

IEEE Standard Specification Format Guide and Test Procedure for Linear Single-Axis, Nongyroscopic Accelerometers

Sponsor
**Gyro and Accelerometer Panel
of the
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Abstract: The specification and test requirements for a linear, single-axis, nongyroscopic accelerometer for use in internal navigation, guidance, and leveling systems are defined. A standard specification guide and a compilation of recommended test procedures for such accelerometers are provided. Informative annexes are given on the various types of such accelerometers (force or pendulous torque rebalance with analog or digital output, vibrating beam, and micromechanical) and error effects, on filtering, noise, and transient analysis techniques, and on calibration and modeling techniques (multipoint tumble analysis, vibration and shock test analyses, and geophysical effects in inertial instrument testing).

Keywords: accelerometer, inertial instrument, inertial sensor, pendulous accelerometer, vibrating beam accelerometer, micromechanical accelerometer, power spectral density, vibration and shock, geophysical effects, specification, testing.

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Introduction

(This introduction is not part of IEEE Std 1293-1998, IEEE Standard Specification Format Guide and Test Procedure for Linear, Single-Axis, Nongyroscopic Accelerometers.)

This standard is provided as a guide for the preparation of an accelerometer specification (Part I) and an accelerometer test procedure (Part II). The accelerometer considered in this standard utilizes a linear, single-axis, nongyroscopic acceleration sensor. The capture-loop, pickoff, oscillator, and readout electronics, when used, can be considered either as a part of the accelerometer or as separately provided by the user. The format was prepared by the Gyro and Accelerometer Panel of the Aerospace and Electronic Systems Society of the Institute of Electrical and Electronics Engineers (IEEE). It is intended to provide 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 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, sign, axes, etc. Boxed statements are included for information only and are not part of the specification format nor test procedure. The figures presented are to be used as a guide for the preparation of specific figures or drawings.

The annexes are informative and cover

- Typical block diagrams for accelerometer response
- The various types of accelerometers considered (including pendulous torque rebalance, vibrating beam, and micromechanical)
- Error effects
- Filtering, noise, and transient analysis techniques
- Calibration and modeling techniques (multipoint tumble analysis, vibration and shock test analyses, and geophysical effects in inertial instrument testing)

The terminology used conforms to IEEE Std 100-1996, The IEEE Standard Dictionary of Electrical and Electronics Terms, and the units used conform to IEEE/ASTM SI 10-1997, IEEE Standard for Use of the International System of Units (SI)—The Modern Metric System. 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.

The accelerometer is used to provide an analog, digital, or frequency output that is a measure of either acceleration or velocity increment, or both. An acceleration applied along the input axis of the acceleration sensor causes its proof mass to deflect. For open-loop accelerometers, the pickoff error signal caused by this motion is the measure of acceleration.

For force-rebalance accelerometers, the pickoff error signal is utilized in the electronics to produce a restoring force or torque. When static equilibrium is reached, the reaction force or torque of the proof mass to the average acceleration is balanced by the mean value of the restoring force or torque. The average rebalance current or pulse rate required to maintain this equilibrium condition is proportional to the average acceleration and provides the analog or digital output signal.

For vibrating beam accelerometers (VBAs) acceleration causes one resonator to increase in frequency (f_1) and the other resonator to decrease in frequency (f_2). The variation of the frequency of each resonator, therefore the difference ($f_1 - f_2$) is a measure of the applied acceleration.

This standard represents a large-scale group effort. A total of 111 individuals attended 50 bimonthly meetings of the Gyro and Accelerometer Panel during preparation of this standard. The following persons were on the Gyro and Accelerometer Panel:

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IEEE Standard Specification Format Guide and Test Procedure for Linear, Single-Axis, Nongyroscopic Accelerometers

Part I—Specification format

1. Overview

This specification defines the requirements for a linear, single-axis, nongyroscopic accelerometer. The accelerometer is used as a sensing element to provide an electrical signal proportional to acceleration or velocity change with a transfer function that is nominally low-pass (rather than bandpass). The output is [an analog voltage, an analog current, a binary pulse train, a ternary pulse train, pulse width modulated, a frequency output, ...] representing [acceleration, velocity change].

This specification defines not only the performance requirements of an inertial accelerometer as a unique device, but also its specific variational but repeatable and predictable performance parameters.

1.1 Scope

This specification defines requirements for [accelerometer type].

This specification format guide and test procedure standard applies to force-rebalance accelerometers (pendulous or translational proof mass), vibrating beam accelerometers (VBAs), and micromechanical accelerometers that range from lesser accuracy to high-accuracy devices (see 5.1).

All accelerometers have biases, scale factors, misalignments, nonlinearities, noise characteristics, and other parameters. Many of the specification requirements and verification test methods for these parameters; their stabilities; their temperature, magnetic, and other sensitivities; the accelerometer behavior through and across vibration, shock, and other environments; and the accelerometer lifetime and reliability are independent of the accelerometer type. Requirements and tests that are specific to a particular accelerometer type are described separately.

Only the clauses applicable to the given accelerometer type should be used.

This specification is not intended to define requirements for the pendulous integrating gyroscopic accelerometer (PIGA) or for the specific force integrating receiver (SFIR). These high-precision single degree-of-freedom (DOF) accelerometers use gyroscopic precessional torque to rebalance the specific force effect of nongravitational acceleration acting on a pendulous proof mass on the gyro float.

This specification also does not apply to devices (such as seismometers or open-loop piezoelectric accelerometers) that measure ac rather than low-pass and dc accelerations. Gravimeters having a limited dc measurement range around +1 g with input axis (IA) vertical are also not considered.

1.2 Purpose

This specification describes the design and performance requirements for _____ [model number, part number, change letter (if any), other identification], manufactured by _____ [name, address].

2. References

The following standards 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 terminology and requirements of this document and the listed documents, the terminology and requirements of this document shall govern. When the following standards are superseded by an approved revision, the revision shall apply.

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms.¹

IEEE Std 260.1-1993, American National Standard Letter Symbols for Units of Measurement (SI Units, Customary Inch-Pound Units, and Certain Other Units).

IEEE Std 315-1975, IEEE Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters).

IEEE Std 528-1994, IEEE Standard for Inertial Sensor Terminology.

IEEE Std 836-1991, IEEE Recommended Practice for Precision Centrifuge Testing of Linear Accelerometers.

IEEE/ASTM SI 10-1997, Standard for Use of the International System of Units (SI): The Modern Metric System.

Give the identification number, title, date of issue, and revision letter of each listed document. Other documents that may be important to a specification include the following:

ISO 5347, Methods for the calibration of vibration and shock pick-ups, Parts 1–21 and Part 23

MIL-STD-105, Sampling procedures and tables for inspection by attributes

MIL-STD-461, Requirements for the control of electromagnetic interference emissions and susceptibility

MIL-STD-785, Reliability program for systems and equipment development and production

MIL-E-5272, Environmental testing, aeronautical and associated equipment, general specifications for

MIL-P-116, Preservation, methods of

¹IEEE 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>).

3. Definitions

IEEE Std 100-1996², IEEE Std 528-1994, and the model equation of 8.3 define terminology used in this specification.

3.1 activity dip: For a vibrating beam accelerometer (VBA), the phenomenon where at certain frequencies the resonator vibration amplitude decreases due to parasitic resonances within itself or with the surrounding structure.

3.2 Allan variance: The average of the variance of adjacent pairs of elements in a contiguous time series of data versus the averaging time used to generate the elements [see I.8]. The term “Allan variance” is also used to refer to its square root versus averaging time, although “square root of Allan variance” would be more proper usage.

3.3 frequency lock: For a vibrating beam accelerometer (VBA), the phenomenon where, in a certain band of acceleration around the crossover point of the dual resonator frequencies, the resonator frequencies lock together and do not normally respond to changes in acceleration.

3.4 plumb bob gravity: At a site on the earth, the force per unit mass acting on a mass at rest relative to the earth, not including any reaction force from the suspension. The plumb bob gravity includes the gravitational attraction of the earth, the effect of the centripetal acceleration due to the earth rotation, and tidal effects.

The time average of the plumb-bob-gravity acceleration in the earth-fixed frame is the vector difference of the earth-Newtonian-gravitational acceleration and the earth-rotation-centripetal acceleration. The earth-Newtonian-gravitational-acceleration vector points generally toward the center of mass of the earth, as modified by the effects of gravity anomalies and the earth's flattening due to the earth rotation. The earth-rotation-centripetal-acceleration vector points toward and is perpendicular to the earth-rotation axis.

The magnitude and direction of the instantaneous plumb-bob-gravity acceleration vary about their averages by approximately $\pm 0.15 \mu g$ and $\pm 0.15 \mu rad$, respectively, with an approximate 12.4 h period due to the effect of lunar-solar earth and ocean tides. The tidal acceleration is due to the difference between the lunar and solar attractions at the site and at the center of the earth, the variation in earth attraction caused by the variation in the distance of the site from the center of the earth due to tidal deformation and ocean tide loading, and the gravitational attraction of the solid earth and ocean tide deformations [see Annex M].

The direction of the plumb-bob-gravity acceleration defines the local vertical down direction, and its magnitude defines the unit of acceleration g used in accelerometer scale factor calibration at a test site (with compensation for tidal effects if accuracy warrants).

3.5 power spectral density (PSD): The Fourier transform of the autocorrelation function of a time series of data. For a stationary ergodic time series, the PSD is equal to the expected value of the magnitude squared of the Fourier transform of the data (see Annex I). The PSD expresses the noise variance in an accelerometer's output as a function of positive and negative frequencies, usually in g^2/Hz , and is calculated as the ensemble or frequency average of the magnitude squared of the fast Fourier transform (FFT) of the data. The one-sided PSD plots twice the PSD value versus positive frequency f , since for a real time series the two-sided PSD values are equal for f and $-f$. The velocity random walk coefficient is calculated from the two-sided PSD acceleration white noise level (half the one-sided PSD level).

3.6 standard gravity: By international agreement, the standard value of gravity acceleration magnitude, or $g_0 = 9.80665 \text{ m/s}^2$, which corresponds closely to the plumb-bob-gravity-acceleration magnitude measured at 45° latitude and sea level. In the calibration of accelerometer scale factor, the local value g of plumb-bob-gravity-acceleration magnitude is used as a reference. If an absolute measurement of scale factor is required, a conversion to the standard gravity unit g_0 or to m/s^2 has to be made.

²Information on references can be found in Clause 2.

In this specification format guide and test procedure, requirements are stated in terms of g as the unit of acceleration because of the manner in which local gravity is used as a reference in accelerometer tests and because of human perception of acceleration. As far as requirements are concerned, g can be taken to be local gravity or standard gravity g_0 . However, when comparing test results from different sites or when using calibrated parameters in an inertial navigation or guidance mission, then local g units must be converted to g_0 or to m/s^2 .

Alternatively, all requirements and test results can be stated in terms of m/s^2 . As far as human perception of acceleration is concerned, note that for the galileo unit of acceleration (cm/s^2) used in gravimetry, a $mgal$ is approximately equal to a μg .

The most accurate absolute determination of the local value of gravity is obtained with the falling laser corner cube gravimeter, where interferometric laser observations of the fall in a vacuum of a corner reflector determines the acceleration due to gravity in terms of laser wavelength and atomic clock time measurements.

4. Applicable documents

4.1 Specifications

4.1.1 Government

4.1.2 Industry/technical

4.1.3 Company

4.2 Standards

4.2.1 Government

4.2.2 Industry/technical

- a) IEEE Std 100-1996
- b) IEEE Std 528-1994
- c) IEEE Std 260.1-1993
- d) IEEE/ASTM SI 10-1997
- e) IEEE Std 315-1975

4.2.3 Company

4.3 Drawings

4.3.1 Government

4.3.2 Industry/technical

4.3.3 Company

Figures 1, 3, and 4 are conceptual examples of the types of drawings that might be delivered with an accelerometer.

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 appropriate subclauses.

5. Requirements

5.1 Description

The accelerometer shall comprise a single-axis, nongyroscopic acceleration sensor [operating, to be operated] with [its own, user-supplied] electronics.

Figures 1a, 1b, and 1c apply to pendulous proof-mass accelerometers. The forcer in Figure 1a is called a torquer. The figures must be appropriately modified for a translational proof-mass accelerometer.

Torque-rebalance capture-loop electronics and/or pickoff electronics are shown in Figure 1a. VBA oscillator electronics are shown in Figures 1b and 1c. The accelerometer may employ a temperature sensor for thermal modeling, control, or monitoring.

The dashed lines in Figures 1a, 1b, and 1c enclose the sensor part of the accelerometer, which responds to the acceleration input. The term “seismic system” is sometimes used in place of the term “acceleration sensor.”

The electronics outside the dotted lines used to generate the accelerometer output and the temperature output, if needed, may be self-contained within or separate from the accelerometer package. The user-supplied electronics may include such items as power conditioner, capture electronics, output signal conditioner, temperature controller, reference clock, and test points.

The input reference axis (nominally along the sensor IA) is defined with respect to the accelerometer mounting surfaces. The sensor may employ stops to limit proof-mass displacement.

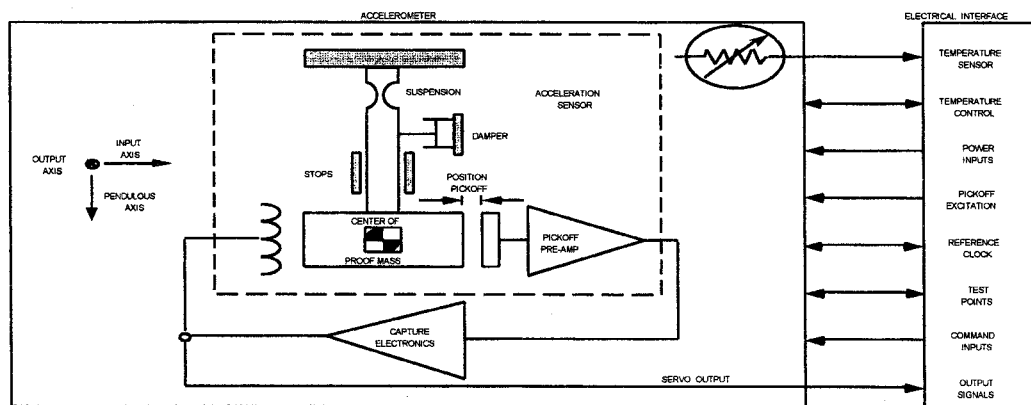


Figure 1a—Diagram of torque-rebalance accelerometer system

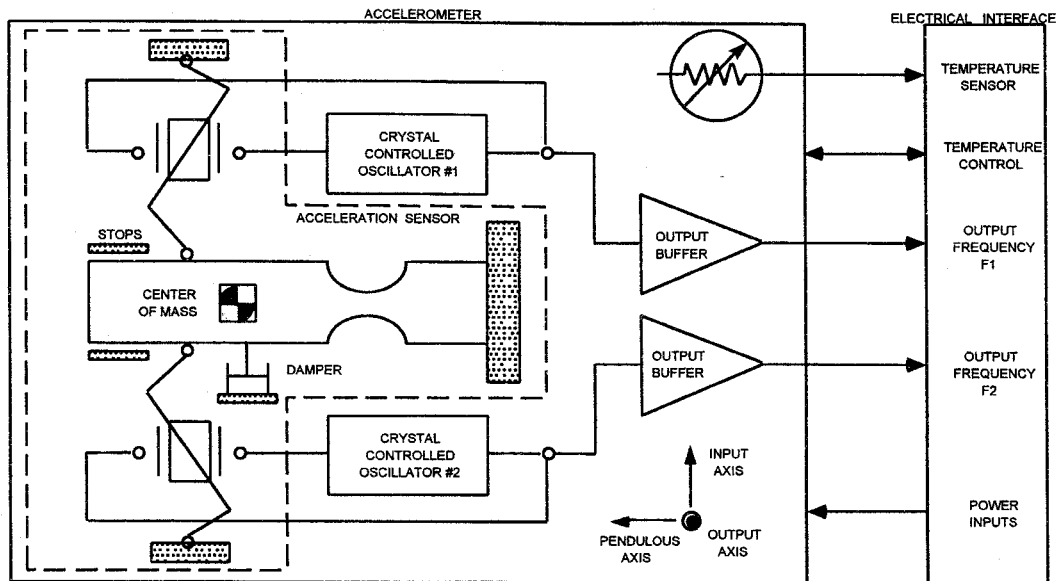


Figure 1b—Diagram of single proof-mass VBA system

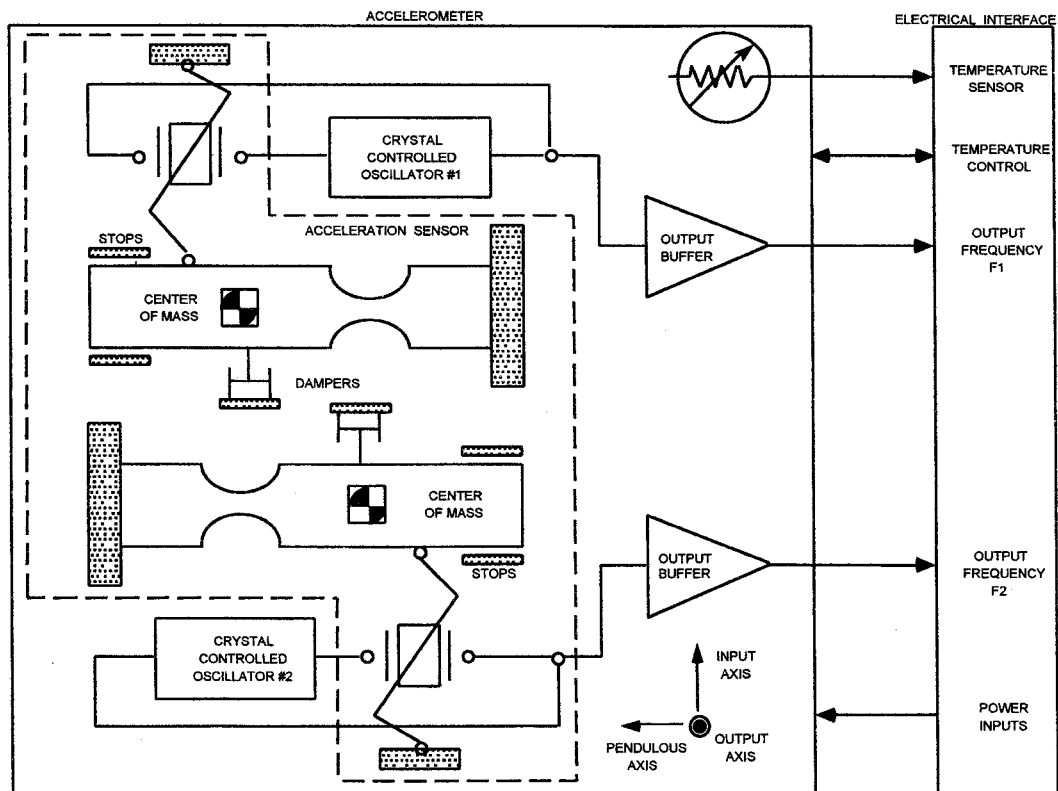


Figure 1c—Diagram of dual proof-mass VBA system

The torque-rebalance capture-loop electronics in Figure 1a may be analog-torque feedback or pulsed-torque feedback, providing as an output either an analog voltage signal proportional to acceleration or a pulse-train, each pulse representing an increment of velocity gained or lost. The method of pendulum torquing or proof-mass forcing may be specified (for example, binary pulse, ternary pulse, pulse-width modulation, analog, or analog converted into pulse-train output by use of a voltage- or current-to-frequency converter).

The pickoff could be electromagnetic, capacitive, optical, or piezoresistive.

Figure 1a applies to a closed-loop micromechanical accelerometer as well as to a macro-sized pendulous accelerometer, although electrostatic capacitive forcing might be used in the former rather than the electromagnetic torquing commonly used in the latter.

An open-loop micromechanical accelerometer dispenses with the servoed capture-loop electronics and measures acceleration by the movement of the proof mass as restrained by the suspension flexure(s). The position pickoff could be capacitive, or the movement of the proof mass could be measured piezoresistively from the strain in the flexure(s).

Open-loop piezoelectric accelerometers, which measure acceleration by the voltage generated by the strain in a piezoelectric proof-mass support, are not considered in this document because leakage of the piezoelectrically generated charge restricts these devices to measuring ac rather than dc accelerations.

VBAs are by their nature open-loop devices as far as proof-mass movement is concerned. That movement is mostly restrained by the stiffness of the crystal resonators (usually piezoelectric quartz or silicon). Usually two crystal resonators are kept vibrating at their resonant frequency by oscillator circuits with a piezoelectric drive for quartz and a capacitive drive for silicon.

The resonators are mounted in a push-pull mode with a single proof mass (Figure 1b) or separate proof masses (Figure 1c). Under acceleration, one resonator goes into tension and increases in frequency and the other goes into compression and decreases in frequency. The measure of acceleration is the difference frequency, in order to obtain improved linearity and lower sensitivities to clock errors, physical environment, and aging effects (see Annex D for more details). The oscillator electronics are usually self-contained within the accelerometer package.

The VBA acronym is commonly applied to all vibrating resonator accelerometers, even if the resonator has other-than-beam geometry (e.g., a double-ended tuning fork, see D.3).

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
- c) Other applicable documents

List other applicable documents in order of precedence; see Clause 2 and Clause 4.

5.2.2 Deliverables

The deliverable item includes the serialized inertial accelerometer plus any accompanying serialized numerical data representing the predictable parameters, such as bias, scale factor, scale factor nonlinearity, and misalignment as defined in this specification.

5.2.3 Other

The application of this accelerometer may require performance parameters defining bias, scale factor, scale factor nonlinearity, and input axis (IA) misalignment with a degree of accuracy not achievable without

analytical modeling based on a priori knowledge of repeatable variation of these parameters. Bias, scale factor, and IA misalignment may be modeled as polynomial functions of the internal temperature indication of the sensor, whereas scale factor nonlinearity may be modeled as a function of indicated acceleration independent of temperature.

List other applicable general requirements.

5.3 Performance

The following clauses are used to specify the performance of a complete accelerometer or an acceleration sensor only, with 5.3.24 through 5.3.29.2 being applicable to an acceleration sensor only.

Table 1 lists the test procedure clauses for verifying the 5.3 through 5.7 requirements clauses.

If modeling is necessary to meet performance requirements, then, during the acceptance testing of each accelerometer for this application, the bias, scale factor, two components of the IA misalignment, nonlinearities, and other parameters if necessary shall be determined over the operating temperature range. The output of the temperature sensor as well as the ambient temperature shall be determined at each temperature data point.

The form of the model and the number and precision of the coefficients shall be mutually agreed upon by the producer and the user. The minimum model requirements will be shown in 8.3.

Each serialized accelerometer shall be accompanied by serialized coefficients as defined in this specification. These serialized items shall be a matched set reflecting proven test data derived from acceptance testing and calibration of the matched set of coefficients.

In the performance paragraphs affected by the need for modeling, each paragraph shall include both the uncompensated error allowable and the magnitude of the allowable error after compensation.

5.3.1 General

When tested with its capture or other electronics, the acceleration sensor shall comply with the performance requirements of this specification before, during (if applicable), and after exposure to the defined combinations of environments specified in 5.6.

Turn-on transients may affect accelerometer performance, and this issue shall be addressed as required for the specific application. For these cases, power-on time and other test conditions prior to taking data should be specified.

Define critical combinations of environments in 5.6.

5.3.2 Input range

The minimum input range shall be $\pm$ _____ g.

The specified input range shall be large enough to include the maximum (peak) translational acceleration combined with the maximum response to vibration falling within the bandwidth of the sensor. The input range need not be symmetrical about the null.

5.3.3 Overload capacity

The accelerometer shall perform to all specification requirements after an acceleration of _____ g has been applied along the _____ [axis, axes] for _____ s a total of _____ times.

5.3.4 Accelerometer temperature

The accelerometer may be specified for thermally controlled applications at a specified temperature or for operation over a wide range of temperatures.

5.3.4.1 Operating temperature

The operating temperature shall be [____ ± ____ °C, from ____ °C minimum to ____ °C maximum] at point ____ in the accelerometer.

The point within the accelerometer at which the operating temperature range is specified could be at the mounting flange or at the location of the accelerometer's temperature sensor (if any).

For temperature-controlled operation, the mounting flange temperature and surrounding ambient temperature (unless the accelerometer were surrounded with insulation with the heat flow path out through the mounting flange) could be specified, with the interior control set point temperature also specified (particularly important for fluid-filled or floated accelerometers).

5.3.4.2 Temperature sensor

A temperature sensor shall be provided [on, within] the accelerometer to indicate the accelerometer temperature over the operating range. The temperature sensor output shall be definable by a model equation that permits recovery of accelerometer temperature to an accuracy of ± ____ °C. The form of the temperature model and the number and precision of the coefficients shall be mutually agreed to.

For thermally controlled applications, it may be appropriate to specify the absolute value and tolerance of the sensor output and its temperature coefficient at the nominal operating temperature.

For temperature-compensated applications, instead of converting the temperature sensor output in, e.g., volts to °C for compensating the accelerometer output as a function of °C, the calibration of the compensation model could be in terms of temperature sensor output directly (i.e., volts in this example). In this case, a precise calibration of the relationship between temperature sensor output and °C would be unnecessary.

5.3.5 Scale factor

5.3.5.1 Absolute value

The scale factor K_1 shall be ____ ± ____ [V, mA, p/s, Hz]/g, measured to an uncertainty of ____ [%, ppm], under the standard test conditions of 11.1.

For the usual ± range in a specification, it is unimportant whether g is the local acceleration due to gravity or the standard gravity acceleration g_0 (see 3.2.6). When verifying accelerometer scale factor via a tumble test and tracking its variation over time or over changes in temperature and other environments at one test site, it is natural to express the scale factor in terms of the local acceleration due to gravity.

When using the scale factor calibrated at a local test site in an application, or when comparing scale factors measured on the same accelerometer at different test sites, the units have to be changed to g_0 or m/s^2 . Alternatively, the scale factor could be expressed in terms of m/s^2 , with each test site having the responsibility of analyzing accelerometer tumble data in terms of this absolute unit instead of in terms of the local acceleration due to gravity, which is used as a reference in a tumble test (see Annex K).

The scale factor K_1 in (p/s)/g in a force- or torque-rebalance accelerometer may be utilized to obtain velocity quantization:

$$\text{velocity quantization in (m/s)/p} = \frac{\text{local value of gravity in (m/s}^2\text{)/g}}{K_1 \text{ in (p/s)/g}}$$

The VBA difference frequency scale factor in Hz/g is the sum of the individual resonator scale factors. Thus, using the difference frequency observable in a dual resonator VBA doubles the scale factor as well as common mode rejects many error effects.

5.3.5.2 Asymmetry

The difference between the scale factor measured with positive applied acceleration and with negative applied acceleration shall not exceed $\pm$ ____ [%, ppm] of the average scale factor for both positive and negative accelerations.

A separate scale factor may be supplied for positive and negative applied accelerations to better define scale factor asymmetry (see 8.3).

5.3.5.3 Short-term stability

The standard deviation of the scale factor from its mean value over a period of ____ [s, min, h, d] of continuous operation under constant conditions shall be less than ____ [%, ppm].

Alternative means of specifying stability may be utilized, such as curve fitting for trend determination, or frequency domain analysis.

5.3.5.4 Long-term stability

The least-squares straight line slope of the scale factor over a period of ____ [h, d, yr] of continuous operation measured under constant conditions shall be less than ____ [%, ppm]/[h, d, yr]. The standard deviation of the scale factor data points from the best fit line shall be less than ____ [%, ppm].

Other criteria for establishing stability may be utilized, such as the root mean square (rms) about the mean, or frequency domain analyses. Stability tests have constant conditions between calibrations, whereas repeatability tests have temperature cycles or other variations between calibrations.

5.3.5.5 Repeatability

The standard deviation of the scale factor from the mean of ____ measurements taken under constant conditions shall be less than ____ [%, ppm]. Between successive measurements, the accelerometer shall be [heated, 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 (e.g., vibration, shock, temperature, remount, power interrupt of specified duration) may be specified. Sufficient time should be allotted to attain thermal equilibrium before making a measurement. Other conditions for repeatability may be specified, such as power-off time with the accelerometer maintained at some fixed temperature.

Alternative means of specifying repeatability may be used, for example, rms deviation about the first day mean, or peak-to-peak deviation.

5.3.5.6 Sensitivity

The absolute value of the sensitivity coefficients of scale factor to variations from the standard test conditions of 11.1 shall not exceed the limits listed below:

- a) Input excitation voltage(s): ____ [%, ppm]/V
- b) Input excitation frequency(ies): ____ [%, ppm]/Hz
- c) Operating temperature: ____ [%, ppm]/°C
- d) Temperature gradient: ____ [%, ppm]/Δ°C
- e) Temperature rate of change: ____ [%, ppm]/(°C/min)
- f) External magnetic induction [ac, dc, or both]: ____ [%, ppm]/[mT, G] per axis
- g) Pressure: ____ [%, ppm]/Pa

One of several methods of curve fitting (such as least-squares straight line or polynomial fit) should be specified to determine the value of each sensitivity coefficient since the scale factor may not be a linear function of the input variable (see 12.3.11).

An accelerometer could have one or several input dc or ac voltage excitations, with or without internal regulation. The sensitivity of the accelerometer output to independent variations in each of these voltages and in the frequency of each ac input voltage (such as for a pickoff excitation) must meet these requirements.

Tesla ($\text{Wb/m}^2 = \text{V}\cdot\text{s/m}^2$ in SI units) and gauss (10^{-4} tesla in cgs electromagnetic units) are units of magnetic induction B . The relation between B in tesla and the magnetic field H in A/m in an isotropic homogeneous medium is $B = \mu H$, where μ is the permeability of the medium. The permeability of empty space is $\mu_0 = 4\pi \times 10^{-7}$ H/m in SI units. In the cgs electromagnetic system of units in which B is measured in gauss, the permeability of empty space is $\mu_0 = 1$, so that $B = H$, where H has units of oersteds. Hence, magnetic induction sensitivity per gauss has often been referred to as magnetic field sensitivity.

5.3.6 Nonlinearity

The absolute values of the second-order nonlinearity coefficient K_2 and the third-order nonlinearity coefficient K_3 shall be less than _____ [g/g^2 , $\mu g/g^2$] and _____ [g/g^3 , $\mu g/g^3$], respectively. The absolute value of the odd quadratic coefficient K_{oq} shall be less than _____ [g/g^2 , $\mu g/g^2$].

A simpler means of specifying nonlinearity for lesser accuracy accelerometers is to place limits on composite error as a function of input acceleration, i.e., what is commonly known as an envelope specification.

The simplest envelope is to specify that the maximum error over the operating range is a specified percent of the accelerometer full-span output, especially for lesser accuracy accelerometer applications where it is not intended to compensate for accelerometer nonlinearities that meet the specifications.

Acceleration nonlinearities typically arise from structural compliance. Changes in accelerometer temperature that occur under acceleration (such as due to varying current through an electromagnetic torquer) could manifest themselves as an apparent acceleration nonlinearity. The maximum such effect could be required to be less than the nonlinearity requirement, or the heating could be regarded as a separate temperature sensitivity problem with compensation using temperature sensor measurements if possible.

5.3.7 Bias

5.3.7.1 Absolute value

The absolute value of bias K_0 shall not exceed _____ g measured to an uncertainty of _____ μg under the standard test conditions of 11.1.

5.3.7.2 Asymmetry

The difference between the bias measured with positive applied acceleration and with negative applied acceleration shall not exceed _____ μg .

A separate bias may be supplied for positive and negative applied accelerations to better define bias asymmetry (see 8.3).

5.3.7.3 Short-term stability

The standard deviation of the bias from its mean value over a period of [s, min, h, d] of continuous operation shall be less than _____ [g , μg].

Alternative means of specifying stability may be utilized, such as curve fitting for trend determination, or frequency domain analysis.

5.3.7.4 Long-term stability

The least-squares straight line slope of the bias over a period of _____ [h, d, yr] of continuous operation measured under constant conditions, shall be less than _____ [g , μg]/[h, d, yr]. The standard deviation of the bias data points from the best fit line shall be less than _____ [g , μg].

Other criteria for establishing stability may be utilized, such as the rms about the mean, or frequency domain analyses. Stability tests have constant conditions between calibrations, whereas repeatability tests have temperature cycles or other variations between calibrations.

5.3.7.5 Repeatability

The standard deviation of the bias from the mean of _____ measurements taken under constant conditions shall be less than _____ [g, μ g]. Between successive measurements, the accelerometer shall be [heated, 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 (e.g., vibration, shock, temperature, remount, power interrupt of specified duration) may be specified. Sufficient time should be allotted to attain thermal equilibrium before making a measurement. Other conditions for repeatability may be specified, such as power-off time with the accelerometer maintained at some fixed temperature.

Alternative means of specifying repeatability may be used, for example, rms deviation about the first day mean, or peak-to-peak deviation.

5.3.7.6 Sensitivity

The absolute value of the sensitivity coefficients of the bias to variations from the standard test conditions of 11.1 shall not exceed the limits listed below:

- Input excitation voltage(s): _____ [g, μ g]/V
- Input excitation frequency(ies): _____ [g, μ g]/Hz
- Operating temperature: _____ [g, μ g]/°C
- Temperature gradient: _____ [g, μ g]/Δ°C
- Temperature rate of change: _____ [g, μ g]/(°C/min)
- External magnetic induction [ac, dc, or both]: _____ [g, μ g]/[mT, G] per axis
- Pressure: _____ [g, μ g]/Pa

One of several methods of curve fitting (such as least-squares straight line or polynomial fit) should be specified to determine the value of each sensitivity coefficient since the bias may not be a linear function of the input variable (see 12.3.11).

5.3.8 IA misalignment

Only IA misalignments about pendulous axis (PA) and output axis (OA) are considered because misalignments of the other axes about IA do not have a material effect on the performance of a single-axis accelerometer.

5.3.8.1 About pendulous axis (PA)

The absolute value of the IA misalignment about the PA δ_p shall be less than _____ [μ rad, mrad, °, °], measured to an uncertainty of _____ [μ rad, mrad, °, °] under the standard test conditions of 11.1.

5.3.8.2 About output axis (OA)

The absolute value of the IA misalignment about the OA δ_o shall be less than _____ [μ rad, mrad, °, °], measured to an uncertainty of _____ [μ rad, mrad, °, °] under the standard test conditions of 11.1.

An alternative method is to specify the total misalignment angle:

$$\delta_t = \sqrt{\delta_o^2 + \delta_p^2}$$

5.3.8.3 Short-term stability

The standard deviation of the two IA misalignment angles from their mean values over a period of ____ [s, min, h, d] of continuous operation and measured under constant conditions shall be less than ____ [μ rad, mrad, $^{\circ}$, $^{\circ}$].

Alternative means of specifying stability may be utilized, such as curve fitting for trend determination or frequency domain analysis.

5.3.8.4 Long-term stability

The least-squares best fit slope of the IA misalignment angle data points over a period of ____ [h, d, yr] shall be less than ____ [μ rad, mrad, $^{\circ}$]/[h, d, yr]. The standard deviation of the misalignment angle data points from the best fit line shall be less than ____ [μ rad, mrad, $^{\circ}$].

Other criteria for establishing stability may be utilized, such as the rms about the mean, or frequency domain analyses. Stability tests have constant conditions between calibrations, whereas repeatability tests have temperature cycles or other variations between calibrations.

5.3.8.5 Repeatability

The standard deviation of the IA misalignment angles from the mean of ____ measurements taken under constant conditions shall be less than ____ [μ rad, mrad, $^{\circ}$, $^{\circ}$]. Between successive measurements, the accelerometer shall be [heated, cooled] to ____ $^{\circ}$ 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 (e.g., vibration, shock, temperature, remount, power interrupt of specified duration) may be specified. Sufficient time should be allotted to attain thermal equilibrium before making a measurement. Other conditions for repeatability may be specified, such as power-off time with the accelerometer maintained at some fixed temperature.

Alternative means of specifying repeatability may be used, for example, rms deviation about the first day mean, or peak-to-peak deviation.

5.3.8.6 Sensitivity

The absolute value of the sensitivity coefficients of the IA misalignments to variations from the standard test conditions of 11.1 shall not exceed the limits listed below:

- a) Input excitation voltage(s): ____ [μ rad, $^{\circ}$]/V
- b) Input excitation frequency(ies): ____ [μ rad, $^{\circ}$]/Hz
- c) Operating temperature: ____ [μ rad, $^{\circ}$]/ $^{\circ}$ C
- d) Temperature gradient: ____ [μ rad, $^{\circ}$]/ Δ° C
- e) Temperature rate of change: ____ [μ rad, $^{\circ}$]/($^{\circ}$ C/min)
- f) External magnetic induction [ac, dc, or both]: ____ [μ rad, $^{\circ}$]/[mT, G] per axis
- g) Pressure: ____ [μ rad, $^{\circ}$]/Pa

One of several methods of curve fitting (such as least-squares straight line or polynomial fit) should be specified to determine the value of each sensitivity coefficient since the misalignment may not be a linear function of the input variable (see 12.3.11).

5.3.9 Temperature model and temperature hysteresis

5.3.9.1 Temperature-controlled operation

For temperature-controlled operation in the range $T \pm$ ____ $^{\circ}$ C, the temperature sensitivities of the scale factor, bias, and IA misalignments for variations about T° C, as determined by least-squares straight line fits to calibrated values at temperature set points in the operating temperature range $T \pm$ ____ $^{\circ}$ C, shall be less than the values specified in 5.3.5.6, 5.3.7.6, and 5.3.8.6. These sensitivities can be used for linear

temperature model compensation for temperature variations measured by the temperature sensor around the control set point $T^{\circ}\text{C}$.

The temperature hysteresis of the scale factor, bias, and misalignments over the operating temperature range shall be less than ____ [%, ppm], ____ [g, μg], and ____ [μrad , "], respectively.

The temperature hysteresis in a parameter is the width of the plot of the calibrated value of the parameter versus temperature sensor output for increasing and then decreasing values of temperature over the operating temperature range. A measure of the lumped bias and misalignment temperature hysteresis is provided by the width of the plot of the accelerometer output in the IA horizontal orientation versus temperature sensor output for increasing and then decreasing values of temperature. This same test in the IA vertical orientation gives the lumped scale factor and bias temperature hysteresis.

The temperature hysteresis value indicates how closely the output of the accelerometer at a temperature arrived at in the increasing temperature direction is equal to its output arrived at in the decreasing temperature direction. The error caused by hysteresis after appropriate modeling is half the hysteresis width.

5.3.9.2 Non-temperature-controlled operation

For non-temperature-controlled, temperature-compensated operation in the temperature range ____ $^{\circ}\text{C}$ to ____ $^{\circ}\text{C}$, the scale factor, bias, and IA misalignments shall be modeled as polynomials of order ____ in the temperature sensor output relative to the reference temperature ____ $^{\circ}\text{C}$.

The reference temperature is typically midway in the temperature range. The temperature model could be expanded to include the effects of temperature gradients and/or temperature rates of change.

For approximately ____ equally spaced temperature set points in an increasing and then decreasing temperature variation over the temperature range, the results of polynomial fits to the calibrated scale factor, bias, and IA misalignments from four-point or other tumble tests at each temperature set point shall satisfy the values in Table 1:

Table 1—Temperature model calibration requirements

Quantity	Scale factor [% , ppm]	Bias [g, μg]	Misalignments [μrad , "]
1st order coefficient	< ____ per $^{\circ}\text{C}$	< ____ per $^{\circ}\text{C}$	< ____ per $^{\circ}\text{C}$
2nd order coefficient	< ____ per $^{\circ}\text{C}^2$	< ____ per $^{\circ}\text{C}^2$	< ____ per $^{\circ}\text{C}^2$
etc.			
Rms residual	< ____	< ____	< ____
Hysteresis	< ____	< ____	< ____

5.3.10 Cross-axis nonlinearity

The absolute value of the cross-axis nonlinearity coefficients K_{00} , K_{pp} shall be less than ____ [$\text{g}/\text{g}_{\text{cross}}^2$, $\mu\text{g}/\text{g}_{\text{cross}}^2$].

A common cause of cross-axis nonlinearity is case compliance, which allows the true IA to move relative to the case reference axes. As such, cross-axis nonlinearity can be specified as a structural compliance in ____ $\mu\text{rad}/\text{g}_{\text{cross}}$.

5.3.11 Cross coupling

The absolute values of the cross-coupling coefficients K_{ip} , K_{io} , and K_{po} shall be less than ____ [$\text{g}/\text{g}_{\text{cross}}^2$, $\mu\text{g}/\text{g}_{\text{cross}}^2$].

5.3.12 Warm-up time

The output of the accelerometer shall be within ____ [g, μg] of its steady-state value in no more than ____ [s, min] after power application [from ____ $^{\circ}\text{C}$, over the temperature range ____ $^{\circ}\text{C}$ to ____ $^{\circ}\text{C}$].

To fully define the turn-on characteristics, a number of individual items could be specified, such as the peak deviation from the steady-state or final value of the output along with the time constant of the transient, beginning at a specific point in time after turn-on.

Alternatively, one could specify the maximum output drift rate averaged over a specified period of time, beginning at a specific point in time after power application, in output units per time increment. The allowable drift could also be specified in terms of the maximum integral of the deviation of the output from its steady-state or final value, in velocity units, beginning at a specific point in time after power application.

One could also define limits for the output transient and/or lost information resulting from a specified power interruption.

5.3.13 Acceleration threshold

The threshold shall be less than ____ [g, μ g].

5.3.14 Acceleration resolution

The resolution shall be less than ____ [g, μ g].

5.3.15 Acceleration dead band

5.3.15.1 Force-rebalance dead band

The dead band shall be less than ____ [g, μ g].

5.3.15.2 Vibrating beam accelerometer (VBA) frequency lock

The effect of VBA frequency lock shall be less than ____ [g, μ g] peak to peak.

5.3.15.3 VBA activity dips

No discernible (less than ____ μ g) activity dips in the ± 1 -g range shall exist. Activity dips in the remainder of the $\pm$ ____ -g range of operation shall be less than ____ [g, μ g] peak to peak.

5.3.16 Repeatability across shut-down or nonoperational environment

After the output has stabilized, the standard deviation of a series of ____ turn-on measurements shall be less than ____ [g, μ g] under the standard test conditions of 11.1.

Application of environments between measurements may be specified, such as vibration, shock, and temperature cycling, either singly or in combination. In addition, turn-on repeatability may be specified in various orientations with respect to the gravity vector. Alternative means of specifying turn-on repeatability may be utilized, such as peak-to-peak deviation from the mean of the ensemble of data.

5.3.17 Turn-on hysteresis

The absolute value of the turn-on hysteresis shall be less than ____ [g, μ g].

5.3.18 Inversion transient

The output of the accelerometer shall be within ____ [g, μ g] of its steady-state value in no more than ____ [s, min] after inversion. The magnitude of the inversion transient shall be less than ____ [g, μ g].

When an accelerometer is rotated from $+1$ g to -1 g, or vice versa, transient settling behavior may be significant in high-precision applications. The shift and/or transient across an inversion could vary at different temperature set points within the operating temperature range. To fully define the inversion transient characteristics, a number of individual items could be specified, such as the peak deviation from the steady-state or final value of the output along with the time constant of the transient beginning at a specific point in time after the inversion is completed. See Annex J.

5.3.19 Velocity storage

The time integral of acceleration (velocity) stored in an accelerometer as a result of its dynamics is a function of accelerometer design. It is sometimes verified by analysis rather than actual test.

The velocity storage of a fluid damped accelerometer is linearly proportional to the viscosity of the damping fluid, which can vary greatly with nontemperature-controlled operation.

5.3.19.1 Normal operation

The maximum velocity stored in the accelerometer during normal operation shall not exceed ____ [g·s, m/s].

For a force-rebalance accelerometer, the amount of velocity stored in normal operation is a function of the tightness of the torque loop. For a pulse-torqued accelerometer, it is a function of the pulse quantization as well as the dynamics of the torque loop (including moding effects).

5.3.19.2 Over-range operation

The minimum velocity storage for an over-range acceleration pulse shall exceed ____ [g·s, m/s].

The amount of velocity that can be stored in over-range operation or across a power interrupt before the pendulum hits the stops is larger with fluid damping than it is with gas damping.

5.3.19.3 Across power interrupt

The velocity storage for normal operation across a power interrupt up to ____ [μs, ms] in duration shall exceed ____ [g·s, m/s].

The velocity stored across a power interrupt or over-range input is recovered in the accelerometer output when, for instance, a torque-rebalance loop is reclosed, except for any error effects that have accumulated while the loop was open.

For a VBA, the resonator(s) keep vibrating because of their high quality factor Q when power is interrupted. Velocity storage in a VBA is accomplished by reconstructing the unobserved cycles that have occurred during the power interrupt using analytic algorithms in a microprocessor attached to the VBA.

5.3.20 Noise

The power spectral density (PSD) of the self-generated output noise when measured at [0 g, 1 g, ____ g] with the power supply noise less than ____ mV root mean square (rms) from ____ Hz to ____ Hz shall have an average not exceeding ____ g²/Hz from ____ Hz to ____ Hz and not exceeding ____ g²/Hz from ____ Hz to ____ Hz. The velocity random walk due to the white noise portion of the acceleration PSD shall be less than ____ (m/s)/√h.

Power spectral density (PSD) limits of the output noise are sometimes defined in graphical form and in the velocity domain rather than the acceleration domain. Allan variance can also be used to define noise requirements. See Annex I.

The rms of IA vertical drift data (filtered output interval ____ s) about the mean shall be less than ____ [g, μg] for ____ [h, d].

5.3.21 Frequency response

The frequency response of the accelerometer shall meet the requirements given in [Table, Equation, Figure] ____.

System frequency response for linear analog capture loops may be specified by defining the required amplitude and phase behavior versus frequency using equations or tables, which may include allowable limits. For nonlinear capture loops, such as the pulse-rebalance type, the describing function interpretation may be invoked, whereby the response is derived as the ratio of the output at the fundamental frequency to the input, neglecting the output harmonics generated by the nonlinear system. Caution must be exercised to assure that the describing function exists for a given system. Frequency response may be determined by either analysis or test, which should include the effects of temperature, pressure, etc. Note that generally the undamped natural frequency is

$$f_n = \sqrt{f_{45} f_{135}}$$

where

- f_n is natural frequency,
- f_{45} is frequency at which the phase shift is at 45°,
- f_{135} is frequency at which the phase shift is 135°.

5.3.22 Vibration-induced errors

The rectification error shall not exceed _____ g while the accelerometer is subjected to the vibration environment of Figure _____ along any combination of axes.

Vibropendulous and anisoelastic effects are two causes of rectification errors, as is asymmetry. Vibropendulous error shall be specified for vibration acceleration applied in a plane normal to the OA and at 45° to the input reference axis. Most vibration-induced errors are approximately proportional to the square of the vibration input, although scale factor asymmetry is an example of one that is not.

Rectification errors may be specified for specific environments that best represent the actual application environment, such as sine vibration with specific amplitude and frequency or random vibration with PSD as a function of frequency.

5.3.23 Self-test scale factor

The accelerometer self-test scale factor shall be _____ ± _____ g /mA.

In some cases, the self-test scale factor may be specified in units of (p/s)/V or as a response to a logic or fixed input.

The following clauses, 5.3.24 through 5.3.29.2, are necessary to specify the interface between the acceleration sensor and its analog or digital capture loop, required when *only* the *acceleration sensor* is being specified. (These clauses are *not* required when the *complete* accelerometer is being specified.)

5.3.24 Pickoff characteristics

5.3.24.1 Pickoff excitation

- a) Voltage: _____ ± _____ V [ac, dc]
- b) Frequency: _____ ± _____ Hz
- c) Nominal current: _____ A
- d) Harmonic content: _____ %, maximum

This specification may be necessary for both sensor only and complete accelerometer.

5.3.24.2 Scale factor

The pickoff scale factor shall be _____ ± _____ V[ac,dc]/[rad,cm] at nominal pickoff excitation.

In some cases it may be desirable to specify the pickoff linearity.

5.3.24.3 Phase/polarity

For a square wave excitation, it may be necessary to specify the duty cycle and logic state voltages in addition to the following characteristics.

- a) *Sensor with ac output.* When the displacement of the proof mass is positive, the output voltage measured from terminal ____ (high) to terminal ____ (low) shall [lead, lag] the pickoff excitation by ____ $\pm$ ____°.

For opposite displacement, the output voltage (high to low) shall [lead, lag] the pickoff excitation by ____ $\pm$ ____°. These requirements shall be met for all output voltages greater than ____ V rms.

- b) *Sensor with dc output.* For positive displacement of the proof mass, the pickoff output (high-to-low) shall be ____ [positive, negative], and for opposite displacement, ____ [negative, positive].

5.3.24.4 Electrical null

The minimum electrical output shall not exceed ____ V rms when normally loaded.

In ac output cases, it may be desirable to specify the fundamental, its harmonics, and quadrature components of the residual null. The rms output includes random noise.

5.3.24.5 Output limits

The magnitude of the output voltage for maximum proof-mass deflection in each direction shall be ____ $\pm$ ____ V [rms, dc].

The output limits need not be symmetrical about the null.

5.3.24.6 Output impedance

The pickoff output impedance at nominal excitation frequency shall be ____ $\pm$ ____ [+, -]
j ____ $\pm$ ____ Ω .

5.3.24.7 Frequency response

The transfer function of the pickoff shall meet the requirements given in [Table, Equation, Figure] ____.

5.3.25 Reference constants

Some users may request the manufacturer to supply nominal values of the following reference constants for use in users' servo analyses or evaluation of proposed acceleration sensors. Nominal values can be obtained from mathematical analysis or from physical measurements. Although analyses may be carried out without knowledge of these constants by use of data required in other portions of the document, they provide insight into the design of the sensor.

The VBA dual-resonator crossover frequency should be outside the ± 1 -g range, where the input is likely to dwell (see D.5.9). The resonator zero temperature coefficient (ZTC) temperatures should be matched as closely as possible to obtain the greatest common mode rejection of temperature effects (see D.5.2). Operation near the ZTC temperature yields the lowest noise performance.

Table 2—Reference constants for acceleration sensors

Reference constant	Nominal value
Pendulum parameters (rotational proof mass)	
Effective moment of inertia	_____ $\pm$ _____ g·cm ²
Pendulosity	_____ $\pm$ _____ g·cm
Damping coefficient	_____ $\pm$ _____ dyn·cm-s
Anisoinertia	_____ $\pm$ _____ cm
or Translational proof mass	_____ $\pm$ _____ g
Force-rebalance parameters	
Forcer or torquer scale factor	
Electromagnetic	_____ $\pm$ _____ [dyn, dyn·cm]/[mA, mA ²]
Electrostatic or capacitive	_____ $\pm$ _____ [dyn, dyn·cm]/[V, V ² , V ² -s]
Pickoff sensitivity	
Rotational proof mass	_____ $\pm$ _____ V/rad
Translational proof mass	_____ $\pm$ _____ V/cm
VBA resonator parameters	
Quality factor Q	> _____
Unstressed frequency	
Individual resonator	_____ $\pm$ _____ Hz
Dual resonator match	_____ $< f_1 - f_2 <$ _____ Hz
Zero temperature coefficient (ZTC) temperature	
Nominal	_____ $\pm$ _____ °C
Dual resonator match	_____ °C

5.3.26 Torquer polarity

With a positive voltage applied to terminal _____ (high) referenced to terminal _____ (low), the pickoff output voltage shall be [in phase, out of phase, positive, negative] with respect to [pickoff excitation voltage, ground reference].

5.3.27 Sensor transfer function

The open-loop transfer function of the acceleration sensor as measured from forcer current input to pickoff output shall fall within the limits given in [Table, Equation, Figure] _____ for magnitude and phase over the specified frequency range.

The open-loop transfer function of the acceleration sensor must be specified in absolute terms, defined and toleranced so that when it is combined with the transfer function of the associated capture-loop specified in 5.3.29.2, the required servo stability of the accelerometer is attained. The limits specified in 5.3.27 must be defined in cooperation with the acceleration sensor manufacturer.

5.3.28 Proof-mass elastic restraint

The elastic restraint K_r for a rotational proof-mass pendulum shall be $\text{___} \pm \text{___} \text{ g/rad}$ for displacements within the range of $0 \pm \text{___}$ radians. The elastic restraint K_r for a translational proof mass shall be $\text{___} \pm \text{___} \text{ g/cm}$.

Proof-mass elastic restraint includes all restraints such as flex lead spring restraint, pivot spring restraint, and pickoff reaction torque, but it does not include the principal restraint (rebalance torque provided by the capture loop). K_r is related to K_e of Annex A by the following relationship: $K_r = K_e / (980 \times \text{pendulosity})$, where 980 cm/s^2 is the approximate value of the local acceleration due to gravity.

5.3.29 [Analog, Pulse-rebalance] capture-loop electronics

The capture-loop electronics shall have the following characteristics in order to achieve the specified acceleration sensor performance.

The parameters defined below are for a capture loop that uses an input from a typical ac pickoff and must be modified for other pickoff types.

5.3.29.1 Capture-loop input characteristics

- a) Input impedance: $\text{___} \pm \text{___} [+, -] j \text{___} \pm \text{___} \Omega$
- b) Input voltage, maximum: $\text{___} \text{ V [ac, dc]}$
- c) Input voltage, quadrature: $\text{___} \text{ V [rms, peak to peak]}$
- d) Input voltage, harmonics: $\text{___} \text{ V [rms, peak to peak]}$
- e) Input phase angle (relative to reference voltage): $\text{___} \pm \text{___} ^\circ$
- f) Pickoff excitation frequency: $\text{___} \pm \text{___} \text{ Hz}$

5.3.29.2 Capture-loop frequency response

The transfer function of the [analog, digital] capture loop shall meet the requirements given in [Table, Equation, Figure] ___ .

The specification must define the transfer function of the capture loop required to produce the desired closed-loop response characteristics. See box note under 5.3.21.

The following clauses, 5.3.29.3 through 5.5.5, are general and are **required** regardless of whether the sensor only or the complete accelerometer is being specified.

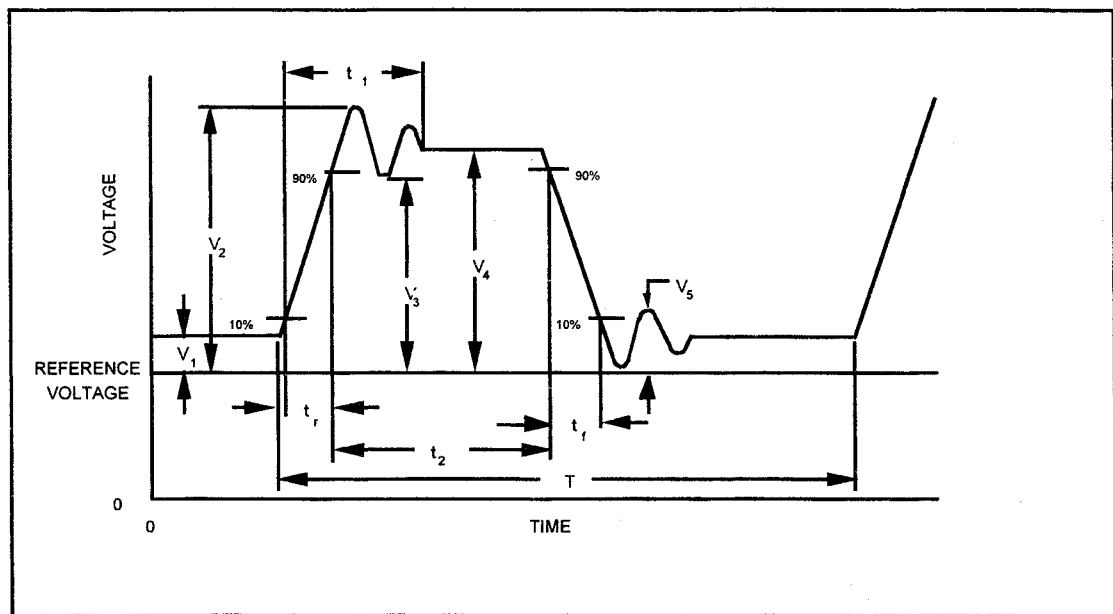
5.3.29.3 Capture-loop output characteristics

- a) Analog output characteristics
 - 1) Load impedance: $\text{___} \pm \text{___} [+, -] j \text{___} \pm \text{___} \Omega$
 - 2) Output impedance: $\text{___} \pm \text{___} [+, -] j \text{___} \pm \text{___} \Omega$
 - 3) Polarity positive with [in-phase, out-of-phase] input
 - 4) Voltage range: $+\text{___} \pm \text{___} \text{ V}$ to $-\text{___} \pm \text{___} \text{ V}$
 - 5) Current range: $+\text{___} \pm \text{___} \text{ mA}$ to $-\text{___} \pm \text{___} \text{ mA}$
 - 6) With grounded input, output: $< \text{___} \text{ Vdc}$
 - 7) Quadrature rejection: $> \text{___} \text{ dB}$ (applicable only to ac-pickoff servo)
 - 8) Noise: $< \text{___} \text{ mV rms}$, 0 to $\text{___} \text{ Hz}$ for all input conditions of 5.3.29.1
 - 9) Gain K_A : $\text{___} \pm \text{___} \text{ V dc/V [rms, dc]}$ with the above specified output load impedance

b) Digital output characteristics

Digital output pulses indicating positive velocity increments on one signal line and pulses indicating negative velocity increments on a second line are assumed. Other types of outputs are possible, depending on user's interface. See Annex B.

- 1) Source impedance: _____ $\pm$ _____ $[+, -] j$ _____ $\pm$ _____ Ω
- 2) Load impedance: _____ $\pm$ _____ $[+, -] j$ _____ $\pm$ _____ Ω
- 3) Phasing with respect to clock reference: $[+, -]$ _____ $\pm$ _____ s
- 4) Polarity of output signal with +1 g along the input reference axis
- 5) Wave shape: (see Figure 2)
- 6) Repetition rate: _____ pulses/s (p/s)



Units	Maximum	Minimum	Results
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	—	—	Duration of turn-on transient time
t_2 seconds	—	—	Duration of high voltage on time
t_1/t_2	—	N/A	Ratio of the turn-on transient time to required on time
T seconds	—	—	Waveform period
t_2/T	—	—	$(t_2/T)(100) = \% \text{ duty cycle}$

Figure 2 — Wave shape requirements for pulse-type signals

5.3.29.4 Command input(s)

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

- a) Type
 - 1) On/Off
 - 2) Self Test
- b) Characteristics:
 - 1) Source input impedance: $\text{_____} \pm \text{_____} [+,-] j \text{_____} \pm \text{_____} \Omega$
 - 2) Load impedance: $\text{_____} \pm \text{_____} [+,-] j \text{_____} \pm \text{_____} \Omega$
 - 3) Input voltage: $\text{_____} \pm \text{_____} [\text{V dc, V ac}]$

5.3.29.5 Clock reference

Specify the characteristics of the clock reference, necessary only for digital output sensors. For example,

- a) Source impedance: $\text{_____} \pm \text{_____} [+,-] j \text{_____} \pm \text{_____} \Omega$
- b) Load impedance: $\text{_____} \pm \text{_____} [+,-] j \text{_____} \pm \text{_____} \Omega$
- c) Repetition rate: $\text{_____} \pm \text{_____} \text{ p/s}$
- d) Wave shape: (see Figure 2)
- e) Stability: $\pm \text{_____} \text{ ppm per } \text{_____} [\text{h, d, yr}]$

5.4 Mechanical requirements

The following mechanical requirements apply to the external case to the extent specified.

5.4.1 Exterior surfaces

All exterior surfaces must withstand the environment specified herein and the handling expected in the normal course of operation, testing, transportation, and maintenance without deterioration that would cause nonconformance to this specification.

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

5.4.2 Dimensions

The outline, mounting dimensions, and center of gravity shall conform to Figure ____.

Figure 3 is a sample outline drawing. Controlled dimensions should be required only for critical parameters, as dictated by the application.

5.4.3 Identification of product

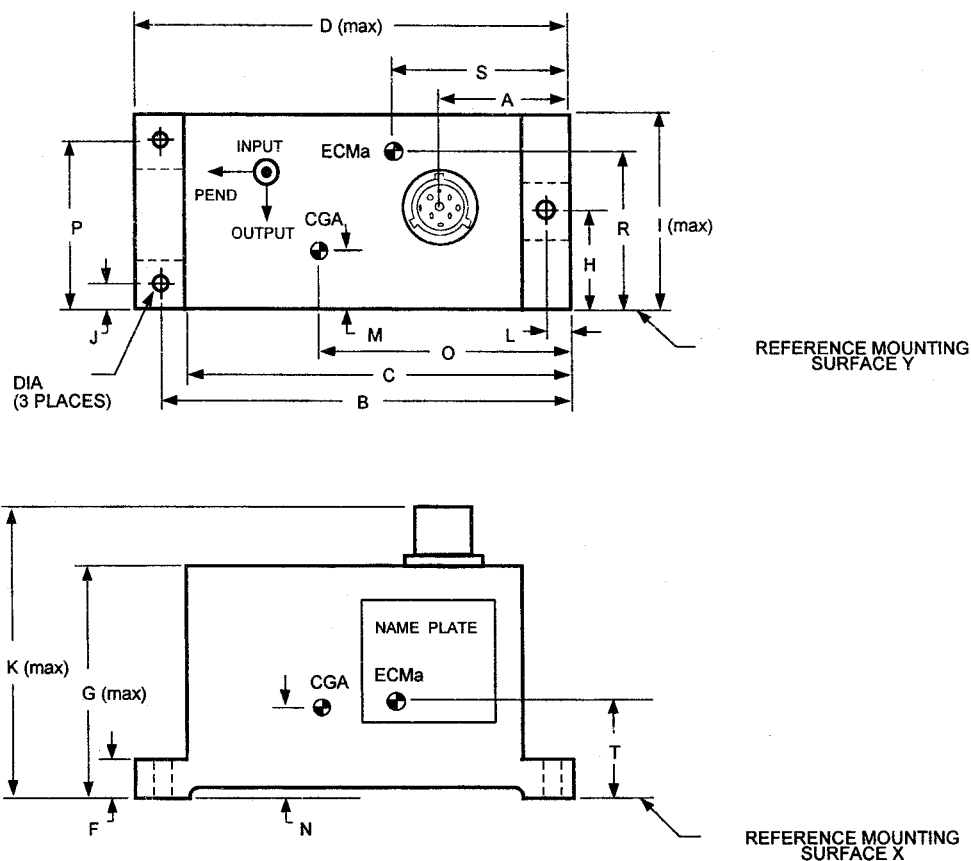
The accelerometer sensor case shall be marked _____.

The following information is typically required by the purchase agreement, although additional information may be specified:

- a) Name of component
- b) Model number
- c) Vendor code
- d) Part number
- e) Contract number
- f) Unit serial number
- g) Manufacturer's name or symbol

5.4.4 Sensor axes

The positive directions of the input, pendulous, and output reference axes (IA, PA, and OA) shall be identified by external markings and by reference mounting surface(s) on the case, or by other means to allow correct installation. The axes shall be designated so that the cross product of the IA and PA shall be along the OA (see Figure 3).



PIN	DESCRIPTION
A	
B	
C	
etc	

CGA = CENTER OF GRAVITY OF THE ACCELEROMETER

ECMa = EFFECTIVE CENTER OF MASS (PERCUSSION)

THE REFERENCE MOUNTING SURFACES X AND Y ARE USED FOR LOCATING THE INPUT REFERENCE AXIS

It is not intended that this sample drawing offer specific information, but is intended to be used as a guide. The accelerometer may be cylindrical, square, etc. Give nominal dimensions and tolerances.

Figure 3—Outline drawing

A micromechanical accelerometer for which IA misalignment and cross-axis error compensation is not employed may have only the IA direction marked on the external package.

For a pendulous accelerometer, the PA points towards the pendulosity from the center of rotation of the pendulum, when the pendulum is at the neutral position. Nongravitational acceleration along the IA causes the pendulum to rotate relative to the accelerometer case about the OA. The amount of this sensed rotation against elastic restraint is the measure of acceleration for an open-loop accelerometer or is used to determine the commanded torque to return the pendulum to the neutral position for a closed-loop accelerometer. The amount of commanded torque is then the measure of acceleration.

Hence the designations IA, PA, and OA are natural terminologies for open-loop or torque-rebalance pendulous accelerometers. One example of a pendulous accelerometer has a cylinder with a pendulosity along a radial axis that is neutrally buoyant in a fluid with any off-buoyancy compensated by magnetic suspensions. The OA is along the cylindrical axis. There is essentially no physical contact between the pendulous cylinder and the accelerometer case. The more common pendulous accelerometer design has the pendulum constrained to rotate about the OA by a hinge or flexure (see Annex C). The OA is then sometimes called the hinge axis (HA) or the flexure axis (FA), with various conventions for the axis orientation (see F.2.4).

A VBA commonly has its resonators attached to pendulous proof mass(es) with nongravitational acceleration along the IA putting one resonator in tension and the other in compression. The measure of acceleration is the difference frequency of the two resonators. The PA is naturally chosen to be the PA of one of the pendulums. The cross product of the IA and PA is still designated the OA, even though sensed rotation about the OA is not the measure of acceleration nor is it used in a torque-rebalance loop.

For a translational proof-mass accelerometer, the motion in response to nongravitational acceleration along the IA is also along the IA. The natural designation of the axes other than the IA would depend on the particular design.

In the design in which the translational motion is restrained and guided by flexures [e.g., see F.2.2 c)], there might be a natural designation for a FA. The third axis as the cross product of the first two would then have no relationship to the terminology "OA."

A translational proof-mass design used to measure low-level nongravitational accelerations in space has capacitive sensing of the position of a proof mass in a cavity with the electrostatic force required to keep the proof mass centered being the measure of acceleration. One device can potentially measure all three acceleration DOFs; therefore, the natural designation of the accelerometer axes is IA_1 , IA_2 , and IA_3 .

5.4.5 Weight or mass

The mass of the [acceleration sensor, accelerometer] shall be _____ $\pm$ _____ [g, kg, _____].

If appropriate, only the maximum mass need be specified. When accessories such as cable and connector are to be included in the mass requirement, the specification shall so state.

5.4.6 Seal

The following requirements shall be met:

Specify either a) or b) below, as appropriate.

- a) *Fluid filled.* No fluid leakage shall be 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 _____ [s, min].
- b) *Gas-filled or evacuated.* Maximum gas leakage rate shall not exceed _____ cm³/s of _____ gas measured at standard conditions for a minimum period of _____ [s, 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 to facilitate leak detection.

5.5 Electrical and magnetic requirements

The accelerometer's electrical and magnetic design requirements shall be as specified below, and shall meet the performance criteria of 5.3 during all reasonable variations of the inputs of 5.5.1.

5.5.1 Electrical interface

The electrical interface may consist of the connections illustrated in Figures 4a and 4b, as modified for the particular accelerometer under test.

Other connections may also be included for which electrical characteristics must be specified.

The following characteristics are measured in nonoperating tests, whereas the electrical characteristics in 5.3.24 and 5.3.29, for example, are measured in operating tests.

5.5.1.1 Torquer or forcer characteristics

- a) Resistance: _____ $\pm$ _____ Ω
- b) Inductance: _____ $\pm$ _____ H
- c) Capacitance: _____ $\pm$ _____ F

These data are needed for acceleration sensor-only specification.

5.5.1.2 Pickoff characteristics

- a) Resistance: _____ $\pm$ _____ Ω
- b) Inductance: _____ $\pm$ _____ H
- c) Capacitance: _____ $\pm$ _____ F

5.5.1.3 Heater characteristics

- a) Resistance: _____ $\pm$ _____ Ω
- b) Inductance: _____ $\pm$ _____ H

The nonoperating measurement of the heater characteristics is done with a small current level at room temperature unless otherwise specified. The resistance will change at operating current levels and temperature.

5.5.1.4 Temperature sensor characteristics

- a) Resistance: _____ $\pm$ _____ Ω
- b) Inductance: _____ $\pm$ _____ H

The nonoperating measurement of the temperature sensor characteristics is done at room temperature. The resistance will vary as the temperature varies during operation. Other types of temperature sensors may have different characteristics and outputs (e.g., frequency, current).

5.5.1.5 Self-test torquer or forcer characteristics

- a) Resistance: _____ $\pm$ _____ Ω
- b) Inductance: _____ $\pm$ _____ H
- c) Capacitance: _____ $\pm$ _____ F

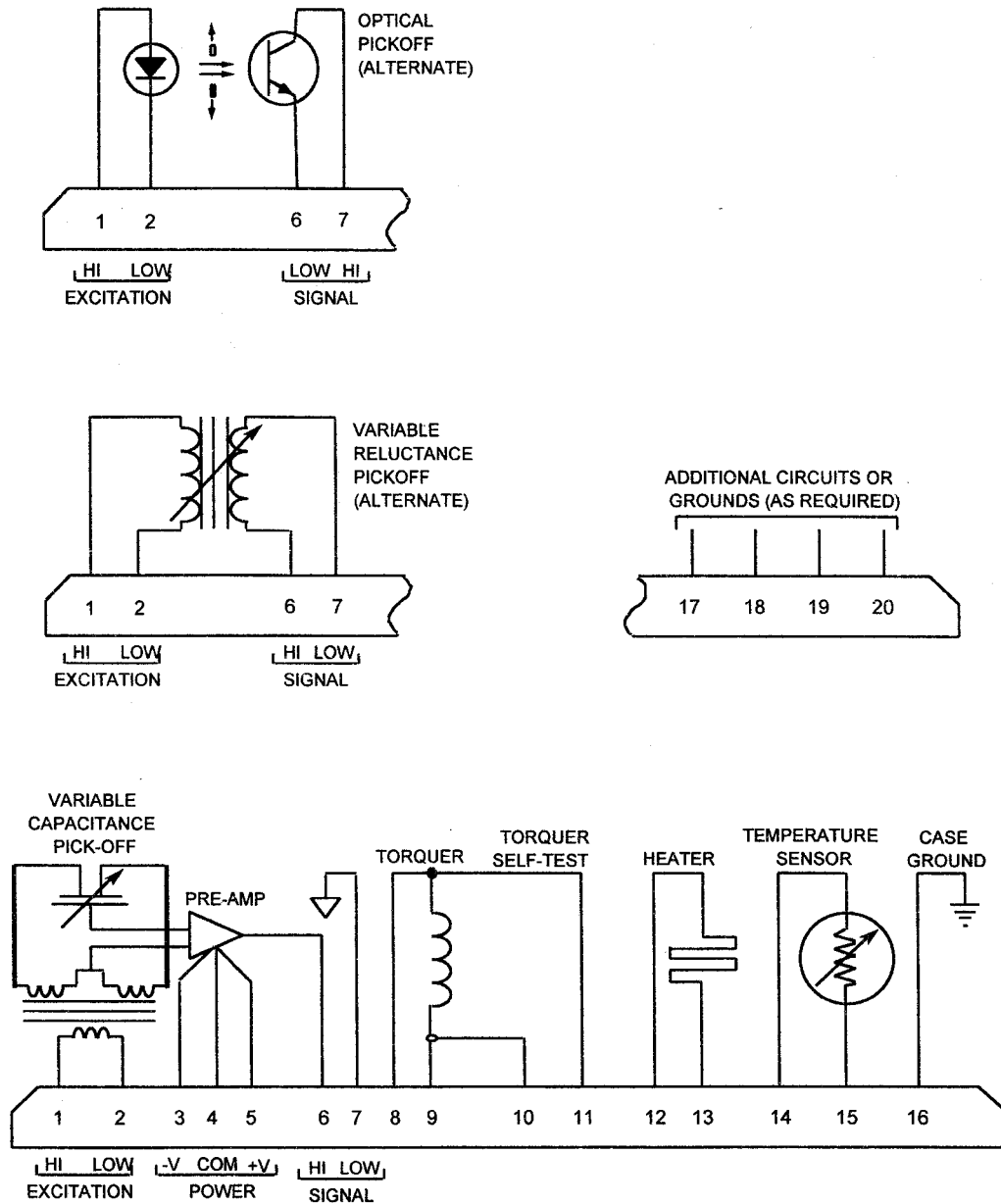


Figure 4a—Example of torque-rebalance electrical interface

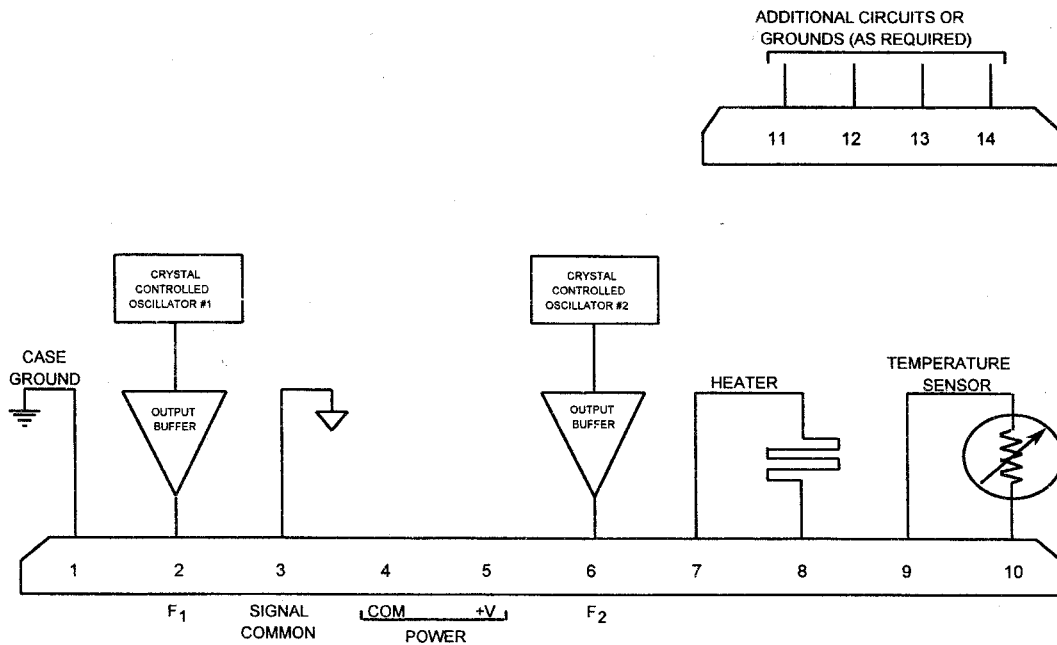


Figure 4b—Example of VBA electrical interface

5.5.2 Electromagnetic interference/compatibility

Describe the requirements for electromagnetic radiated and conducted emissions and susceptibility. In the United States, the requirements and test methods may be selected from MIL-STD-461 and MIL-STD-462.

5.5.3 Insulation resistance

The insulation resistance between the isolated interface circuits and the case shall not be less than _____ Mohm measured at _____ $\pm$ _____ V dc applied for _____ $\pm$ _____ s.

Different voltages may be specified for different circuits. A time duration is specified for the measurement to detect any breakdown phenomenon in the resistance between the isolated circuits at the applied voltage.

5.5.4 Dielectric strength

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

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

5.5.5 Magnetic leakage

The magnetic leakage shall not exceed _____ [mT, G] at a distance of _____ m from the accelerometer sensor in any direction.

5.6 Environmental requirements

The accelerometer may be subjected to the environmental conditions in this clause during storage, transportation, handling, or operation. The accelerometer shall be designed to satisfy the performance requirements in 5.3 during (if appropriate) and after exposure to these environments.

5.6.1 Nonoperating environment

The following conditions, occurring separately or in combination, may be encountered during transportation, handling, or storage. The accelerometer shall conform to all the performance requirements of 5.3 after exposure to any reasonable combination of the specified conditions.

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

5.6.1.1 Temperature

Ambient temperature may vary from a minimum of _____ °C to a maximum of _____ °C.

5.6.1.2 Thermal shock

From _____ °C to _____ °C, the heating and cooling rates of the ambient environment shall not exceed _____ °C/s.

For cyclic conditions, temperature limits must be specified for each level, with dwell times and sequence.

5.6.1.3 Vibration

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

5.6.1.4 Mechanical shock

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

5.6.1.5 Pressure

The ambient pressure shall be in the range _____ [Pa, psia] to _____ [Pa, psia]. The rate of change of pressure shall be nominally _____ [Pa/s, psia/s].

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

5.6.1.6 Humidity

The relative humidity shall not exceed _____ % RH.

5.6.1.7 Magnetic induction

Define magnitude, direction with respect to each axis, and duration. If there is exposure to magnetic induction resulting from ac, specify the intensity versus frequency.

5.6.1.8 Nuclear radiation

Describe the nuclear environment(s). For each environment include the type of radiation (e.g., X-ray, gamma, neutron), intensity, spectrum, exposure duration, and axes of application.

5.6.1.9 Other nonoperating environments

Include any other appropriate nonoperating environmental conditions, such as acceleration, acoustic noise, rain, fungus, salt spray, sand, and dust.

5.6.1.10 Storage life

Under the storage conditions of 5.6.1, the accelerometer shall meet the requirements of this specification

after a storage interval of ____ yr. The maximum allowed parameter changes across the storage environment are

- a) Bias: ____ μg
- b) Scale factor: ____ ppm
- c) IA misalignment: ____ [μrad , "]

Maximum allowed changes in nonlinearity and other parameters may also be specified. Any allowed repairs during the storage life may also be specified.

5.6.2 Operating environment

The following conditions, occurring separately or in combination, may be encountered during operation. The accelerometer shall conform to all the performance requirements of 5.3 during, unless otherwise specified, and after exposure to any reasonable combination of the specified service conditions.

5.6.2.1 Temperature (high and low)

Ambient air temperature may vary from ____ $^{\circ}\text{C}$ to ____ $^{\circ}\text{C}$.

5.6.2.2 Thermal shock

From ____ $^{\circ}\text{C}$ to ____ $^{\circ}\text{C}$, the heating and cooling rates of the ambient environment shall not exceed ____ $^{\circ}\text{C/s}$.

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

5.6.2.3 Other thermal conditions

Other thermal conditions that may affect performance shall be specified, for example, equivalent heat sink, radiant energy from surrounding surfaces, and power dissipation. Restrictions on allowable heat transfer may also be specified as, for example, conduction only, radiation only, or convection only. If cooling air is available, its characteristics must be specified, providing volume, rate, and air temperature.

5.6.2.4 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 figure if applicable), tolerance, bandwidth, peak acceleration level, total rms acceleration, duration, and axes of application.

5.6.2.5 Mechanical shock

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

5.6.2.6 Acceleration

Specify the maximum acceleration along each of the three axes and the duration.

5.6.2.7 Pressure

The ambient pressure shall be in the range ____ [Pa, psia] to ____ [Pa, psia]. The rate of change of pressure shall be nominally ____ [Pa/s, psia/s].

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

5.6.2.8 Humidity

The operating relative humidity shall not exceed _____ % RH.

5.6.2.9 Acoustic noise

Describe the acoustic noise environment. Supply the specific noise spectrum in decibels versus frequency, tolerance, bandwidth, peak level, and duration. Use a 0 dB reference of 20 μ Pa.

5.6.2.10 Magnetic induction

Define magnitude, direction with respect to each axis, and duration. If there is exposure to magnetic induction resulting from ac, specify the intensity versus frequency.

5.6.2.11 Nuclear radiation

Describe the nuclear environments(s). For each environment include the type of radiation (e.g., X-ray, gamma, neutron), intensity, spectrum, exposure duration, and axes of application.

5.6.2.12 Other operating environments

Include any other appropriate operating environmental conditions, such as rain, fungus, salt spray, sand, and dust.

5.6.2.13 Operating life

Under the specified operating conditions of 5.6.2, the accelerometer shall be capable of operating and performing within the requirements of this specification for a minimum accumulated operating period of _____ [h, d, yr] for a minimum of _____ and a maximum of _____ on-off cycles. The maximum allowed lifetime parameter changes are

- a) Bias: _____ μ g
- b) Scale factor: _____ ppm
- c) IA misalignment: _____ [μ rad, "]

Maximum allowed changes in nonlinearity and other parameters may also be specified. Any allowed repairs during the operating life may also be specified.

5.6.3 Dormancy environment

The following conditions, occurring separately, in combination, or in a defined sequence, may be expected during dormant storage.

The temperature, pressure, vibration, shock, radiation, and other environments shall be specified.

The accelerometer shall perform to the requirements of 5.3 after _____ [d, yr] of dormancy. The maximum allowed parameter changes across dormancy are

- a) Bias: _____ μ g
- b) Scale factor: _____ ppm
- c) IA misalignment: _____ [μ rad, "]

Periodic monitoring may be a condition of dormancy. The parameters to be monitored and the period of monitoring shall be specified. Maximum allowed changes in nonlinearity and other parameters may also be specified.

5.7 Reliability

5.7.1 Reliability program

The reliability program shall be in accordance with _____.

In the United States, a commonly used standard is MIL-STD-785.

5.7.2 Mean time between failure (MTBF)

The MTBF shall be a minimum of _____ h with a lower confidence limit of _____ %.

6. Quality assurance

All tests required by this specification shall be conducted in accordance with detailed test procedures prepared by the contractor and approved by the buyer.

6.1 Classification of tests

The inspection and testing of the accelerometer shall be classified as follows:

- a) *Acceptance tests.* Acceptance tests are those performed on accelerometers submitted for acceptance under contract.
- b) *Qualification tests.* Qualification tests are those performed on samples submitted for qualification as a satisfactory product.
- c) *Reliability tests.* Reliability tests are those performed to demonstrate the level of reliability and to assure the ability to maintain, with a certain confidence level, the required reliability.
- d) *Analysis.* A process used in lieu of or in addition to testing to verify compliance with specifications. The technique typically includes interpretation or interpolation/extrapolation of analytical or empirical data under defined conditions or reasoning to show theoretical compliance with stated requirements.

Acceptance test environments are those expected to be encountered in the application for which the accelerometer is intended. Qualification test environments are usually more severe than those used in acceptance testing, since the purpose of qualification testing is to demonstrate design margin. Accelerometers that have undergone qualification testing are usually not considered mission-worthy. Accelerated reliability and life testing may involve more severe than operational environments.

The cross reference Table 3 provides a summary of the verification methods and test procedures typically used to satisfy the requirements. The table should serve as a guideline. For each requirement, a verification method (acceptance test, qualification test, reliability test, or analysis) is agreed upon by the manufacturer and the procuring organization. Requirements can also be verified by similarity of a given accelerometer with previously tested accelerometers, or by demonstration based on data from subcomponent tests or tests of technologically related accelerometers. Requirements can be added to or deleted from this list.

Table 1—Test requirement matrix

Requirement		Verification method				Test procedure(s)
		Acceptance test	Qualification test	Reliability test	Analysis	
5.3	Performance					
5.3.2	Input range					12.3.14
5.3.3	Overload capacity					12.3.14
5.3.4	Accelerometer temperature					12.2.7
5.3.5	Scale factor					12.3.4, .5, .8 to .12, .18
5.3.6	Nonlinearity					12.3.5, .15, .17
5.3.7	Bias					12.3.4, .5, .8 to .12, .18
5.3.8	IA misalignment					12.3.4, .5, .8 to .12
5.3.9	Temperature model & temp. hysteresis					12.3.12
5.3.10	Cross-axis nonlinearity					12.3.5, .15, .17
5.3.11	Cross coupling					12.3.5, .15, .17
5.3.12	Warm-up time					12.3.7
5.3.13	Acceleration threshold					12.3.6
5.3.14	Acceleration resolution					12.3.6
5.3.15	Acceleration dead band					
5.3.15.1	Force-rebalance dead band					12.3.6
5.3.15.2	VBA frequency lock					12.5.1
5.3.15.3	VBA activity dips					12.5.2
5.3.16	Repeatability across shut-down, nonoperational environment					12.3.10
5.3.17	Turn-on hysteresis					12.4.5
5.3.18	Inversion transient					12.3.3
5.3.19	Velocity storage					
5.3.19.1	Normal operation					12.3.20, 12.4.8
5.3.19.2	Over-range operation					12.3.20, 12.4.7
5.3.19.3	Across power interrupt					12.3.13
5.3.20	Noise					12.3.2
5.3.21	Frequency response					12.3.16
5.3.22	Vibration-induced errors					12.3.20
5.3.23	Self-test scale factor					12.4.6
5.3.24	Pickoff characteristics					12.4.1
5.3.25	Reference constants					12.3.21, 12.4.4, .6.2
5.3.26	Torquer polarity					12.4.2
5.3.27	Sensor transfer function					12.4.3
5.3.28	Proof-mass elastic restraint					12.4.4, 12.6.2, .6
5.3.29	[Analog, Pulse-rebalance] capture-loop electronics					12.2.3, 12.3.1, .16
5.4	Mechanical requirements					
5.4.1	Exterior surfaces					12.2.1
5.4.2	Dimensions					12.2.1
5.4.3	Identification of product					12.2.1

Table 1—Test requirement matrix (Continued)

Requirement	Verification method				Test procedure(s)
	Acceptance test	Qualification test	Reliability test	Analysis	
5.4.4 Sensor axes					12.2.1
5.4.5 Weight or mass					12.2.2
5.4.6 Seal					12.2.6
5.5 Electrical and magnetic requirements					
5.5.1 Electrical interface					12.1.2.1, 12.2.3
5.5.2 Electromagnetic interference/compatibility					NA
5.5.3 Insulation resistance					12.2.5
5.5.4 Dielectric strength					12.2.4
5.5.5 Magnetic leakage					12.3.22
5.6 Environmental requirements					
5.6.1 Nonoperating environment					12.7.1, 12.9
5.6.2 Operating environment					12.7.2, 12.9
5.6.3 Dormancy environment					12.7.1, 12.9
5.7 Reliability					
5.7.1 Reliability program					NA
5.7.2 Mean time between failure (MTBF)					12.8

6.2 Acceptance tests

Acceptance tests shall consist of individual and/or sample tests.

6.2.1 Individual tests

Each accelerometer shall be subjected to the following tests described under 6.6.

The list of individual tests should be specified by the procuring organization based on the requirements. The number or type of individual tests specified is at the discretion of the procuring organization. Tests frequently specified as individual tests are listed below.

- Examination of product: 6.6.2.1
- Seal: 6.6.2.6
- Impedance: 6.6.2.3
- Dielectric strength: 6.6.2.4
- Insulation resistance: 6.6.2.5
- Pickoff characteristics: 6.6.4.1
- Torquer and self-test torquer polarity: 6.6.4.2
- Frequency response: 6.6.3.16
- Velocity storage across power interrupt: 6.6.3.13
- Scale factor and bias: 6.6.3.4.1
- IA misalignment: 6.6.3.4.2
- Turn-on hysteresis: 6.6.4.5
- Repeatability: 6.6.3.10
- Short-term stability: 6.6.3.8
- Centrifuge input range: 6.6.3.14

Other individual tests are not generally specified but may be included, and some listed above may be deleted, depending on the requirements of the specific application.

6.2.2 Sampling plan and tests

6.2.2.1 Sampling plan

Accelerometers selected per [describe sampling method] shall be subjected to the tests specified in 6.2.2.2.

This paragraph is intended to designate a sampling plan whereby samples are periodically selected for more complete tests, if required. Sampling plans are at the discretion of the procuring organization based upon usage, size of contract, individual requirements, etc.

In the United States, selection according to MIL-STD-105 is common.

6.2.2.2 Sampling tests

Accelerometers selected in accordance with 6.2.2.1 shall be subjected to the following tests described under 6.6:

The procuring organization should specify the tests that shall be performed on accelerometers selected in accordance with the sampling plan, 6.2.2.1. Tests frequently specified for sample tests are listed below. Sampling plan units may be used for delivery unless the procuring organization specifies life tests or other destructive tests under the sampling plan.

- Individual tests: 6.2.1
- Weight or mass: 6.6.2.2
- Warm-up time: 6.6.3.7
- Static multipoint: 6.6.3.5
- Precision centrifuge: 6.6.3.15
- Threshold, resolution, and dead band: 6.6.3.6
- Magnetic leakage: 6.6.3.22
- Temperature (high, low): 6.6.9.5

6.2.3 Rejection and retest

When a unit fails to meet the specification requirements, the action taken shall be in accordance with contractual agreements between the user and producer.

The contract may call for notification of any acceptance test failures and possibly for a failure analysis to an appropriate level. The contract may also specify requirements for repair and retest.

6.2.4 Defects in accepted items

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 detecting and correcting them.

6.3 Qualification tests

6.3.1 Qualification test samples

A preproduction sample of _____ accelerometers manufactured in accordance with the requirements of this specification shall be subjected to qualification tests specified herein. The procuring organization may designate an independent facility at which one or more of these tests may be performed.

If the product is later modified in any way, the modified form 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 own part number and any other information required by the procuring organization.

6.3.2 List of qualification tests

The procuring organization should specify from 6.6 the tests that should be performed on the qualification test samples.

6.4 Reliability tests

The MTBF requirements of 5.7.2 shall be demonstrated by testing _____ production units for _____ h minimum each and a minimum time of _____ h combined.

Other methods of demonstration testing may be selected at the discretion of the procuring organization. A demonstration test plan should be prepared to define test conditions, types of tests, failures, etc. In some cases it may be desirable to combine reliability and life tests.

6.5 Test conditions and equipment

The procuring organization should specify from Clause 11 of this standard the nominal test conditions and the requirements for the test equipment. The test equipment may be listed by name and model, part number, or performance requirements. The conditions should apply to all tests unless otherwise specified. When a test condition is specified, the complete test conditions should be detailed in this specification.

6.6 Test methods

Instructions for performing specified tests are detailed in Clause 12 of this standard. When a test is specified, the complete test method shall be detailed in this specification, including requirements to be met after test to determine satisfactory performance. A test method should not be listed in 6.6 unless a requirement exists in Clause 5 of this specification.

6.6.1 Test setup

6.6.1.1 Nonoperating test setup

6.6.1.2 Operating test setup

6.6.2 Accelerometer nonoperating tests

6.6.2.1 Examination of product

6.6.2.2 Weight or mass

6.6.2.3 Impedance

6.6.2.4 Dielectric strength

6.6.2.5 Insulation resistance

6.6.2.6 Seal

6.6.2.7 Temperature sensor characteristics

6.6.3 Accelerometer operating tests

6.6.3.1 Functional checkout

6.6.3.2 Noise

6.6.3.3 Inversion transient

6.6.3.4 Four-point tumble

- 6.6.3.4.1 Scale factor and bias**
- 6.6.3.4.2 IA misalignment**
- 6.6.3.5 Static multipoint**
- 6.6.3.6 Threshold, resolution, and dead band**
- 6.6.3.7 Warm-up time**
- 6.6.3.8 Short-term stability**
- 6.6.3.9 Long-term stability**
- 6.6.3.10 Repeatability**
- 6.6.3.11 Sensitivity**
- 6.6.3.12 Temperature model calibration and temperature hysteresis**
- 6.6.3.13 Velocity storage across power interrupt**
- 6.6.3.14 Centrifuge input range and overload capacity**
- 6.6.3.15 Precision centrifuge**
- 6.6.3.16 Frequency response**
- 6.6.3.17 Vibration calibration (nonlinear terms)**
- 6.6.3.18 Vibration and shock calibration (scale factor and bias)**
- 6.6.3.19 Performance through and across environment**
- 6.6.3.20 Velocity storage in normal and over-range shock**
- 6.6.3.21 Slew calibration**
- 6.6.3.22 Magnetic leakage**
- 6.6.4 Electromagnetically torqued pendulous accelerometer tests**
 - 6.6.4.1 Pickoff characteristics**
 - 6.6.4.2 Torquer and self-test torquer polarity**
 - 6.6.4.3 Open-loop frequency response**
 - 6.6.4.4 Pickoff scale factor and pendulum elastic restraint**
 - 6.6.4.5 Turn-on hysteresis**
 - 6.6.4.6 Self-test torquer scale factor**
 - 6.6.4.7 Velocity storage— open-loop test**
 - 6.6.4.8 Velocity storage— pulse-torque steady-state operation**