

The purpose of this test is to determine the amount of angle stored in the CVG when subjected to angular rates and angular accelerations that are outside the operating environmental limits.

12.13.2.2 Over-range operation angle storage test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Means of recording the pickoff signal
b) Rate table

12.13.2.3 Over-range operating angle storage test—setup and procedure

Mount the CVG with IA parallel to the test table rotation axis. While recording the CVG pickoff signal, impart angular rates and angular accelerations sufficiently outside the operating environmental limits of clause __________ such that the capability of the force-rebalance loop is exceeded.

12.13.2.4 Over-range operating angle storage test—results

Determine that the angle storage indicated by the maximum excursion of the CVG pickoff signal meets the requirements of clause __________.

12.13.3 Across power interrupt angle storage

This test applies to force-rebalance and whole angle modes.

12.13.3.1 Purpose of across power interrupt angle storage test

The purpose of this test is to determine the amount of angle stored in the CVG when subjected to a power interrupt.

12.13.3.2 Across power interrupt angle storage test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Means of recording the gyro output
b) Rate table with angle output

12.13.3.3 Across power interrupt angle storage test—setup and procedure

Mount the CVG with IA parallel to the test table rotation axis. While recording the CVG output, impart angular rates and angular accelerations within the operating environmental limits of clause __________, and interrupt power to the CVG for the time specified in clause ______.

12.13.3.4 Across power interrupt angle storage test—results

a) In whole angle mode, for the given environmental input, determine if the output signal after the power interrupt is within the accuracy required in clause _________.
b) In force-rebalance mode, for the given environmental input, determine if the integrated output after the power interrupt is within the accuracy required in clause _________.

12.14 Run-down time

This test requires the gyro to have externally available vibration amplitude maintaining control loop inputs.

12.14.1 Purpose of run-down time test

The purpose of this test is to measure the time it takes for the CVG to stop vibrating.

12.14.2 Run-down time test—equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Means of recording the input signal to the vibration amplitude maintaining control loop

12.14.3 Run-down time test—setup and procedure

Turn off the vibration amplitude maintaining control loop and other functions of the CVG while continuing to record the signal input to the amplitude maintaining control loop that measures the vibration amplitude.

12.14.4 Run-down time test—results

Determine if the time required for the vibration amplitude to decrease to zero or to a small threshold value is greater than the requirement in clause _________.

12.15 Transfer function

12.15.1 Purpose

The purpose of this test is to demonstrate the transfer function of the gyro (response amplitude and phase lag versus input angular rate frequency).

12.15.2 Test equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Rate table with angle or rate output, depending on gyro output data format
b) Gyro mounting fixture
c) Gyro and table output measuring and recording equipment

12.15.3 Test setup and procedure

Mount the gyro on the rate table with its positive IRA in the same direction as the rate table axis vector. Align the two axes to within ____ [mrad, ____]. Oscillate the test table at several frequencies. Measure the outputs of both the gyro and rate table for each test frequencies. Determine the phase and amplitude of the gyro output with respect to the rate table output.

If the outputs are analog, a dynamic signal analyzer may be used to compare the outputs of the gyro and rate table. If the outputs are digital, then transfer function analysis software may be used to compare the outputs of the gyro and rate table. Care should be taken if the rate table and gyro outputs are not of the same kind (angle or rate, analog or digital).

12.15.4 Test results

The transfer function shall satisfy the requirements of _____.

12.16 Generated fields

12.16.1 Electromagnetic interference

The purpose of these tests is to measure the electromagnetic emissions of the gyro.

MIL-STD-462 is a reference commonly used in the U.S. to describe test procedures and equipment required for this test.
These tests should be outlined in the following manner to conform to the format used in the rest of this standard:

12.16.1.1 Purpose
12.16.1.2 Test equipment
12.16.1.3 Test setup and procedure

12.16.1.4 Test results

12.16.2 Acoustic noise

The purpose of this test is to measure the acoustic noise generated by the gyro.

MIL-STD-740 is a reference commonly used in the U.S. to describe test procedures and equipment required for this test.
The test should be outlined in the following manner to conform to the format used in the rest of this standard:
12.16.2.1 Purpose
12.16.2.2 Test Equipment
12.16.2.3 Test setup and Procedures
12.16.2.4 Test Results

12.17 Environment test series

These tests are to verify that the gyro performs as specified during or after subjection to environments outside of the standard operation conditions, or both, but within the specified environmental limits.

Procedures for most environmental tests are covered by existing industry, government, and military documents, an example of which is MIL-STD-810. Selection criteria should include:

1) importance of the stability and sensitivity of the parameter in a given environment
2) practicability of running the test with existing equipment. Testing should be limited to that required by the application.

The tests should be outlined in the following manner to conform to the format used in the rest of this standard:
12.17.1 Name of Test
12.17.1.1 Purpose
12.17.1.2 Test Equipment
12.17.1.3 Test setup and procedure
12.17.1.4 Test Results

12.18 Life tests

12.18.1 Non-operating

12.18.1.1 Purpose

The purpose of this test is to demonstrate that the gyro parameters vary by less than the requirements for the specified storage or dormancy period, and that the gyro performs as required after the storage or dormancy period.

12.18.1.2 Test equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Rate table
b) Gyro mounting fixture
c) Gyro output measuring and recording equipment

12.18.1.3 Test setup and procedure

The setup for checking the gyro at the beginning and end of the test period shall be in accordance with 12.9.3 and 12.11.3. The test procedure is:

a) Determine the scale factor per 12.9 and the bias per 12.11.

b) Place the protective packaged gyro into the storage environment, which may include periodic subjection to vibration, shock, temperature cycling, and/or other non-operating environmental conditions for ____ [days, months, years].

or

b') Place the gyro in a dormant, non-operating condition, which could be with its temperature at the operating point or some other point, and with periodic structural, mechanical, electrical, or other environmental stresses for ____ [days, months, years].

c) At the end of the storage or dormancy period again determine the scale factor and bias.

If desired, periodic measurements of performance parameters during storage or dormant life may be specified, and additional parameters such as misalignments and non-linearities may be measured. However, removing the gyro from its test fixture affects misalignment estimates.

12.18.1.4 Test results

The scale factor and bias values for all measurements shall meet the requirements of ____.

12.18.2 Operating

12.18.2.1 Purpose

The purpose of this test is to demonstrate that the gyro parameters vary by less than the requirements for the specified operating life period and that the gyro performs as required during the operating life period.

12.18.2.2 Test equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Rate table
b) Gyro mounting fixture
c) Gyro output measuring and recording equipment

12.18.2.3 Test setup and procedure

The setup shall be in accordance with 12.9.3 and 12.11.3. The gyro shall be operated continuously, except for periodic on-off cycles per the requirements of _____.

Every ____ [hours, days] for ____ [months, years] determine the scale factor and bias per 12.9 and 12.11. Accumulate the operating time and the number of on-off cycles, until the requirements of _____ are met.

12.18.2.4 Test results

The maximum scale factor and bias variations during the operating life shall satisfy the requirements of ____.

Maximum allowed changes in misalignment, nonlinearity, and other parameters may also be tested for.

12.19 Reliability tests

12.19.1 Purpose

The purpose of this test is to demonstrate the MTBF statistics for a representative sample of gyros.

12.19.2 Test equipment

In addition to the standard operating equipment from 11.2.2, the following test equipment from 11.2.3 is required for this test and should be listed in this subclause:

a) Gyro mounting fixture for multiple gyros
b) Gyro output measuring and recording equipment

If the reliability test is done simultaneously with the operating life test, the fixture should be mounted on a rate table per 12.18.2.2 to allow periodic parameter calibrations.

12.19.3 Test setup and procedure

Mount the gyros in the reliability test fixture. Accumulate gyro-operating hours with periodic on-off cycles per the requirements of _____. Record the number of failures, the failure type, and the operating times at which they occur.

A gyro fails when it no longer meets its performance characteristics specified in 5.3. The parameters observed during reliability testing, exactly what constitutes a failure, performance data recorded during testing, and test times should be clearly defined, with user approval, prior to initiation of reliability testing.

In some cases, accelerated testing is appropriate. Accelerated reliability testing subjects the gyro to periodic hot soaks, temperature cycles, increased on-off cycles, vibration, shock, etc., in order to obtain a measure of the MTBF over the projected lifetime of the device in a shorter test time. Accelerated reliability tests of key subassemblies may also be performed to estimate gyro MTBF. Typically, the trade off between applied environments and the amount of accelerated aging they cause is presented in the form of a table. Both the manufacturer and the user must agree upon the use of this table for qualification testing of the gyro.

12.19.4 Test results

The MTBF statistics from the reliability tests shall conform to the requirements of _____.

Annex A

(informative)

Design features of Coriolis Vibratory Gyros

A CVG contains either a) a vibrating shell where the Coriolis effect of inertial rotation on a vibration standing wave pattern is controlled or monitored, or b) vibrating proof mass(es) where the Coriolis effect of inertial rotation perpendicular to the driven vibration direction is monitored. The gyro can be macro-sized, or it can be a micro-electro-mechanical system (MEMS) fabricated from silicon or quartz chips by photolithographic and chemical etching processes used in the integrated circuit industry.

A CVG generic block diagram is presented in Figure A.1 and examples of CVG physical structures are presented in Figure A.2.

A CVG has a number of control loops, such as for automatic gain control of the drive amplitude, vibration frequency control at the resonant natural frequency, quadrature vibration nulling, etc. The CVG is termed open-loop if the readout motion is monitored but not controlled, whereas it is termed force-rebalance if the readout motion is nulled.

For an open-loop CVG, the Coriolis-effect motion is read out electrostatically, optically, with a force transducer, or some other way. The output signal is sinusoidal with amplitude proportional to the angular rate about the input axis.

An axisymmetric CVG structure can be operated in either the whole angle mode or in the force-rebalance mode. In force-rebalance mode, the force to keep the vibration standing wave pattern stationary relative to the case is the measure of input inertial angular rotation rate. In whole-angle mode, the change in the position of the standing wave pattern relative to the case is the measure of the change in inertial angle. For an introduction to the theory of operation of the CVG, see Annex B.

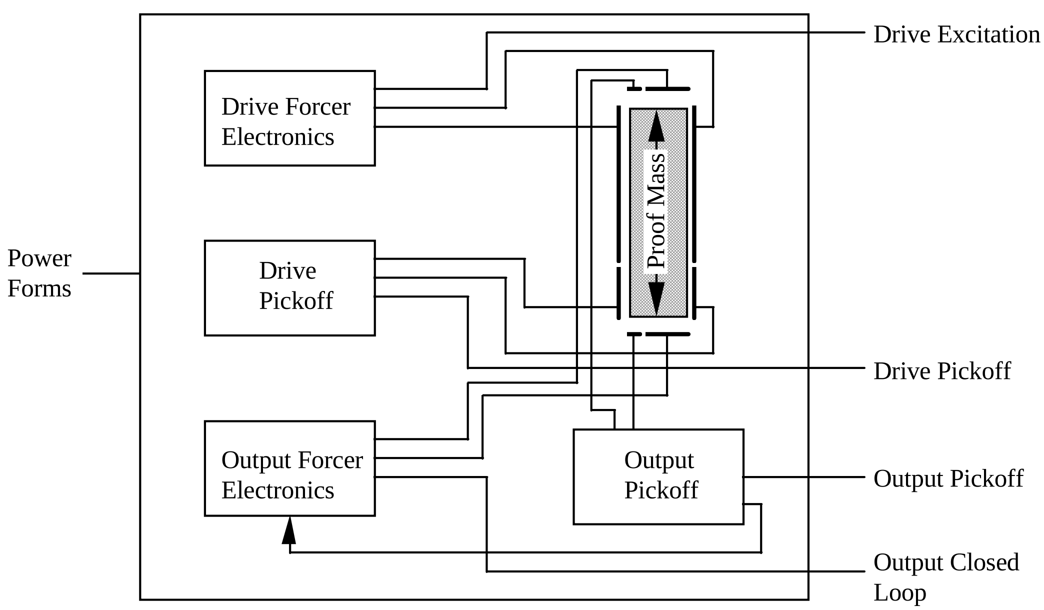


Figure A.1—CVG generic block diagram

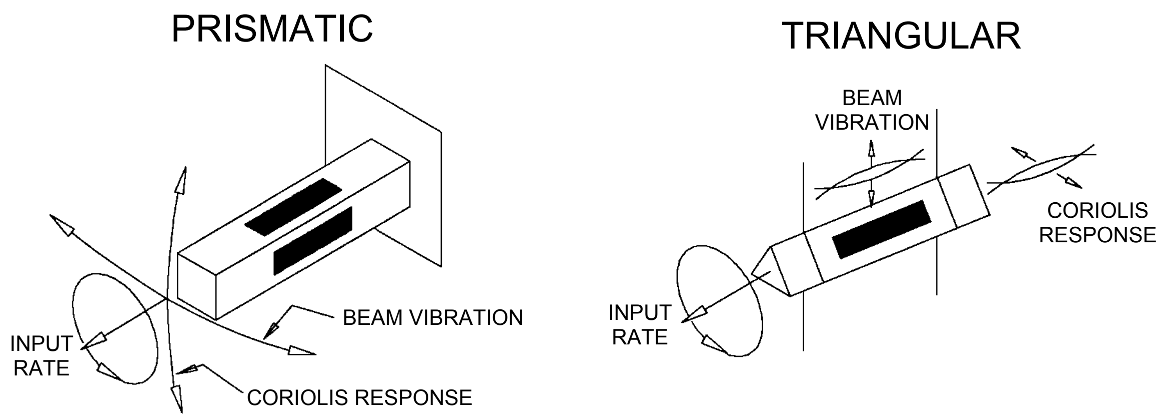


Figure A.2a—Examples of CVG physical structures – vibrating beams

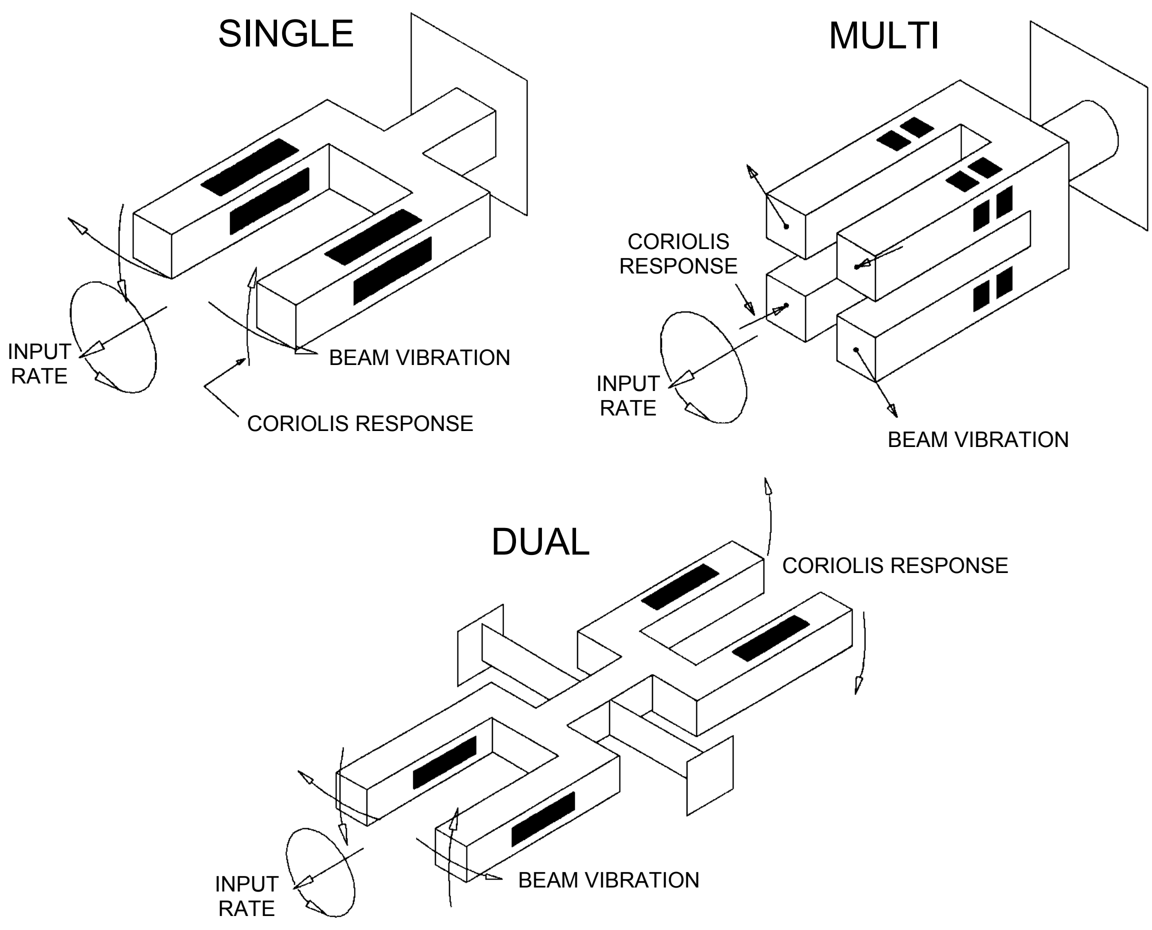


Figure A.2b—Examples of CVG physical structures – tuning forks

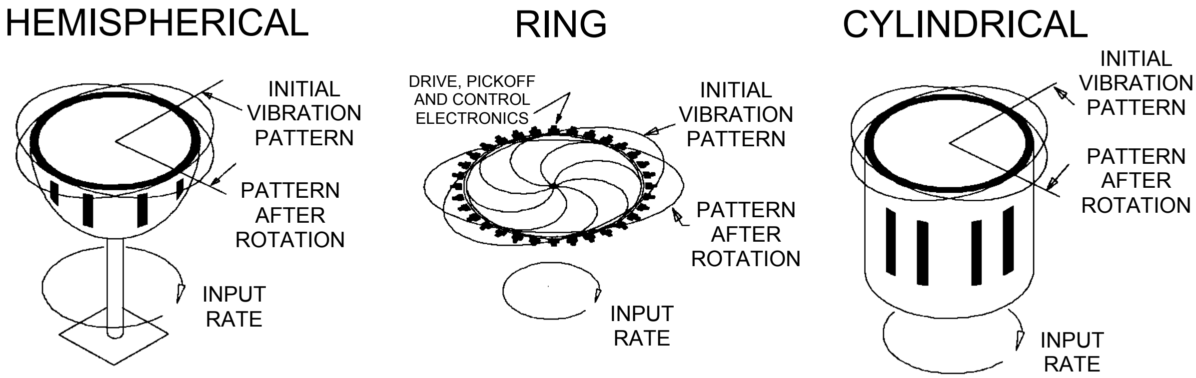


Figure A.2c—Examples of CVG physical structures – vibrating shells

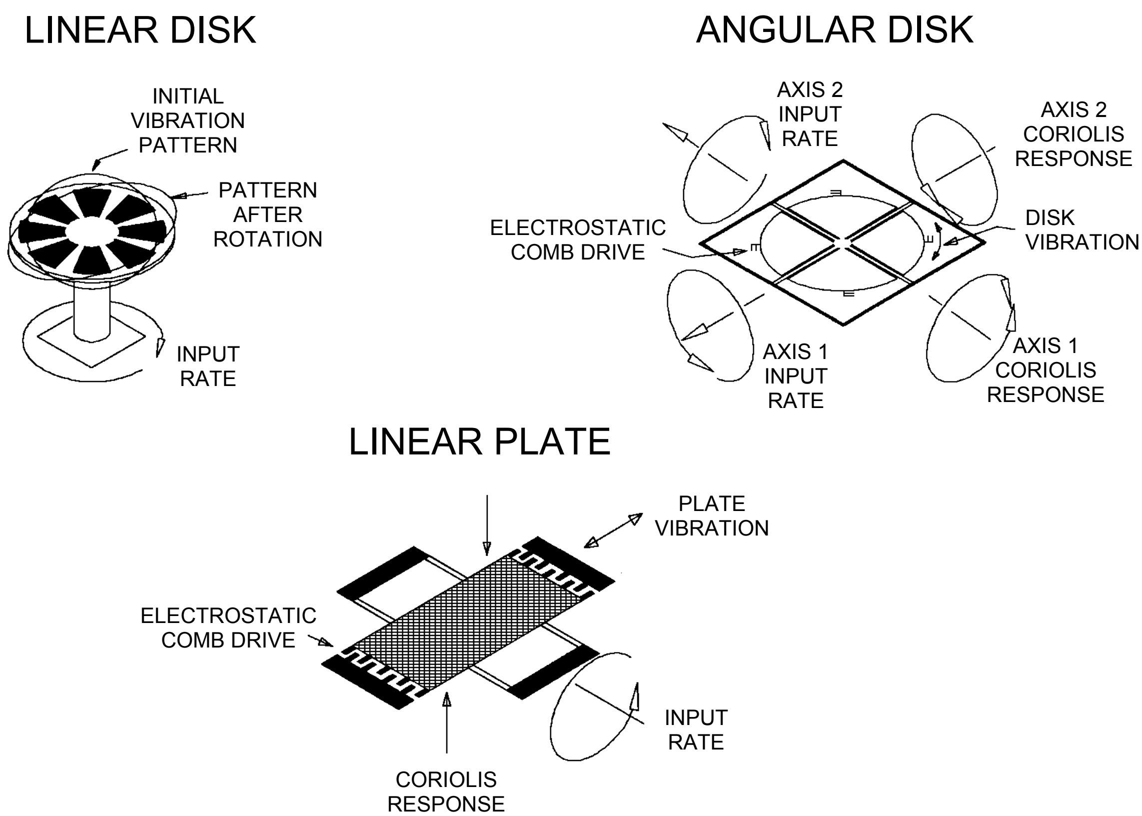


Figure A.2d—Examples of CVG physical structures – vibrating plates

Annex B

(informative)

Coriolis Vibratory Gyros

B.1 Introduction

Examples of Coriolis Vibratory Gyros (CVGs) are described in Annex A. Detailed descriptions of the principal CVGs (up until about the mid-1980s) are presented in Reference [B1] based on the British and American patent literature. In a CVG, one of the resonant modes of an elastic body is excited to a prescribed amplitude. When the device rotates about a particular body-fixed axis, the resulting Coriolis forces acting on the body's vibrating mass elements excite a different resonant mode. (See section 39 of Reference [B2] for a definition of Coriolis force.) The rate at which energy is transferred to this second mode is a measure of the rotation rate about the sensitive axis. In most cases, the natural frequency of the second mode is at or near that of the first.

CVGs represent an important inertial technology, they lend themselves to miniaturization, and some have demonstrated navigation grade performance (sub 0.01 deg/hr drift error).

CVGs fall into two classes, depending on the nature of the two vibration modes involved. In the first class, the modes are different. An example of this class is the tuning fork gyro (see Figure A.2), in which the mode driven is the ordinary vibration mode of the fork (tines moving towards and away from one another), while the second or readout mode is the torsional oscillation of the fork about its axis of symmetry. In the second class, the two modes are identical, being two orthogonal degenerate modes (modes of the same natural frequency) of an axisymmetric elastic body. Examples are the vibrating string, the vibrating prismatic (square) bar, the vibrating cylindrical and hemispherical shells, and in fact the Foucault pendulum. One mode of the pendulum, for example, can be taken as its swinging in a north-south direction, and the orthogonal mode is then its swinging in an east-west direction.

The Foucault pendulum, or equivalently a point mass constrained to oscillate about the origin in the *xy* plane by an axisymmetric set of linear springs, embodies the principal characteristics of all CVGs of the second (degenerate- or same-mode) class. To every dynamical state of one of these CVGs there corresponds an equivalent pendulum orbit. Pendulum orbits may therefore be used to represent the properties of CVG dynamical states diagrammatically. The theory developed to describe the dynamical behavior and control of one of these CVGs can be applied virtually unchanged to the others.

CVGs can be mechanized to operate as rate gyros in an open-loop mode or a closed-loop force-rebalance mode, or they can be mechanized to operate as rate-integrating gyros in a whole-angle mode. In the open-loop mode, one of the vibration modes (the driven mode) is excited by a force of a prescribed amplitude. Inertial rotation about the input axis then results in the excitation of the second mode (the readout mode). The amplitude of the readout-mode vibration is proportional to the input rate. The bandwidth of CVGs mechanized in the open-loop mode is directly related either to the time it takes the readout-mode vibration to take on its new steady-state value after a step change in input rate or to the separation of the two natural frequencies. Required bandwidths are achieved in practice either by increasing the damping, or by separating the driven-mode and readout-mode natural frequencies. In open-loop mechanizations, there is therefore a tradeoff between bandwidth and sensitivity, since increasing either the modes' frequency separation or damping results in a smaller steady-state response to a given inertial input rate.

This tradeoff between bandwidth and sensitivity is eliminated by operating the CVG in the force-rebalance mode. In the force-rebalance mode, the driven mode is again maintained at a prescribed amplitude, but the vibration arising in the readout mode as a result of inertial rotation is driven to zero. The force required to null the readout-mode vibration is then proportional to the input rotation rate.

CVGs of the same-mode class can be operated in the whole-angle mechanization mode. In the whole-angle mechanization mode, the Coriolis forces resulting from input rotation are allowed to transfer energy freely between the two modes. The result (as in the Foucault pendulum) is that the change in the equivalent pendulum angle (arctangent of the ratio of the mode amplitudes) in any time interval is directly proportional to the total inertial angle the CVG has rotated through during that interval. The proportionality constant is called the angular gain factor of the CVG.

It has been stated frequently in the literature that only CVGs of the same-mode class can be mechanized in the whole-angle mode. In fact, a simple rescaling of the independent variables converts the equations of motion of any of the CVGs of the unlike-mode class into pendulum equations. The scaling change is very simple. The new variable representing the vibration-mode amplitude is the product of the original variable and the square root of the mode effective mass (or moment of inertia). The new variables have the property that their squares are proportional to the energy in the mode.

The conclusion is that all CVGs can be mechanized in the whole-angle mode. (There may, of course, be reasons that make the mechanization of a particular CVG in the whole-angle mode impractical, such as the requirement that the natural frequencies of the two modes be closely matched. In fact, to date, only CVGs of the same-mode class have been mechanized in the whole-angle mode.) The single-tuning-fork gyro may be given as an example. If the lateral deflection of one of the tine ends, y, is employed as the first mode dynamical variable, and the torsional rotation angle of the tine ends, Θ, is used for the independent variable that describes the second mode, the rescaled variables $\xi_1 = \sqrt{m}\,y$, $\xi_2 = \sqrt{I}\,\Theta$ satisfy pendulum equations with angular gain factor $k = G/\sqrt{mI}$, where G is the Coriolis-coupling coefficient in the original equations. These equations describe the transfer of energy between the tuning-fork mode and the torsion mode caused by the rotation of the device about the tine axis of symmetry. If the tuning-fork mode is excited initially, and control loops are put in place to resupply damping losses and to keep the two component oscillations in phase, in the presence of constant input rate energy gradually builds up in the torsion mode at the expense of the tuning-fork mode. A point is reached when all of the energy is in the torsion mode. If the initial tine amplitude was y_{peak}, the amplitude of the torsion mode at this point, Θ_{peak} is related to y_{peak} by the energy equation $1/2\, m y_{peak}^2 = 1/2\, I \Theta_{peak}^2$. As time progresses, the energy is transferred back to the tuning-fork mode, etc. During any interval $t - t_0$, the change $\theta - \theta_0$ in the pendulum angle $\theta = \tan^{-1}(\xi_2/\xi_1)$ is related to the inertial rate Ω by the equation

$$\theta(t) - \theta_0 = -k \int_{t_0}^{t} \Omega(t')\,dt' \tag{B.1}$$

This equation, which demonstrates that CVGs operating in the whole-angle mode are ideal integrating gyros, is valid when the vibration amplitudes are small enough so that nonlinear effects may be neglected. There is a subclass of unlike-mode CVGs in which deviations from this ideal behavior occur in the linear theory. In CVGs of this subclass, two rigid bodies are constrained in gimbal-like structures (much like the structures of dynamically tuned gyros) in such a way that rotation about a sensitive axis results in the transfer of energy between the two orthogonal modes of vibration of the structure. An example is the CVG of Reference [B3]. In these CVGs, there is an additional coupling between the orthogonal modes proportional to the product of the angular acceleration about the sensitive axis and a linear combination of the moments of inertia of the rigid bodies. Although these additional angular-acceleration coupling terms result in a deviation from the ideal pendulum behavior described above, their only significant effect is to cause a nonzero drift sensitivity to sinusoidal angular acceleration about the sensitive axis when the angular acceleration varies at twice the vibration mode natural frequency.

B.2 Two-dimensional oscillator

The starting point for all CVG analysis are the equations of motion of the driven- and readout-vibration modes. The mode amplitudes satisfy linear, second-order equations with coupling terms proportional to input rate, angular acceleration, etc. As discussed above, either the equations are identical in form to those of the two-dimensional linear oscillator (CVGs of the same-mode class), or they can be transformed to this form by a simple change of variable (CVGs of the unlike-mode class). The starting point for all CVG control-loop analysis can therefore be taken to be the equations of motion of the ideal two-dimensional linear oscillator shown in Figure B.1. A point mass, m,

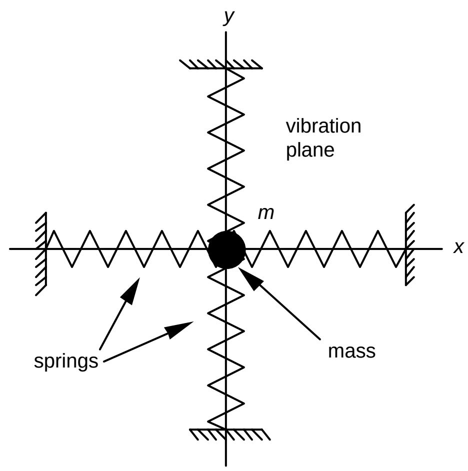


Figure B.1—The two-dimensional oscillator

is limited to motion in the *xy* plane where it experiences a restraining force directed towards the origin of magnitude $F = -K\sqrt{x^2 + y^2}$. The coordinate frame (and the device) are rotating about the *z* axis at rate Ω with respect to an inertial frame. The non-relativistic equations of motion of a point mass in a general non-inertial frame are given in Equation (39.7) of Reference [B2]. When these equations are specialized to the two dimensional oscillator and are generalized by including an angular gain factor *k* as a multiplier of the Coriolis and angular acceleration terms and a multiplier *k'* of the centrifugal terms, they become

$$\begin{aligned} \ddot{x} - k\left(2\Omega\dot{y} + \dot{\Omega}y\right) + \left(\omega^2 - k'\Omega^2\right)x &= f_x \\ \ddot{y} + k\left(2\Omega\dot{x} + \dot{\Omega}x\right) + \left(\omega^2 - k'\Omega^2\right)y &= f_y \end{aligned} \tag{B.2}$$

where $\omega = \sqrt{K/m}$ is the mass point's natural frequency of oscillation. f_x and f_y represent external force components per unit mass. In the analysis of the solutions of these equations, the effects of the centrifugal force components Ω^2_x and Ω^2_y are usually neglected.

B.3 Pendulum variables

When the inertial rate Ω and the external force components are absent, the equations reduce to

$$\begin{aligned} \ddot{x} + \omega^2 x &= 0 \\ \ddot{y} + \omega^2 y &= 0 \end{aligned} \tag{B.3}$$

The general solution of Equation (B.3) represents the orbiting of the mass point about the origin in a stationary elliptical orbit as shown in Figure B.2.

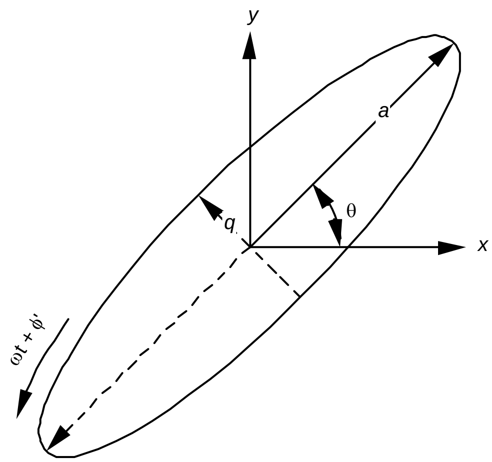


Figure B.2—The pendulum variables

In terms of the orbit parameters a,q,θ,ϕ' defined in the figure, the solution is clearly

$$\begin{aligned} x &= a\cos\theta\cos(\omega t+\phi') - q\sin\theta\sin(\omega t+\phi') \\ y &= a\sin\theta\cos(\omega t+\phi') + q\cos\theta\sin(\omega t+\phi') \end{aligned} \tag{B.4}$$

Neglecting the centrifugal force terms (terms of order Ω^2), the general solution to Equation (B.2) with no external force components is (compare Equation (B.1))

$$\begin{aligned} x &= a\cos\left(\theta_0 - k\int_{t_0}^{t}\Omega(t')dt\right)\cos(\omega t+\phi') - q\sin\left(\theta_0 - k\int_{t_0}^{t}\Omega(t')dt\right)\sin(\omega t+\phi') \\ y &= a\sin\left(\theta_0 - k\int_{t_0}^{t}\Omega(t')dt\right)\cos(\omega t+\phi') + q\cos\left(\theta_0 - k\int_{t_0}^{t}\Omega(t')dt\right)\sin(\omega t+\phi') \end{aligned} \tag{B.5}$$

(The fact that Equation (B.5) is a solution to Equation (B.2) when terms of order Ω^2 are neglected and $f_x = f_y = 0$ may be verified by direct substitution.)

Equation (B.5) demonstrates that, in the absence of external forces and damping, pendulum orbits of the ideal two-dimensional oscillator retain their shape and rotate in response to the inertial rotation of the case. In a given time interval, the rotation angle of the orbit with respect to the case is $-k$ times the rotation angle of the case with respect to inertial space. The ideal two-dimensional oscillator is a perfect rate-integrating gyro. This characteristic is the basis of all CVG operation.

B.4 Control of a CVG

The fact that Equation (B.5) with constant a,q,θ_0,ϕ' is a solution to the ideal two-dimensional oscillator equations provides a convenient starting point for CVG loop design and analysis. In the absence of external forces and damping, and when the natural frequencies of the two component oscillators are identical, the pendulum variables a, q, θ_0, ϕ' are constant and the CVG is a perfect gyro. A mismatch in the component-oscillator natural frequencies, damping losses, mismatch in the damping losses of the component oscillators, external forces, etc., cause a, q, θ_0, ϕ' to vary as a function of time. For any practical CVG, this time variation is slow on a time scale determined by the oscillator period, $2\pi/\omega$. Therefore, a very accurate approximate analysis of Equation (B.2) (including frequency mismatch, damping and damping mismatch, external forces, etc.) is provided by the method of averaging (see Reference [B4] - [B6]) In the method of averaging, the two oscillator-component second-order equations are converted to four approximate first-order equations for the pendulum variables a, q, θ, ϕ'. These four approximate equations provide the basis for loop analysis and simulation.

CVG control loops required for force-rebalance and whole-angle CVGs are discussed in the next paragraphs. The open-loop CVG is discussed in the final section of this Annex.

Reference-phase loop

To control a CVG, forces must be exerted which have time components in the vicinity of the oscillator natural frequency and have the appropriate phase. A reference-phase generator (voltage-controlled oscillator, self-oscillator loop, clock, etc.) is therefore necessary. The reference phase generator both provides the signals from which forces of the correct phase are derived and provides the reference signals for demodulating the output signals from the CVG. It is from the demodulated output signals that estimates of the pendulum variables a, q, θ, ϕ' are obtained. It is usually convenient to implement a phase-locked loop to phase lock the reference phase generator to the pendulum phase variable ϕ'.

Amplitude-control loop

An amplitude-control loop is required in all force-rebalance and whole-angle CVGs. The rate at which the amplitude diminishes due to damping is proportional to a/τ, where $\tau = 2Q/\omega$ is the damping time constant. Forces must be applied to sustain the amplitude a against these damping losses.

Quadrature-control loop

In higher-accuracy CVGs, a control loop is put in place to restrict the value of q, usually driving it to zero. q is referred to as the quadrature component of the pendulum orbit because it is oscillating in phase quadrature with the principal component a (see Figure B.2). Also, in force-rebalance CVGs, it is the readout component in phase quadrature with the driven mode oscillation. The principal source of the generation of quadrature is the mismatch in the two natural frequencies. Other sources include axis misalignments in certain CVGs.

Rebalance (rate) loop

In the force-rebalance CVG, a fourth loop is implemented to maintain the pendulum angle θ at a prescribed value, usually zero.

B.5 CVG in the force-rebalance mode

The force-rebalance CVG is considerably simpler than the whole-angle CVG because the equivalent pendulum orbit is (usually) lined up with the pickoff system. The pickoff outputs, which indicate the driven-mode and readout-mode motion, after demodulation provide direct estimates of the pendulum variables a, q, θ, ϕ'. In fact, assuming the force-rebalance loop maintains the pendulum angle θ in the vicinity of zero, the following approximate relations are valid (see Figure B.2 and Reference [B6])

$$c_x \approx a \quad s_x \approx a(\phi - \phi') \\ c_y \approx a\theta \quad s_y \approx q \tag{B.6}$$

where ϕ is the reference-phase generator phase and c_x, s_x, c_y, s_y are the components of x,y in phase and in quadrature with the reference phase. Because of the approximate validity of these relations, the pickoff demodulated quantities c_x, s_x, c_y, s_y can be used directly as the control variables in the loops.

As an illustration, a common mechanization of the control loops of the force-rebalance CVG is shown in Figure B.3. The CVG pickoff outputs x,y are demodulated to obtain the components in phase and in quadrature with the reference phase c_x, s_x, c_y, s_y. The quadrature component of the driven-mode output s_x is used as the error signal in the phase-locked loop that phase locks the voltage-controlled oscillator (VCO) to the driven-mode phase. P,I (proportional plus integral) GAIN in the diagram stands for the operation gain factor times a linear combination of the error signal and its integral.

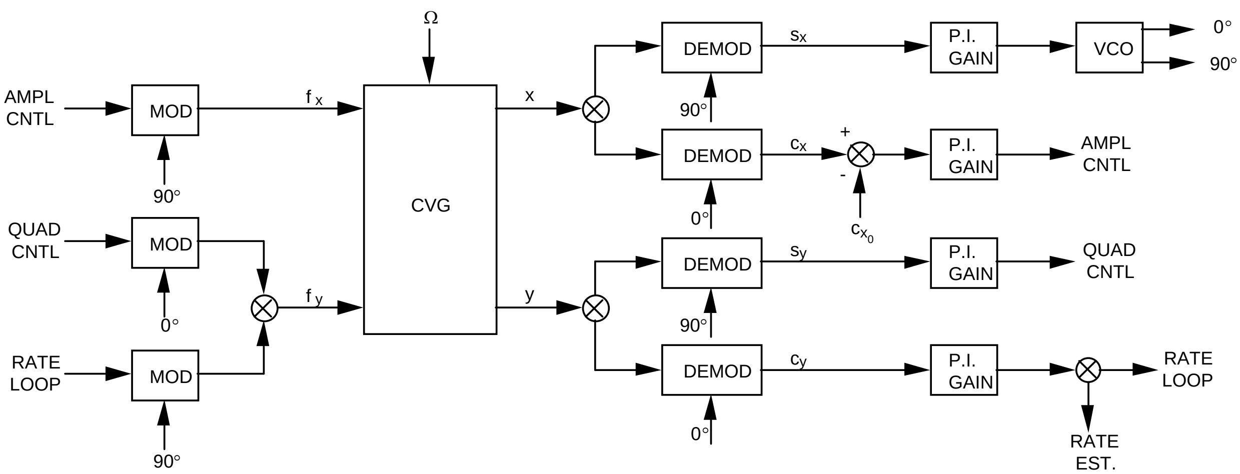


Figure B.3—The force-rebalance CVG

The difference between the in-phase component of the driven-mode output c_x and the reference (prescribed) amplitude c_{x_0} serves as the error signal in the amplitude-control loop. The quadrature component of the readout-mode output s_y provides the error signal in the quadrature-control loop, and the in-phase component c_y is used for the error signal in the force-rebalance (rate) loop. The output of the P,I GAIN element in the rate loop, multiplied by the appropriate scale factor, is the gyro output (rate estimate).

B.6 CVG in the whole-angle mode

In the whole-angle mode, the pendulum orbit is allowed to rotate freely in response to an input inertial rate. Changes in the pendulum angle θ provide a measure of the corresponding case rotation as in Equation (B.1). Here the control problem is to maintain the amplitude a at a prescribed value a_0 and to null the quadrature amplitude q. The mechanization illustrated in Figure B.3 can be used (after disengaging the rate loop) by including a transformation block that converts the pickoff demodulated quantities c_x, s_x, c_y, s_y into the pendulum variables $a, \phi - \phi', \theta, q$. These quantities can then be input into the appropriate P,I GAIN blocks to develop the correct VCO outputs and the control-force amplitudes. One of the outputs of this pickoff-to-pendulum variable transformation is the pendulum angle θ. In addition to being the gyro output variable, it can be used as an input to a coordinate (orthogonal) transformation which transforms the outputs of the P,I GAIN elements into the x,y coordinate frame before they are modulated and input as force components f_x, f_y to the gyro.

There are many approximate, yet practical approaches to implementing the $c_x, s_x, c_y, s_y \rightarrow a, \phi - \phi', \theta, q$ transformation in whole-angle CVG mechanizations. An optimum transformation is given in References [B5] - [B6].

B.7 Generalized two-dimensional oscillator equations

In order to provide an adequate basis for the analysis of all CVGs, Equation (B.2) must be generalized to include damping terms and to provide for different natural frequencies and damping coefficients of the two modes. The derivation of such generalized two-dimensional oscillator equations is carried out in Reference [B6]. The equations are

$$\begin{aligned}
&\ddot{x} - k\left(2\Omega\dot{y} + \dot{\Omega}y\right) + \frac{2}{\tau}\dot{x} + \Delta\left(\frac{1}{\tau}\right)\left(\dot{x}\cos 2\theta_\tau + \dot{y}\sin 2\theta_\tau\right) \\
&+\left(\omega^2 - k'\Omega^2\right)x - \omega\Delta\omega\left(x\cos 2\theta_\omega + y\sin 2\theta_\omega\right) = f_x + \gamma_x g_x \\
&\ddot{y} + k\left(2\Omega\dot{x} + \dot{\Omega}x\right) + \frac{2}{\tau}\dot{y} - \Delta\left(\frac{1}{\tau}\right)\left(-\dot{x}\sin 2\theta_\tau + \dot{y}\cos 2\theta_\tau\right) \\
&+\left(\omega^2 - k'\Omega^2\right)y + \omega\Delta\omega\left(-x\sin 2\theta_\omega + y\cos 2\theta_\omega\right) = f_y + \gamma_y g_y
\end{aligned} \tag{B.7}$$

where

$$\begin{aligned}
&\omega^2 = \frac{\omega_1^2 + \omega_2^2}{2}; \quad \frac{1}{\tau} = \frac{1}{2}\left(\frac{1}{\tau_1} + \frac{1}{\tau_2}\right) \\
&\omega\Delta\omega = \frac{\omega_1^2 - \omega_2^2}{2}; \quad \Delta\left(\frac{1}{\tau}\right) = \frac{1}{\tau_1} - \frac{1}{\tau_2}
\end{aligned} \tag{B.8}$$

The suspension system of Figure B.1 has not only been made asymmetric, so that the natural frequencies of the two modes, ω_1 and ω_2, are different, but the normal-mode axes have been assumed not to coincide with the pickoff axes x and y. θ_ω is the aximuth of the ω_2 normal-mode axis measured from the x direction. Similarly, the principal damping time constants, τ_1 and τ_2, are assumed different and the principal damping directions are assumed not to coincide with the pickoff axes x and y. θ_τ is the azimuth of the τ_1 damping axis. The equations have been written in terms of the average and difference frequencies, and the average and difference damping constants, because in most CVGs, ω_1 and ω_2, and τ_1 and τ_2 are nearly equal. (ω and $\Delta\omega$ have been defined as the average and difference of the squares of the natural frequencies in order to keep the form of the equations simple while at the same time preserving their complete generality. They continue to be valid for large values of both $\Delta\omega$ and $\Delta(1/\tau)$). In addition, the equations have been further generalized by including forcing terms proportional to the components of the deceleration of the frame, g_x, g_y, with multipliers γ_x, γ_y. This is typically the form of the forces that arise from mass unbalance.

B.8 Simplified analysis of the force-rebalance CVG

In this section, we take $\gamma_x = \gamma_y = 0$ and neglect the influence of the centrifugal and the angular-acceleration force terms.

In the force-rebalance CVG, an amplitude-controlled self-oscillator loop (or equivalent) is closed around the x axis. It develops the necessary force f_x to sustain an oscillation of the form

$$x = c_{x_0} \cos \omega_x t \tag{B.9}$$

where

$$\omega_x^2 = \omega^2 - \omega\Delta\omega\cos 2\theta_\omega \tag{B.10}$$

The y equation then becomes

$$\ddot{y} + \frac{2}{\tau_y}\dot{y} + \omega_y^2 y = f_y + \omega_x c_{x_0}\left[2k\Omega + \Delta\left(\frac{1}{\tau}\right)\sin 2\theta_\tau\right]\sin\omega_x t + c_{x_0}\omega\Delta\omega\sin 2\theta_\omega\cos\omega_x t \tag{B.11}$$

where

$$\begin{aligned}\omega_y^2 &= \omega^2 + \omega\Delta\omega\cos 2\theta_\omega \\ \frac{1}{\tau_y} &= \frac{1}{\tau} - \frac{1}{2}\Delta\left(\frac{1}{\tau}\right)\cos 2\theta_\tau\end{aligned} \tag{B.12}$$

The simplified analysis of the force-rebalance CVG is completed by assuming that an infinite-gain, infinite bandwidth loop is closed about the y axis which maintains y identically zero under all conditions. The force the loop develops to do this is

$$f_y = -\omega_x c_{x_0}\left[2k\Omega + \Delta\left(\frac{1}{\tau}\right)\sin 2\theta_\tau\right]\sin\omega_x t - c_{x_0}\omega\Delta\omega\sin 2\theta_\omega\cos\omega_x t \tag{B.13}$$

An estimate of the input rate is obtained by demodulating the current in the y loop (proportional to f_y) with $\sin\,\omega_x t$ as the reference The quadrature term proportional to the frequency difference $\Delta\omega$ (ordinarily controlled by a quadrature control loop) is discriminated against. We write the estimate in the form

$$\hat{\Omega} = SF \bullet \text{ demod}\left(f_y\right)\Big|_{\sin\omega_x t} + B \tag{B.14}$$

with scale factor SF and bias B given by

$$\begin{aligned}SF &= -\frac{1}{2k\omega_x c_{x_0}} \\ B &= \frac{1}{2k}\Delta\left(\frac{1}{\tau}\right)\sin 2\theta_\tau\end{aligned} \tag{B.15}$$

B.9 Simplified analysis of the open-loop CVG

We again take $\gamma_x = \gamma_y = 0$ and neglect the influence of the centrifugal and the angular-acceleration force terms.

In the open-loop CVG, the driven mode (x) is excited by a sinusoidal forcing function (not necessarily at the driven-mode natural frequency ω_x) of constant amplitude. The unrestrained ($f_y = 0$) readout mode (y) is excited when an input rate Ω is present due to the Coriolis coupling to the driven mode. The information about the input rate is contained in the response y.

Since the open-loop CVG design parameters are such that y always remains small compared to x, we neglect the y terms in the x equation of Equation (B.7) in the analysis and write it in the form

$$\ddot{x} + \frac{2}{\tau_x}\dot{x} + \omega_x^2 x = f_x \tag{B.16}$$

where

$$\frac{1}{\tau_x} = \frac{1}{\tau} + \frac{1}{2}\Delta\left(\frac{1}{\tau}\right)\cos 2\theta_\tau \tag{B.17}$$

The steady-state response x to the forcing function

$$f_x = -f_{x_0}\sin\omega_{f_x}t \tag{B.18}$$

is given approximately (valid for $\omega_{fx} \approx \omega_x$; the minus sign is included so that the expressions will be consistent with the earlier results) by

$$x = c_{x_0}\cos\left(\omega_{f_x}t + \phi_x\right) \tag{B.19}$$

with

$$c_{x_0} = \frac{f_{x_0}/2\omega_x}{\sqrt{\frac{1}{\tau_x^2} + \left(\omega_x - \omega_{f_x}\right)^2}} \qquad \phi_x = \tan^{-1}\left[\left(\omega_x - \omega_{f_x}\right)\tau_x\right] \tag{B.20}$$

Putting this result into the y equation of Equation (B.7), we get the analog of Equation (B.11) for the open-loop CVG

$$\ddot{y} + \frac{2}{\tau_y}\dot{y} + \omega_y^2 y = \omega_{f_x}c_{x_0}\left[2k\Omega + \Delta\left(\frac{1}{\tau}\right)\sin 2\theta_\tau\right]\sin\left(\omega_{f_x}t + \phi_x\right) + c_{x_0}\omega\Delta\omega\sin 2\theta_\omega\cos\left(\omega_{f_x}t + \phi_x\right) \tag{B.21}$$

The steady-state solution is (compare Equation (B.13), $\omega_{fx} \approx \omega_x \approx \omega_y$),

$$y = c_{y0}\cos\left(\omega_{fx}t + \phi_x + \phi_y\right) + s_{y0}\sin\left(\omega_{fx}t + \phi_x + \phi_y\right) \tag{B.22}$$

where

$$c_{y_0} = -\frac{\frac{f_{x_0}}{4\omega_x}\left[2k\Omega + \Delta\left(\frac{1}{\tau}\right)\sin 2\theta_\tau\right]}{\sqrt{\frac{1}{\tau_x^2}+\left(\omega_x - \omega_{f_x}\right)^2}\sqrt{\frac{1}{\tau_y^2}+\left(\omega_y - \omega_{f_x}\right)^2}}$$

$$s_{y_0} = \frac{\frac{f_{x_0}}{4\omega_x}\left[\Delta\omega \sin 2\theta_\omega\right]}{\sqrt{\frac{1}{\tau_x^2}+\left(\omega_x - \omega_{f_x}\right)^2}\sqrt{\frac{1}{\tau_y^2}+\left(\omega_y - \omega_{f_x}\right)^2}} \tag{B.23}$$

$$\phi_y = \tan^{-1}\left[\left(\omega_y - \omega_{f_x}\right)\tau_y\right]$$

The estimate of the input rate in this case is obtained by demodulating the y pickoff signal (proportional to y) with $\cos(\omega_{f_x}t + \phi_x + \phi_y)$ as the reference. The spurious contribution from $\Delta\omega$ is again discriminated against. We write the estimate in the form (compare Equation (B.14) and (B.15))

$$\hat{\Omega} = SF \bullet \ \mathrm{demod}\left(y\right)\Big|_{\cos\left(\omega_{f_x} t+\phi_x+\phi_y\right)} + B \tag{B.24}$$

with scale factor SF and bias B given by

$$SF = -\frac{1}{kc_{x_0}}\sqrt{\frac{1}{\tau_y^2}+\left(\omega_y - \omega_{f_x}\right)^2}$$

$$= -\frac{2\omega_x}{kf_{x_0}}\sqrt{\frac{1}{\tau_x^2}+\left(\omega_x - \omega_{f_x}\right)^2}\sqrt{\frac{1}{\tau_y^2}+\left(\omega_y - \omega_{f_x}\right)^2} \tag{B.25}$$

$$B = \frac{1}{2k}\Delta\left(\frac{1}{\tau}\right)\sin 2\theta_\tau$$

To understand the dependence of scale factor and bandwidth on the design parameters, we consider the response to a step change in Ω. Disregarding the $\Delta(1/\tau)$ and the $\Delta\omega$ terms in Equation (B.21), we write the response y to a constant input rate Ω that is turned on at $t = 0$ (in the approximation $\omega_y - \omega_{f_x} << \omega_y$, $1/\tau_y << \omega_y$),

$$y = c_{y_0}\left[\cos\left(\omega_{f_x}t + \phi_x + \phi_y\right) - e^{-\frac{t}{\tau_y}}\cos\left(\omega_y t + \phi_x + \phi_y\right)\right] \tag{B.26}$$

with c_{y0} given by Equation (B.23). Two open-loop CVG design approaches are apparent. The desired bandwidth ω_B can be obtained either (1) by adjusting the damping time constant of the readout mode to a value $1/\tau_y \geq \omega_B$, or (2) by adjusting the driven-mode forcing frequency to a value $|\ \omega_y - \omega_{fx}\ | \geq \omega_B$. In the second design choice, the transient ($\cos(\omega_y t + \phi_x + \phi_y)$) term is discriminated against in the demodulation process. (For either design approach, a frequency-domain analysis should be completed that goes beyond the present overly-simplified treatment.)

The dependence of the scale factor on the frequencies and damping time constants, as seen in Equation (B.25), is $SF \propto \sqrt{1/\tau_x^2 + \left(\omega_x - \omega_{f_x}\right)^2}\sqrt{1/\tau_y^2 + \left(\omega_y - \omega_{f_x}\right)^2}$. For the first design approach, the maximum value of the scale factor achievable is obtained when $\omega_x = \omega_y = \omega_{f_x}$. This results in $SF \sim 1/(\tau_x \tau_y) = \omega_B / \tau_x$. For the second design approach, the maximum value of the scale factor achievable is obtained when $\omega_{f_x} = \omega_x$, which also results in (assuming $1/\tau_y << \omega_B$) $SF \sim \omega_B / \tau_x$.

B.10 Annex B Bibliography

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Annex C

(informative)

Compliance matrix

Clause 5 #	Clause 5 Requirement	Clause 6 #	Clause 6.6 Test Method
5.	Requirement	N/A	
5.1	Description	N/A	
5.2	General Requirements	N/A	
5.2.1	Precedence	N/A	
5.3	Performance	N/A	
5.3.1	Input Rate Limits	6.6.10	Input Rate Limits Test
5.3.2	Gyro Scale Factor	6.6.9.1	Gyro Scale Factor
5.3.2.1	Gyro Scale Factor Errors	6.6.9.2	Gyro Scale Factor Errors
5.3.2.1.1	Linearity Error	6.6.9.2.2	Linearity
5.3.2.1.2	Asymmetry Error	6.6.9.2.1	Asymmetry
5.3.2.1.3	Repeatability	6.6.9.2.3	Repeatability
5.3.2.1.4	Stability	6.6.9.2.4	Stability
5.3.2.1.5	Hysteresis	6.6.9.2.5	Hysteresis
5.3.2.1.6	Other Errors	N/A	
5.3.2.2	Gyro Scale Factor Sensitivities	6.6.9.3	Gyro Scale Factor Sensitivities
5.3.2.2.1	Temperature	6.6.9.3.1	Temperature
5.3.2.2.2	Acceleration, Sa	6.6.9.3.2	Acceleration
5.3.2.2.3	Other Sensitivities	6.6.9.3.3	Other Sensitivities
5.3.3	Drift Rate, D	6.6.11	Drift Rate Test Series
5.3.3.1	Systematic Drift Rate	6.6.11	Drift Rate Test Series
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5.3.3.1.2	Environmentally Sensitive Drift Rate, E	6.6.11.1.2	Sensitivities
5.3.3.2	Random Drift Rate, D_R	6.6.11.3	Random Drift
5.3.4	Input Axis Alignment	6.6.12	Input Axis Alignment Test Series
5.3.4.1	IA Misalignment	6.6.12.1	Misalignment (Nominal)
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5.3.5	Operating Temperature	6.6.8.2	Operating Temperature
5.3.6	Activation Time	N/A	
5.3.6.1	Turn-On Time	6.6.5	Turn-on Time
5.3.6.2	Warm-Up Time	6.6.6	Warm-up Time
5.3.7	Angle storage	6.6.13	Angle Storage Tests
5.3.7.1	Normal operation	6.6.13.1	Normal operation angle storage
5.3.7.2	Over-range operation	6.6.13.2	Over-range operation angle storage
5.3.7.3	Across power interrupt	6.6.13.3	Across power interrupt operation angle storage
5.3.8	Run-down time	6.6.14	Run down time
5.3.9	Output Signal Polarities	6.6.7	Polarity
5.3.9.1	Input Axis	6.6.7	Polarity
5.3.9.2	Output signals	6.6.7	Polarity
5.3.10	Mechanical Isolation (radiated signals)	6.6.16	Generated Fields
5.3.11	Transfer Function	6.6.15	Transfer Function
5.3.12	Reference Constants	N/A	
5.3.12.1	Drive Frequency	N/A	
5.3.12.2	Sense Frequency	N/A	
5.3.12.3	Other resonances	N/A	
5.3.12.4	Pickoff orientation	N/A	

Clause 5 #	Clause 5 Requirement	Clause 6 #	Clause 6.6 Test Method
5.4	Mechanical Requirements	6.6.1	Examination of Product (Mechanical)
5.4.1	Exterior Surface	6.6.1	Examination of Product (Mechanical)
5.4.2	Outline and Mounting Dimensions	6.6.1	Examination of Product (Mechanical)
5.4.3	Gyro Axes	6.6.1	Examination of Product (Mechanical)
5.4.4	Weight	6.6.1	Examination of Product (Mechanical)
5.4.5	Seal	6.6.3	Leak Test
5.4.6	Identification of Product	6.6.1	Examination of Product (Mechanical)
5.4.7	Acoustic Noise	6.6.16.2	Acoustic Noise
5.5	Electrical Interface Requirements	6.6.2	Examination of Product (Electrical)
5.5.1	Schematic	N/A	
5.5.2	Impedances	6.6.2.2	Impedances
5.5.3	Input Power	6.6.4	Input Power
5.5.4	Test Points	6.6.2	Examination of Product (Electrical)
5.5.5	Grounding	6.6.2	Examination of Product (Electrical)
5.5.6	Output signals	6.6.2	Examination of Product (Electrical)
5.5.7	Temperature Sensors	6.6.8.1	Temperature Sensor Characteristics
5.5.8	Insulation Resistance	6.6.2.1	Insulation Resistances
5.5.9	Dielectric Strength	6.6.2.3	Dielectric Strength
5.5.10	Electromagnetic Interference	6.6.16.1 & 6.6.17.15	Electromagnetic Interference & Electromagnetic Fields
5.5.11	Electrostatic Discharge (ESD)	6.6.17.15	Electromagnetic Fields
5.6	Environmental Requirements	6.6.17	Environmental Test Series
5.6.1	Storage	6.6.17	Environmental Test Series
5.6.2	Transport	6.6.17	Environmental Test Series
5.6.3	Operation	6.6.17	Environmental Test Series
5.6.3.1	Operating Environment	6.6.17	Environmental Test Series
5.6.3.2	Survival Environment, Operating	6.6.17	Environmental Test Series
5.6.3.3	Survival Environment, Non-operating	6.6.17	Environmental Test Series
5.6.4	Environments	N/A	
5.6.4.1	Vibration	6.6.17.4	Vibration
5.6.4.1.1	Linear Vibration	6.6.17.4.1	Linear
5.6.4.1.2	Angular Vibration	6.6.17.4.2	Angular
5.6.4.2	Mechanical Shock	6.6.17.2	Mechanical Shock
5.6.4.3	Acceleration	6.6.17.5	Acceleration
5.6.4.3.1	Linear Acceleration	6.6.17.5.1	Linear
5.6.4.3.2	Angular Acceleration	6.6.17.5.2	Angular
5.6.4.4	Temperature	6.6.9.3.1	Temperature
5.6.4.5	Thermal Shock	6.6.17.3	Thermal Shock
5.6.4.6	Thermal Radiation	6.6.17.10	Thermal Radiation
5.6.4.7	Ambient Air Pressure	6.6.17.13	Pressure
5.6.4.8	Acoustic Noise	6.6.17.9	Acoustic Noise
5.6.4.9	Humidity	6.6.17.7	Humidity
5.6.4.10	Air Currents	6.6.17.11	Air Currents
5.6.4.11	Fungus	6.6.17.6	Fungus
5.6.4.12	Salt Spray	6.6.17.8	Salt Spray
5.6.4.13	Nuclear Radiation	6.6.17.12	Nuclear Radiation
5.6.4.14	Magnetic Fields	6.6.17.14	Magnetic Fields
5.6.4.15	Electromagnetic Fields	6.6.17.15	Electromagnetic Fields

Clause 5 #	Clause 5 Requirement	Clause 6 #	Clause 6.6 Test Method
5.6.4.16	Sand and Dust	6.6.17.16	Sand and Dust
5.6.4.17	Solar Radiation	6.6.17.17	Solar Radiation
5.6.4.18	Rain	6.6.17.18	Rain
5.7	Life	6.6.18	Life Test
5.7.1	Non-operating	6.6.18.1	Non-operating
5.7.2	Operating	6.6.18.2	Operating
5.8	Reliability	N/A	
5.8.1	Reliability Program	N/A	
5.8.2	MTBF	6.19	Reliability Test