

IEEE Standard Specification Format Guide and Test Procedure for Nongyroscopic Inertial Angular Sensors: Jerk, Acceleration, Velocity, and Displacement

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

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Foreword

(This Foreword is not a part of IEEE Std 671-11985, IEEE Standard Specification Format Guide and Test Procedure for Nongyroscopic Inertial Angular Sensors: Jerk, Acceleration, Velocity, and Displacement.)

This standard was prepared by the Gyro and Accelerometer Panel of the Aerospace and Electronic Systems Society of the Institute of Electrical and Electronics Engineers. It is a guide for the preparation of a specification and test procedure for an inertial angular sensor. It is intended to provide a common meeting ground of terminology and practice for manufacturers and users of an array of sensors which have been developed to meet needs not easily met by traditional spinning rotor gyroscopes. These needs have included greater dynamic range, lower noise, lower power, longer service life, and greater ruggedness. To cover this variety, the standard is written in black box input versus output terms which could be applied to any inertial angular sensor, including laser and conventional gyroscopes. It is not intended to compete with existing standards for specific devices with highly specific models and error sources, such as spring restrained rate gyros. Rather, the standard is to provide a uniform guide for those inertial angular sensors which have not been covered elsewhere.

The sensors described may have analog or digital outputs and may measure angular jerk, acceleration, rate or displacement with or without response down to zero frequency.

This standard consists of a main text and three appendixes. The main text is a specification format guide and test procedure for inertial angular sensors. The specification format guide is intended to provide a common format for manufacturers and users in the preparation of an angular sensor specification. The test procedure is intended to provide a means of verifying that the specifications have indeed been met.

Appendix A is a compilation of block diagrams characterizing the dynamic response of several types of inertial angular sensors.

Appendix B describes the modifications of some of the tests of this standard which are necessary to accommodate sensor classes other than the sensor which is used as an example in this standard, or for those sensors which have unusual error sources requiring specialized testing. The special problems and techniques of dynamic angular testing is also discussed in Appendix B.

Appendix C discusses some of the necessary accommodations which shall be made to the described tests of this standard when testing sensors with digital, rather than analog, outputs.

The user is cautioned not to overspecify; 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 format are not precluded.

Blank spaces permit the insertion of specific parameter values and their tolerances. Brackets are used to enclose alternate choices of dimensional units, signs, axes, etc. The choices shown are the recommended options, but are not meant to include all possibilities. Boxed statements are included for information only and are not part of the specification format. The figures presented are to be used as a guide for the preparation of specific figures or drawings.

The terminology used conforms to ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms and IEEE Std 528-1984, IEEE Standard Inertial Sensor Terminology. The units used conform to ANSI/IEEE Std 268-1982, American National Standard Metric Practice. In this standard, the symbol g is used to denote a unit of acceleration equal in magnitude to the local value of gravity at the test site or other specified value of gravity. This symbol is thus distinguished from g which is the standard symbol for gram.

This publication represents a group effort on a large scale. The major contributors to this standard were as follows:

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IEEE Standard Specification Format Guide and Test Procedure for Nongyroscopic Inertial Angular Sensors: Jerk, Acceleration, Velocity, and Displacement

1. Scope

This standard defines the requirements and test procedures for a [single, multi-] axis nongyroscopic angular [jerk, acceleration, velocity, displacement] sensor. The output is [an analog electrical signal, a digital electrical pulse train] proportional to angular [jerk, acceleration, velocity, displacement]. The electronics are to be considered part of the sensor to the extent specified herein. All parameters specified in this standard refer to the overall sensor output unless otherwise specified. The device will hereafter be referred to as the sensor.

In some instances, the sensor mechanism and the electronics may be housed in separate packages. In these cases, the term sensor may be reserved for the mechanism, while the overall device is called the transducer, accelerometer, etc.

2. Applicable Documents

The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of the specification to the extent specified herein. In the event of any conflict between the requirements of this standard and the listed documents, the requirements of this standard shall govern.

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

2.1 Specifications

2.1.1 Government

2.1.2 Industry/Technical

2.1.3 Company

2.2 Standards

2.2.1 Government

2.2.2 Industry/Technical

2.2.2.1

ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.¹

2.2.2.2

IEEE Std 528-1984, IEEE Standard Inertial Sensor Terminology.

The units and symbols used in this standard comply with:

ANSI/IEEE Std 260-1978 (R1985), IEEE Standard Letter Symbols for Units of Measurement (SI Units, Customary Inch-Pound Units, and Certain Other Units)

ANSI/IEEE Std 268-1982, IEEE Standard Metric Practice

ANSI/IEEE Std 315-1975, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams

2.2.3 Company

2.3 Drawings

2.3.1 Government

2.3.2 Industry/Technical

2.3.3 Company

2.4 Other Publications

Other applicable documents should be listed under the appropriate categories.

¹These documents are available from the Sales Department, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854. They are also available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

3. Requirements

3.1 General

3.1.1 Precedence

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

- 1) The purchase agreement
- 2) This standard and its applicable drawings
- 3) Other applicable documents

List other applicable documents in order of precedence. See Section 2.
--

3.1.2 Other

List other applicable general requirements.

3.2 Description

The angular [jerk, acceleration, velocity, displacement] sensor is a [single, multi-] axis, nongyroscopic device which provides [an analog electrical signal, a digital electrical pulse rate] proportional to angular [jerk, acceleration, velocity, displacement], and associated electronics as shown in Fig 1.

If a torque balance capture loop is used, specify if it is to be part of the device or the test equipment. The information shown in Fig 1 is intended to be suggestive only, due to the large variety of sensors which it can represent. Figure 1 is not intended as a replacement for the outline drawing, but rather provides a means of clearly distinguishing the device being specified from the remainder of the system.
--

3.2.1 Mechanical and Thermal Design

The following mechanical and thermal requirements apply to sensor package(s) to the extent specified.

The configuration should be specified to convey the user's limitations and specific needs. The sensor may consist of more than one package.

3.2.1.1 Exterior Surface

All exterior surfaces shall withstand the environment specified herein and the handling expected in the normal course of operation, testing, and maintenance without deterioration which causes nonconformance to this standard.

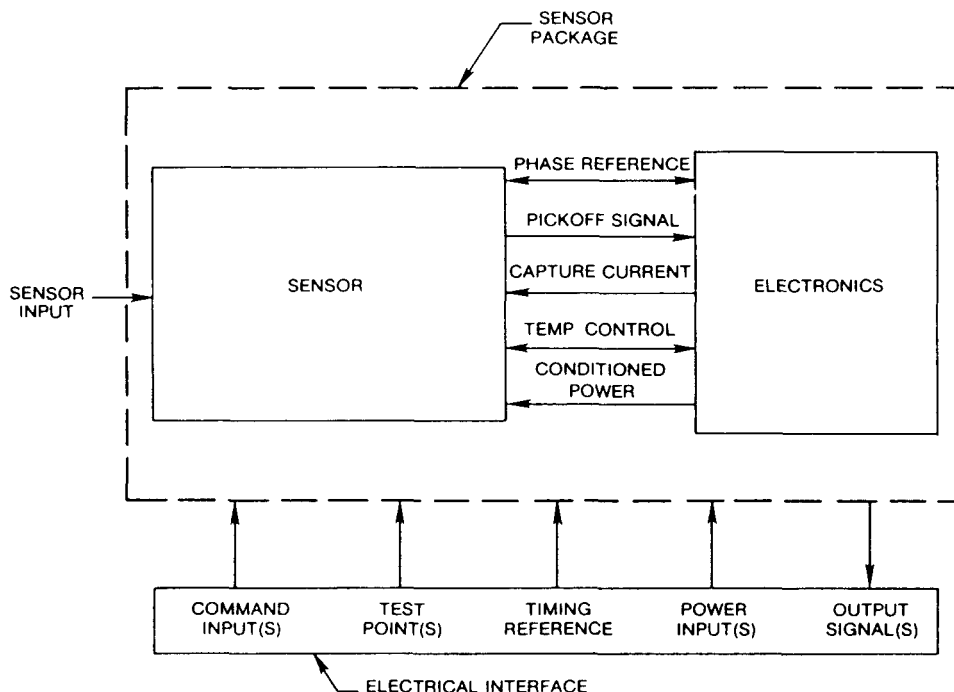


Figure 1—Angular Sensor Block Diagram

Additional requirements controlling surface finish protective treatment, metals, dissimilar metals, workmanship, etc, may be designated. Mounting surfaces which define the location of the input axis may require special consideration.

3.2.1.2 Dimensions

The outline and mounting dimensions shall conform to the outline of drawing number _____.

The center of gravity of each package may be specified with appropriate tolerances.

3.2.1.3 Identification of the Product

The sensor shall be marked as specified on the outline drawing.

The specification may require

- 1) Name of component
- 2) Part number
- 3) Serial number
- 4) Contract number
- 5) Manufacturer's name and symbol.

3.2.1.4 Sensor Reference Axes

The positive direction of the input [axis, axes] shall be defined by external markings and by a reference [surface, line] on the package which contains the sensor. The positive directions of the axes shall be as defined in 3.3.2 and drawing _____.

Physically significant axes orthogonal to the input reference may also be defined. See Fig 2.

3.2.1.5 Weight

The weight shall be _____ $\pm$ _____ [g, kg]

If appropriate, only the maximum weight needs to be specified. When accessories such as cable and connector are to be included in the weight requirement, the specification shall so state. When the sensor consists of more than one package, the weight may be specified for each package.

3.2.1.6 Seal

The sensor package shall meet the following seal requirements:

Specify either (1) or (2), as appropriate. If required, specify the appropriate seal requirements for the other package(s).

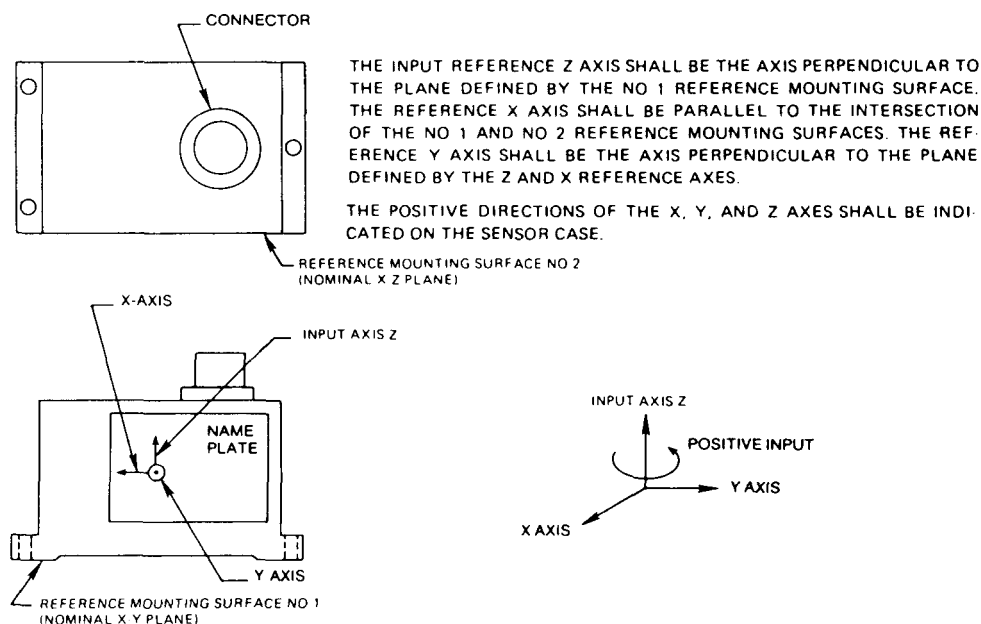


Figure 2—Sensor Reference Axes

- 1) **Liquid Filled.** The sensor shall be sealed so that no liquid leakage is detected under _____ power magnification after being subjected to an external vacuum at _____ $\pm$ _____ Pa and a temperature of _____ $\pm$ _____ °C for a minimum period of _____ min.

In some cases, other procedures may be more appropriate, such as the use of fluorescent tracers in the fluid to facilitate leak detection.

- 2) **Gas Filled.** The sensor shall be sealed so that the maximum gas leakage rate shall not exceed _____ cm³/s of _____ gas, measured at standard conditions for a minimum period of _____ min while being subjected to a vacuum of _____ $\pm$ _____ Pa at a temperature of _____ $\pm$ _____ °C.

Tracer gases may be added to the fill gas so as to facilitate leak detection.

3.2.1.7 Controlled Operating Temperature

The controlled operating temperature as indicated by a temperature sensor (on, within) the sensor shall be _____ $\pm$ _____ °C.

This requirement is applicable only to a sensor with its own temperature control. If electronics and the sensor are separately controlled, specify the operating temperature for each.

In some applications, consideration should be given to the magnitude of the thermal gradients existing across the sensor.

3.2.2 Electrical Design

The sensor's electrical and magnetic design requirements shall be as specified below. The sensor shall meet the performance criteria of 3.3 during all permissible variations of the inputs of 3.2.2.1.

3.2.2.1 Electrical Interface

The electrical interface for the sensor consists of the signals, power, and test points listed below and illustrated in Fig 1.

3.2.2.1.1 Power Inputs

Specify the characteristics of the power in put(s). For example:

- 1) Source impedance $\pm$ [+, -] j $\pm \Omega$
- 2) Load impedance $\pm$ [+, -] j $\pm \Omega$
- 3) Voltage $\pm$ [V ac, V dc]
- 4) Rise time _____ ms maximum
- 5) Frequency $\pm$ Hz
- 6) Nominal current $\pm$ A
- 7) Peak current _____ A for _____ [s, min]
- 8) Harmonic content _____ %

3.2.2.1.2 Output Signal(s)

Specify the characteristics of the output signal(s).

The output(s) may be characterized by analog variables) or by discrete variables), for example, pulse trains or binary word formats. The variables) may represent angular displacements) or any applicable time derivatives. For example (see Fig 1):

Type: Analog [voltage, current] proportional to the magnitude of the angular velocity input.

Characteristics:

- 1) Source impedance $\pm$ [+, -] j $\pm \Omega$
- 2) Load impedance $\pm$ [+, -] j $\pm \Omega$
- 3) Polarity positive with [positive, negative] input
- 4) Voltage range $\pm$ V to $\pm$ V
- 5) Current range $\pm$ mA to $\pm$ mA

In some cases, output voltage or current limits may be specified to prevent overranging system inputs. Also, overrange voltage or current recovery time may be specified.

An example of a digital sensor may be found in Appendix C, Section C3.

3.2.2.1.3 Command Input(s)

Specify the type and characteristics of command input(s), if required. For example:

Type:

- 1) ON/OFF
- 2) Self test (see 3.3.17)

Characteristics:

- 1) Source impedance $\pm$ [+, -] j $\pm \Omega$
- 2) Load impedance $\pm$ [+, -] j $\pm \Omega$
- 3) Input voltate $\pm$ [V ac, V dc]

3.2.2.1.4 Timing Reference

Specify the characteristics of the timing reference, if required. For example:

- 1) Source impedance $\pm$ [+, -] j $\pm$ Ω
- 2) Load impedance $\pm$ [+, -] j $\pm$ Ω
- 3) Repetition rate $\pm$ [pulse per second (p/s), Hz]
- 4) Wave shape (specify tolerance)
- 5) Stability $\pm$ % per [h, d]

3.2.2.1.5 Test Points

Specify the test points required for monitoring and testing the sensor. These may include test points provided for monitoring excitation voltage, pickoff output signal, torquer signal, and other control signals or temperature sensor resistances. Any special buffering or scaling requirements should be specified.

3.2.2.1.6 Grounding

Specify electrical grounding design requirements (for example, requirements for isolation between input, output, and power returns, and the grounding requirements for shields, chassis, and critical components).

3.2.2.2 Dielectric Strength

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

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

3.2.2.3 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 Ω measured at $\pm$ V dc, applied for $\pm$ s.

Different voltages may be specified for different circuits.

3.2.2.4 Electromagnetic Interference

The maximum electromagnetic interference from the sensor package(s) shall conform to _____.

Describe the requirements. In the United States, a common standard is MIL-STD-461.²

²MIL publications are available from the Director, US Navy Publications and Printing Service, Eastern Division, 700 Robbins Avenue, Philadelphia, PA 19111.

3.2.2.5 Electromagnetic Compatibility

Describe the requirements. MIL-STD-463 defines EMC as follows:

“electromagnetic compatibility. The capability of electronic equipment or systems to be operated with a defined margin of safety in the intended operational environment at designed levels of efficiency without degradation due to interference.”

When applied to single electronic devices such as the sensor, this form of compatibility is sometimes referred to as susceptibility.

3.2.2.6 Magnetic Leakage

The magnetic leakage shall not exceed _____ mT at a distance of _____ cm from the sensor package(s) in any direction.

3.2.3 Maintainability

Maintenance for operational sensors shall provide fault isolation to a line replaceable unit (LRU) by use of [built in test equipment, special test equipment, or commonly available test equipment].

3.2.3.1 LRU Interchangeability

Each line replaceable unit shall be interchangeable with like units, with the same part number, without calibration or adjustment. The manufacturer of the angular sensor shall state whether it has fully interchangeable LRU capability, or if not, which aspects do not meet the full interchange LRU standard.

3.2.3.2 LRU Maintenance

LRU maintenance is generally limited to depot or manufacturers' level facilities.

3.3 Performance

For simplification, the example of this subsection refers to a single axis sensor. Suggestions regarding the specification of multi-axis sensors may be found in Appendix B, B3.5

3.3.1 General

The sensor shall comply with the performance requirements of this standard before, during (if applicable), and after exposure to any compatible combination of the environments specified in 3.4.

Generally, limits are specified for each individual requirement. In some cases it may be desirable to specify a root sum square (rss) limit of logically-grouped individual requirements.

3.3.2 Polarity and Input Range

A positive rotation about the input axis shall result in a [positive, negative] output. See [Fig 2, Drawing_____]. The minimum input range shall be from – _____ input units to + _____ input units.

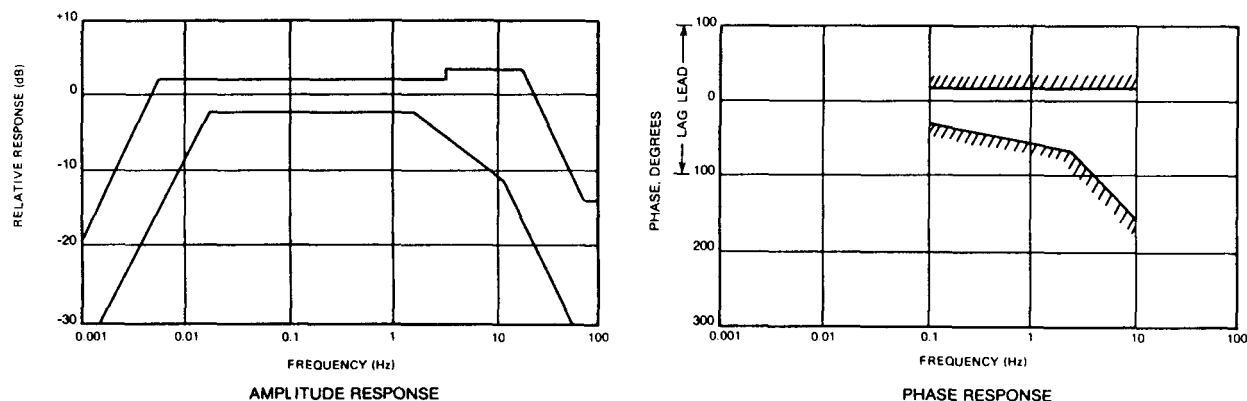


Figure 3—Frequency Response

In some cases secondary limits, for example, angular acceleration on a rate output sensor, shall be specified to prevent internal overranging. A recommended format for a frequency sensitive input range can be found in Fig 3 and the related box note under 3.3.16.

3.3.3 Scale Factor

3.3.3.1 Absolute Value

The scale factor K_1 shall be _____ $\pm$ _____ output units per input unit (compare with 6.3.)

The desired form of the output should be specified, for example, V, mA, or p/s.

3.3.3.2 Asymmetry

The difference between the scale factor measured with a positive applied input and a negative applied input shall not exceed $\pm$ _____ % of the nominal absolute scale factor.

3.3.3.3 Short-Term Stability

The rms deviation of the scale factor from its mean value, over a period of ____ [h, d] of continuous operation, shall be less than _____ %.

Other criteria for establishing stability may be utilized, such as standard deviation, curve fitting for trend determination, or computer analysis to determine the auto-correlation time.

3.3.3.4 Long-Term Stability

The best-fit slope of the scale factor, over a period of, _____ days of continuous operation, shall be less than _____ %/d. The root-mean-square (rms) deviation of the scale factor data points, from the best-fit line, shall be less than _____ %.

The unbiased estimate of the standard deviation may be substituted for the rms deviation. Alternate means of specifying long-term bias stability may be used, for example, rms deviation about the first day mean or peak-to-peak deviation.

3.3.3.5 Repeatability

The rms deviation of the scale factor from the mean of _____ measurements shall be less than _____. Between successive measurements, the sensor shall be cooled to _____ °C for at least _____ h.

Other environmental exposures may be substituted or added to the temperature environment specified. In addition, combinations of various successive environments, for example, vibration, shock, and temperature may also be specified. Alternate means of specifying repeatability may be used, for example, rms deviation about the first day mean or peak-to-peak deviation.

The cool-down time should be sufficient to attain thermal equilibrium. Other conditions for repeatability may be specified, such as turn-off with the sensor maintained at operating temperature.

3.3.3.6 Sensitivity

The absolute value of the sensitivity coefficient of the scale factor to variations from the standard test conditions of 4.5 shall not exceed the following limits:

- 1) Input voltage(s) _____ %/V
- 2) Power input frequency(ies) _____ %/Hz
- 3) Operating temperature _____ %/°C
- 4) Thermal gradients) _____ %/°C (across the instrument)
- 5) External magnetic field(s) _____ %/mT [dc or ac, or both] per axis
- 6) Pressure _____ %/Pa

The thermal gradient shall be defined for each application, for example, temperature difference, where it is to be measured, and the direction of application. In some cases, it may be desirable to specify a variation of scale-factor sensitivity induced by a thermal transient.

3.3.4 Bias

3.3.4.1 Absolute Value

The absolute value of the bias (K_0) shall not exceed _____ input units (IU). (Compare with 6.3.)

Automatic bias nulling (washout) circuits may be desirable in some applications. Automatic bias nulling may operate continuously during operation of the sensor or during turn-on sequence only. It may also operate during both time periods, but in different modes; for example, with different time constants.

3.3.4.2 Short-Term Stability

The rms deviation of the bias, from its mean value over a period of _____ [h, d] of continuous operation, shall be less than _____ IU.

Other criteria for establishing stability may be utilized, such as standard deviation, curve fitting for trend determination, or computer analysis to determine the autocorrelation time.

3.3.4.3 Long-Term Stability

The best fit slope of the bias over a period of _____ days of continuous operation shall be less than _____ IU/d. The rms deviation of the bias data points from the best-fit line shall be less than _____ IU.

The unbiased estimate of the standard deviation may be substituted for the rms deviation. Alternate means of specifying long-term bias stability may be used, for example, rms deviation about the first day mean or peak-to-peak deviation.

3.3.4.4 Repeatability

The rms deviation of the bias from the mean of _____ measurements shall be less than _____ IU. Between successive measurements, the sensor shall be cooled to _____ °C for at least _____ h.

Other environmental exposures may be substituted or added to the temperature environment specified. In addition, combinations of various successive environments, for example, vibration, shock, and temperature may also be specified. Alternate means of specifying repeatability may be used, for example, rms deviation about the first day mean, or peak-to-peak deviation.

The cool-down time should be sufficient to obtain thermal equilibrium. Other conditions for repeatability may be specified, such as turn-off with the sensor maintained at operating temperature.

3.3.4.5 Sensitivity

The absolute value of the sensitivity coefficients of the bias to variations from the standard test conditions of 4.5 shall not exceed the limits:

- 1) Input voltage(s) _____ IU/V
- 2) Power input frequency(ies) _____ IU/Hz
- 3) Operating temperature _____ IU/°C
- 4) Thermal gradient(s) _____ IU/°C (across the instrument)
- 5) External magnetic field(s) _____ IU/mT [dc or ac, or both] per axis
- 6) Pressure _____ IU/Pa

The thermal gradient shall be defined for each application, for example, temperature difference, where it is to be measured, and direction of application. In some cases, it may be desirable to specify a variation of bias sensitivity induced by a thermal transient.

3.3.5 Input Axis Misalignment (IAM)

(Compare with 6.3.)

3.3.5.1 Absolute Value

The maximum value of the angle between the input reference axis and the input axis shall be less than _____ rad.

Physically significant axes orthogonal to the input reference axis may also be defined and misalignment components specified with respect to these axes.

3.3.5.2 Short-Term Stability

The rms deviation of the IAM, from its mean value over a period of _____[h, d] of continuous operation, shall be less than _____rad.

Other criteria for establishing stability may be utilized, such as standard deviation, curve fitting for trend determination, or computer analysis to determine the auto-correlation time.

3.3.5.3 Long-Term Stability

The best fit slope of the IAM over a period of _____d of continuous operation shall be less than _____rad/d. The rms deviation of the IAM data points from the best fit shall be less than _____rad.

The unbiased estimate of the standard deviation may be substituted for the rms deviation. Alternate means of specifying long term IAM stability may be used, for example, rms deviation about the first day mean or peak-to-peak deviation.

3.3.5.4 Repeatability

The rms deviation of the IAM from the mean of _____measurements shall be less than _____rad. Between successive measurements, the sensor shall be cooled to _____°C for at least _____h.

Other environmental exposures may be substituted or added to the temperature environment specified. In addition, combinations of various successive environments, for example, vibration, shock, temperature, etc, may also be specified. Alternate means of specifying repeatability may be used, for example, rms deviation about the first day mean or peak-to-peak deviation.

The cool-down time should be sufficient to obtain thermal equilibrium. Other conditions for repeatability may be specified, such as turn-off with the sensor maintained at operating temperature.

3.3.5.5 Sensitivity

The absolute value of the sensitivity coefficients of the IAM to variations from the standard test conditions of 4.5 shall not exceed the limits:

- 1) Input voltage(s) _____ rad/V
- 2) Power input frequency(ies) _____ rad/Hz
- 3) Operating temperature _____ rad/°C
- 4) Thermal gradient(s) _____ rad/°C (across the sensor)
- 5) External magnetic field(s) _____ rad/mT [dc or ac, or both]
- 6) Pressure _____ rad/Pa

The thermal gradient shall be defined for each application, for example, temperature difference, where it is to be measured, and the direction of application. In some cases it may be desirable to specify a variation of IAM sensitivity induced by a thermal transient.

3.3.6 Warm-Up Time

The output of the angular sensor shall be within _____ output units (OU) of steady-state value in no more than _____ [s, min] after the initial application of power at _____ $\pm$ _____ $^{\circ}\text{C}$.

The orientation of the input axis with respect to the gravity vector or earth's rate, or both, should be specified in the test method. It may be desirable to further specify maximum output permitted during the warm-up period or the maximum time until the sensor's output is functional (activation time), or both. These requirements should also be specified as maximum output deviations from steady state as a function of time. The output of the device may be electronically constrained to near zero output at the start of the warm-up period and then released before the end of the period, at which time the output shall be within the specified requirement. If necessary, define any power interrupt or overrange reset characteristics.

3.3.7 Turn-On Hysteresis

The absolute value of the turn-on hysteresis shall be less than _____ IU.

Turn-on hysteresis associated with some types of sensors may be reduced or eliminated by means of an automatic bias nulling (washout) circuit.

3.3.8 Composite Error

_____ % one-half output span, maximum.

Specific terms comprising composite error may be specified in addition to, or instead of, composite error.

3.3.9 Rate-Squared Sensitivity

(Compare with 6.4.) An output due to an angular rate applied about any axis orthogonal to the input reference axis shall not exceed _____ $\text{OU}/(\text{rad/s})^2$.

This response may be either a direct current offset or the peak value of a transient depending on sensor design. Where the distinction is significant it should be specified, or it may be desirable to impose two limits, or both.

3.3.10 Linear-Acceleration Sensitivity

The output due to an applied linear acceleration shall not exceed _____ IU/g .

The output change may be either a direct-current offset or the peak value of a transient depending on sensor design. It may also be specified as a sinusoidal response to a sinusoidal input at a specified frequency or frequencies, but in this case allowance shall be made for actual angular motion produced by nominally rectilinear vibration exciters. In some devices the effect may be a proportional error in scale factor.

The linear acceleration sensitivities can also be a function of thermal gradients across the instrument, and the axis along which the acceleration is applied.

3.3.11 Vibration-Induced Errors

When the output is low-pass filtered at _____ Hz the rectification error due to an applied vibration input shall not exceed _____ $\text{OU}/(g \text{ rms})^2$ when the sensor is subjected to the vibration input of 3.4.2.2 along any combination of axes.

This response may be either a direct-current offset or the peak value of a transient depending on sensor design and test-vibration mode. The applied vibration may be either a specified random spectrum or a sine sweep at a specified amplitude and sweep rate. In the latter case, the transient criterion shall apply.

3.3.12 Other Motion-Induced Errors

The following examples of motion-induced errors may be significant in a particular application. Other responses, including responses to combined linear and angular motion, may be added as required.

3.3.12.1 Angular-Vibration Rectification

The rectification error due to an applied angular vibration input shall not exceed _____ $\text{OU}/(\text{rad/s}^2)^2$ when the sensor is subjected to the vibration input of 3.4.2.2 about the input-reference axis.

This motion error ordinarily will be significant in the event of resonances in the end use structure. Other axes may be defined if appropriate.

3.3.12.2 Angular Vibration Sensitivity

(Compare with 6.4.)

Angular vibration sensitivity refers to significant odd power terms in the response of an angular sensor to angular acceleration about the input reference axis.

3.3.13 Threshold

Less than IU.

3.3.14 Resolution

The smallest recoverable quantization of the sensor output shall be _____ IU.

3.3.15 Noise

3.3.15.1 Electrical

Output in the band-with _____ Hz to _____ Hz shall be less than _____ equivalent input units rms.

Noise may be specified in multiple band-widths and may also be specified by peak magnitude. For critical applications, power spectral density envelopes provide a more comprehensive specification. In some cases it may be necessary to specify noise both at null and with some steady-state input, for example, for sensors incorporating internal demodulation.

3.3.15.2 Mechanical

In some cases, mechanical noise output from the sensor (acoustical and angular or translational, or both) may be critical relative to an application and shall be specified.

3.3.16 Frequency Response

3.3.16.1 Amplitude

The sinusoidal amplitude response shall be bounded by the limits shown in Fig 3.

3.3.16.2 Phase

The sinusoidal phase response shall be bounded by the limits shown in Fig 3.

The figures shown are examples of typical sensor response. The precise form of the envelopes may vary somewhat depending on whether the specification is based solely on system requirements or written around the known characteristics of a particular sensor. The former approach is recommended when practical. In addition, some sensors may have overrange characteristics which may be a significant function of frequency. Temperature variations in frequency response may be shown by families of envelopes and by imposing limits which include the effects of temperature. In the event that compensation will be used, response may also be described by means of a Laplace transfer function, with limits specified on the significant terms; otherwise the envelope method is preferred, since sensors frequently cannot be described by a simple transfer function, for example, second order.

3.3.17 Self-Test Scale Factor

The self-test scale factor shall be $\pm$ _____OU per test-excitation unit.

A self test of an instrument can be done only if a method of artificially exciting the instrument to produce an output is available. The self-test function may be redefined to supply only a simulated sensor output to processing electronics. If the self test is other than direct current in, direct current out, input and output wave forms should be specified.

3.3.18 Cross Coupling

(Compare with 6.4.) The output due to input rates up to full scale on an orthogonal axis shall not exceed_____ % of full scale.

3.3.19 Cross-Axis Sensitivity (Dynamic)

The quadrature phase output shall be less than $\pm$ _____ % of full scale when the sensor is oscillated at plus and minus full scale at_____ Hz about an axis orthogonal to the true input axis.

3.4 Environmental Requirements

The environmental conditions listed in this subsection are those to which the sensor may be subjected during storage, transportation and handling or operation, or both. The equipment shall be designed to survive these environments and to successfully complete the environmental tests specified in Section 4

3.4.1 Nonoperating Environment

The following conditions, occurring separately or in combination, may be encountered during transportation and handling or storage, or both. The sensor shall conform to all the requirements of 3.3 after exposure to reasonable combinations of the specified service conditions.

Where appropriate, the environment specified shall be adjusted for the protection afforded by packaging.

3.4.1.1 Temperature and Thermal Radiation

Ambient temperature may vary from a minimum of _____ °C to a maximum of _____ °C under unsheltered ground conditions. Areas exposed to direct sunlight shall be considered as unsheltered conditions.

3.4.1.2 Thermal Shock

_____ °C to _____ °C. The heating and cooling rates of the ambient environment shall be _____ ± _____ °C/s.

For cyclic conditions, specify temperature limits for each level, dwell time, and sequence.

3.4.1.3 Vibration

Describe the vibration environment. For sinusoidal vibration, include the specific vibration amplitude versus frequency, duration, or sweep rate and axes of application. For random vibration, specify power spectral density (provide a figure if complex), tolerance, bandwidth, peak acceleration level, total rms acceleration, duration, and axes of application.

3.4.1.4 Mechanical Shock

Specify the shock wave shape or shock spectrum, tolerances, number of shocks, and axes of application.

3.4.1.5 Pressure

_____ [Pa, lbf/in²] to _____ [Pa, lbf/in²]. The rate of change of pressure shall be nominally _____ [Pa/s, (lbf/in²)/s].

If desired, pressure may be expressed in terms of altitude during transportation and rate of climb.