ANSI/IEEE Std 530-1978
(reaffirmed 1986)

IEEE Standard Specification Format Guide and Test Procedure for Linear, Single-Axis, Digital, Torque-Balance Accelerometer

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Foreword

(This Foreword is not a part of IEEE Std 530-1978, Specification Format Guide and Test Procedure for Linear, Single-Axis, Digital, Torque-Balance Accelerometer.)

This standard is provided as a guide for the preparation of a digital accelerometer specification and test procedure. The accelerometer considered in this standard utilizes a linear, single-axis, nongyroscopic acceleration sensor with a permanent magnet torquer. The torquing electronics are considered part of the accelerometer. The format was prepared by the Gyro and Accelerometer Panel of the Aerospace and Electronics System Society of the Institute of Electrical and Electronics Engineers. It is intended to provide a common meeting ground of terminology and practice for manufacturers and users.

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. Appendix A presents a typical block diagram for response of the accelerometer to aid in specifying dynamic environmental effects on the pendulum of the acceleration sensor.

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. 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 100-1977, IEEE Standard Dictionary of Electrical and Electronics Terms; and the units used conform to ANSI/IEEE Std 268-1976, 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.

The accelerometer is used to provide a digital output which is a measure of acceleration or velocity, or both. An acceleration applied along the input axis of the acceleration sensor causes its proof mass to deflect. The pickoff error signal caused by this motion is utilized in the electronics to produce a restoring torque (see Fig 1). When static equilibrium is reached, the reaction torque of the proof mass to the average acceleration is balanced by the mean value of the restoring torque. The pulse rate required to maintain this equilibrium condition, is proportional to the average acceleration and provides a digital output.

The major contributors to this standard were the following:

N. F. Sinnott *(Chairman, 1970)*
M. D. Mobley *(Chairman, 1971)*
K. W. Komb *(Chairman, 1972)*
A. T. Campbell *(Chairman, 1973)*
H. L. Gubbins *(Chairman, 1974)*
G. E. S. Morrison *(Chairman, 1975)*
G. E. S. Morrison *(Chairman, 1976)*
C. O. Swanson *(Chairman, 1977)*

C. E. Bosson
A. M. Brady
J. Claasen
J. F. Conroy
J. H. Crittenden
H. B. Diamond
H. A. Dinter
J. A. Divine
T. A. Fuhrman
K. N. Green
J. E. Hardie
J. G. Hawkins
C. A. Jones
K. J. Klarman
M. G. Koning
W. G. Lane
A. M. Leeking
J. J. Meehan
C. F. Morley
G. C. Murray
G. H. Neugebauer
R. B. Peters
T. M. Rankin
R. F. Rathcke

H. Rogall
B. Schwartz
C. W. Spencer
C. I. Thornburg
R. Van Alstine
M. M. Van Schoiack
C. W. Wellner
B. J. Wimber
H. M. Ziegler

In addition, there were more than 100 other individuals who attended meetings of the Gyro and Accelerometer Panel and who helped develop this standard.

IEEE Standard Specification Format Guide and Test Procedure for Linear, Single-Axis, Digital, Torque-Balance Accelerometer

1. Scope

This specification defines the requirements and test procedures for a digital accelerometer which utilizes a linear, single-axis, nongyroscopic acceleration sensor with a permanent magnet torquer (forcer) operated in a [ternary pulse mode, pulse-width modulation mode, analog mode with voltage to frequency converter, …]. The electronics are considered to be part of the accelerometer which produces a digital output proportional to sensed velocity changes. The digital accelerometer is hereafter referred to as the accelerometer. With appropriate modifications, this specification may also be applied to force balance nonpendulous accelerometers.

2. Applicable Documents

The following documents of the issue in effect, on 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 specification and the listed documents, the requirements of this specification shall govern.

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

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 100-1977, Dictionary of Electrical and Electronics Terms.

2.2.2.2

ANSI/IEEE Std 337-1972, Specification Format Guide and Test Procedure for Linear, Single-Axis, Pendulous, Analog Torque Balance Accelerometer.

2.2.3 Company

2.3 Drawings

2.3.1 Government

2.3.2 Industry/Technical

2.3.3 Company

2.4 Bulletins

2.4.1 Government

2.4.2 Industry/Technical

2.4.3 Company

2.5 Other Publications

> Other applicable documents should listed under appropriate categories.

3. Requirements

3.1 General

3.1.1 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:

1) Purchase agreement
2) This specification 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 Design

The accelerometer shall consist of a single-axis acceleration sensor in accordance with IEEE Std 337-1972 and associated electronics, as shown in Fig 1.

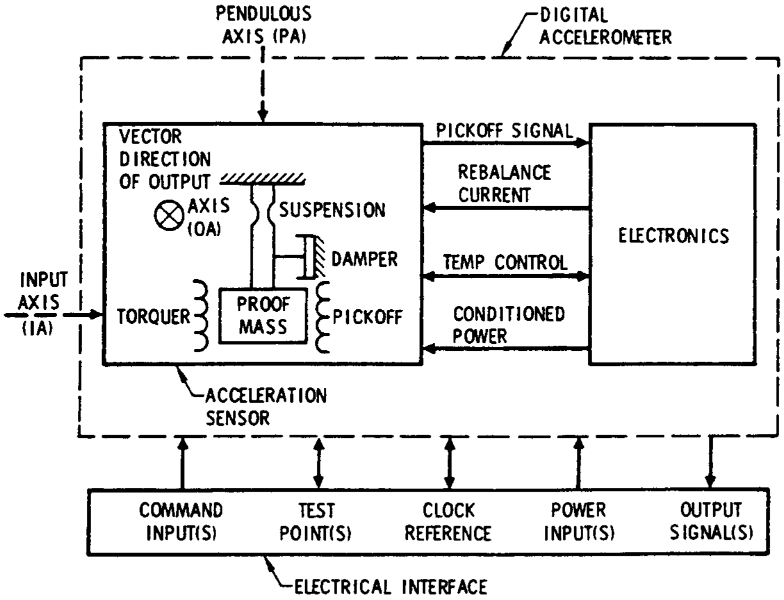


Figure 1—Digital Accelerometer Schematic

The associated electronics shall include the pulse torquing electronics or voltage to frequency converter, and may include such items as power conditioning, signal conditioning, temperature control, clock reference, and test points.

The method of pendulum torquing may be specified (for example, ternary pulse, binary pulse width modulation, analog).

3.2.1 Mechanical and Thermal Design

The following mechanical and thermal requirements apply to accelerometer package(s) to the extent specified:

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

3.2.1.1 *Exterior Surfaces*

All exterior surfaces must 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 specification.

> 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 drawing No _______.

> The following may be specified with appropriate tolerances:
>
> Center of gravity of each package
> Center of gravity of proof mass
> Effective center of mass

3.2.1.3 *Identification of Product*

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

> The specification may require: name of components, part number, serial number, contract number, and manufacturer’s name or symbol.

3.2.1.4 *Sensor Axes*

The input, pendulous, and output reference axes and their positive directions shall be defined by external markings and by reference mounting surface(s) on the package which contains the acceleration sensor. The positive direction of the axes shall be such that the cross product of input and pendulous axes shall be along the output axis. (See Fig 1).

3.2.1.5 *Weight*

The weight shall be _______ ± _______ [g, kg, oz, lb].

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

3.2.1.6 *Seal*

The accelerometer package shall meet the following seal requirements:

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

1) *Fluid Filled.* The accelerometer shall be sealed such that no fluid leakage is detected under _______ power magnification after being subjected to an external vacuum at _______ ± _______ Pa and a temperature of _______ ± _______ °C for a minimum period of _______ minutes.

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 accelerometer shall be sealed such that the maximum gas leakage rate shall not exceed _______ cm^3/s of _______ gas, measured at standard conditions for a minimum period of _______ min while being subjected to a vacuum of _______ ± _______ Pa at a temperature of _______ ± _______ °C.

Tracer gases may be added to the fill gas in order to facilitate leak detection.

3.2.1.7 *Operating Temperature*

The operating temperature, as indicated by a temperature sensor [on, within] the accelerometer shall be _______ ± _______ °C.

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

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

3.2.2 Electrical and Magnetic Design

The accelerometer's electrical and magnetic design requirements shall be as specified below. The accelerometer 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 accelerometer consists of the signals, power, and test points listed below and illustrated in Fig 1.

3.2.2.1.1 *Power Input(s)*

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

Source impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Load impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Voltage _______ ± _______ [V ac, V dc]
Frequency _______ ± _______ Hz
Nominal current _______ A for _______ [s, min]
Peak current _______ A for _______ [s, min]
Harmonic content _______ %

3.2.2.1.2 *Output Signal(s)*

Specify the type and characteristics of output signal(s) required. For example:

Type:

Pulses indicating positive velocity increments on one signal line and pulses indicating negative velocity on a second line.

Characteristics:

Source impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Load impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Phasing with respect to clock reference [+, −] _______ ± _______ s
Polarity of output signal with +1 *g* along the input reference axis
Wave shape (see Fig 2)
Repetition rate _______ pulses per second (p/s)

3.2.2.1.3 *Command Input(s)*

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

Type:

ON/OFF
Self Test
Characteristics:
Source input impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Load impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Input voltage _______ ± _______ [V dc, V ac]

3.2.2.1.4 *Clock Reference*

Specify the characteristics of the clock reference. For example:

Source Impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Load impedance _______ ± _______ [+, −]*j* _______ ± _______ Ω
Repetition rate _______ ± _______ p/s
Wave shape (see Fig 2)
Stability ± _______ % per _______ [hours (h), days (d)]

3.2.2.1.5 *Test Points*

Specify the test points required for monitoring and testing of the accelerometer. These may include excitation voltages pick-off output signal, torquer signal, other control signals, or temperature sensor resistance. 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 _______ ± _______ V rms, at _______ Hz, are applied between isolated interface circuits, and between the case(s) and circuits isolated from the case(s), for _______ ± _______ s.

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

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 _______ MΩ measured at _______ ± _______ V dc, applied for _______ ± _______ s.

Different voltages may be specified for different circuits.

3.2.2.4 *Electromagnetic Interference*

The maximum electromagnetic interference from the accelerometer package(s) shall conform to _______.

Describe the requirements. In the United States, a common standard is MIL-STD-461.

3.2.2.5 *Electromagnetic Compatibility*

Describe the requirements. In the United States, a common standard is MIL-STD-461.

3.2.2.6 *Magnetic Leakage*

The magnetic leakage shall not exceed _______ mT at a distance of _______ m from the accelerometer package(s), in any direction.

3.2.3 Maintainability

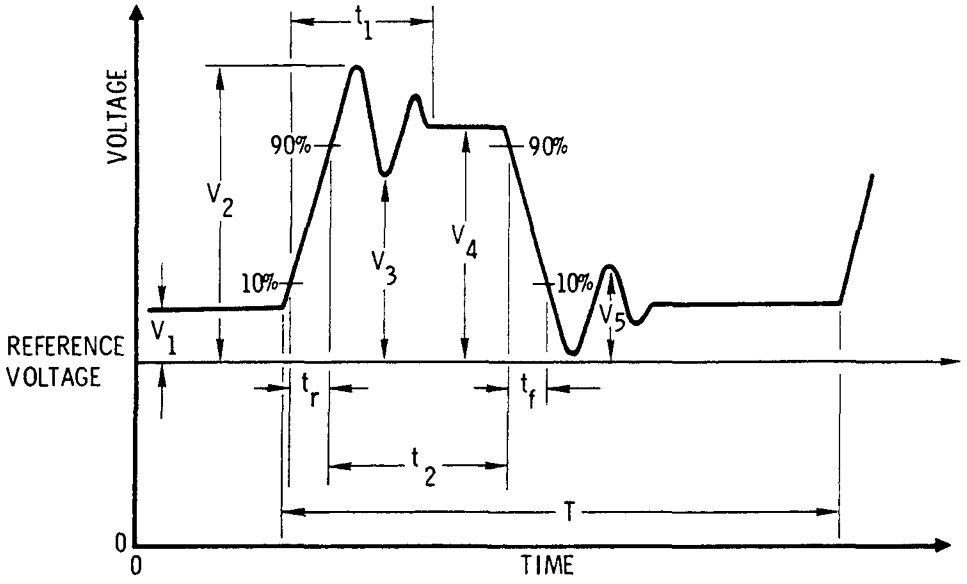
Maintenance for operational accelerometers shall utilize fault isolation to a line replaceable unit (LRU) by use of [built in test equipment, special test equipment, or commonly available test equipment].

3.2.3.1 *LRU Interchangeability*

Each LRU shall be interchangeable with like units, with the same part number, without calibration or adjustment.

3.2.3.2 *LRU Maintenance*

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



	Units	Maximum	Minimum	Remarks
V_1	volts	________	________	steady-state low voltage
V_2	volts	________	N/A	overshoot voltage
V_3	volts	N/A	________	undershoot voltage
V_4	volts	________	________	steady-state high voltage
V_5	volts	________	N/A	maximum low voltage transient
t_r	seconds	________	________	rise time
t_f	seconds	________	________	fall time
t_1/t_2	—	________	N/A	ratio of the TURN-ON transient time to required ON time
t_2	seconds	________	________	duration of high voltage ON time
t_2/T	—	________	________	(t_2/T) (100) = % duty cycle
T	seconds			waveform period

N/A — not applicable

Figure 2—Wave Shape Requirements for Direct Coupled Pulse-Type Signals

3.3 Performance

3.3.1 General

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

3.3.2 Input Range

The minimum input range shall be from minus _______ *g* to plus _____ *g*.

3.3.3 Warm-Up Time

The output of the accelerometer shall be within _______ pulses per second (p/s) of its steady state value in no more than _______ min after starting up from _______ °C.

> The orientation of the input axis with respect to the gravity vector should be specified in the test method.

3.3.4 Scale Factor

3.3.4.1 *Absolute Value*

The scale factor K_1 shall be _______ ± _______ (p/s)/g.

> The scale factor K_1 may also be utilized to obtain velocity quantization:

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

(that is, (m/s)/p)

3.3.4.2 *Asymmetry*

The difference between the scale factor measured with positive applied acceleration and negative applied acceleration shall not exceed ± _______ % of the nominal absolute scale factor.

3.3.4.3 *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 _______ %.

> Alternate means of specifying stability may be utilized, such as standard deviation, curve fitting for trend determination, or computer analysis to determine the auto-correlation time.

3.3.4.4 *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 rms deviation of the scale factor data points, from the best fit line, shall be less than _______ %.

> Other criteria for establishing stability may be utilized such as standard deviation, curve fitting for trend determinations or computer analyses to determine the auto-correlation times.

3.3.4.5 *Repeatability*

The rms deviation of the scale factor from the mean of _______ measurements shall be less than _______ %. Between successive measurements, the accelerometer 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 attain thermal equilibrium. Other conditions for repeatability may be specified, such as turn off with the accelerometer maintained at operating temperature.

3.3.4.6 *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 limits listed below:

Input voltage(s) _______ %/V
Power input frequency(ies) _______ %/Hz
Operating temperature _______ %/°C
External magnetic fields [dc or ac, or both] _______ %/mT per axis
Pressure _______ %/Pa

3.3.5 Bias

3.3.5.1 *Absolute Value*

The absolute value of the bias K_0 shall not exceed _____ *g*.

3.3.5.2 *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 _______ *g*.

> Alternate means of specifying 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 bias, over a period of _____ days of continuous operation, shall be less than _______ *g*/d. The rms deviation of the bias data points from the best fit line shall be less than _______ *g*.

> 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.

3.3.5.4 *Repeatability*

The rms deviation of the bias from the mean of ______ measurement shall be less than ______ *g*. Between successive measurements, the accelerometer 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 attain thermal equilibrium. Other conditions for repeatability may be specified, such as turn off with the accelerometer maintained at operating temperature.

3.3.5.5 *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 listed below:

Input voltage(s)	_____ *g*/V
Power input frequency(ies)	_____ *g*/Hz
Operating temperature	_____ *g*/°C
External magnetic fields [dc or ac, or both]	_____ *g*/mT
Pressure	_____ *g*/Pa

In some applications the sensitivity of accelerometer bias to angular rate or acceleration, or both, may be significant and should be specified.

3.3.6 Input Axis Misalignment

3.3.6.1 *Penduluous Reference Axis*

The absolute value of the input axis misalignment about the pendulous reference axis δ_p shall be less than ______ rad.

3.3.6.2 *Output Reference Axis*

The absolute value of the input axis misalignment about the output reference axis δ_o shall be less than _____ rad.

In some applications it may be desirable to specify the input axis misalignment stability, sensitivity to temperature, etc.

3.3.7 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 and _____ g/g^3, respectively.

3.3.8 Cross Coupling

The absolute values of the cross coupling coefficients K_{ip} and K_{io} shall be less than _______ (*g*/*g*)/cross *g*.

3.3.9 Acceleration Threshold

The threshold shall be less than _______ *g*.

3.3.10 Acceleration Resolution

The resolution shall be less than _______ *g*.

3.3.11 Acceleration Dead Zone

The dead zone at zero indicated output, shall be less than _______ *g*.

> Dead zone at zero *g* input, or other input values may be specified if desired.

3.3.12 Turn-On Hysteresis

The absolute value of the turn-on hysteresis shall be less than _______ *g*.

3.3.13 Velocity Storage

> The velocity stored in an accelerometer is a function of its design and is sometimes verified by analysis rather than actual test.

3.3.13.1 *Normal Operation*

The maximum velocity stored in the accelerometer shall not exceed _____ [*g*·s, m/s].

3.3.13.2 *Overrange Operation*

The minimum velocity storage for an overrange acceleration pulse shall exceed _____ [*g*· s, m/s].

> In some cases the overrange condition may be specified as a shock pulse defined in terms of peak amplitude, waveform duration, or spectrum.

3.3.14 Frequency Response

> Linear system frequency response specifications may be useful in some applications. When stated in these terms, the describing function interpretation is implied. Caution must be exercised, when this technique is applied to a nonlinear system, that a solution exists. Frequency response may be verified by analysis rather than actual test.

3.3.15 Vibration Induced Errors

The rectification error shall not exceed ______ *g* while the accelerometer is subjected to the vibration environment of 3.4.2.2 along any combination of axes.

> Vibropendulous and anisoelastic effects are two examples of rectification errors. Vibropendulous error shall be specified for vibration acceleration applied in a plane normal to the output axis and at 45° to the input reference axis.

3.3.16 Self Test Scale Factor

The accelerometer self test scale factor shall be _______ ± _______ (p/s)/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.

3.4 Environmental Requirements

The environmental conditions listed in this paragraph are those to which the accelerometer may be subjected during storage, transportation, 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 Nonoperative Environment

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

> Where appropriate, the environment specified must 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 times, 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 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/in^2] to _______ [Pa, lbf/in^2]. The rate of change of pressure shall be nominally _______ [Pa/s, (lbf/in^2)/s].

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

3.4.1.6 *Magnetic Fields*

> Define magnitudes, directions of fields with respect to each axis, and duration. If exposure to fields resulting from alternat-current is desired, specify intensity versus frequency.

3.4.1.7 *Nuclear Radiation*

> Describe the nuclear environments). For each environment include the type of radiation (that is, X ray, gamma, etc) intensity, spectrum, exposure duration, and axes of application.

3.4.1.8 *Storage Life*

The life of the accelerometer shall be greater than _______ year (yr).

> Describe storage environment such as temperature, humidity, and pressure, etc.

3.4.1.9 *Other*

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

3.4.2 Operative Environment

The following conditions, occurring separately or in combination, may be encountered during operation. The accelerometer shall conform to all the requirements of 3.3 during, unless otherwise specified, and after exposure to any reasonable combination of the specified service conditions.

3.4.2.1 *Thermal*

3.4.2.1.1 *Temperature (High and Low)*

Ambient air temperature may vary from _______ °C to _______ °C under sheltered conditions (protected from direct sunlight).

3.4.2.1.2 *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 times and sequence.

3.4.2.1.3 *Other*

> Other thermal conditions which may affect performance shall be specified. For example, equivalent heat sink, radiant energy from surrounding surfaces, and power dissipation.

3.4.2.2 *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.

3.4.2.3 *Mechanical Shock*

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

3.4.2.4 *Acceleration*

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

3.4.2.5 *Pressure*

_______ [Pa, lbf/in^2] to _______ [Pa, lbf/in^2]. The rate of change of pressure shall be nominally _______ [Pa/s, (lbf/in^2)/s]

If appropriate, pressure maybe expressed in terms of altitude and rate of climb.

3.4.2.6 *Humidity*

The operative relative humidity shall be _______ % maximum.

3.4.2.7 *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 μPa.

3.4.2.8 *Magnetic Fields*

Define magnitudes, directions of fields with respect to each axis, and duration. If exposure to fields resulting from alternating current is desired, specify intensity versus frequency.

3.4.2.9 *Nuclear Radiation*

Describe the nuclear environment(s). For each environmental include the type of radiation (that is, X ray, gamma, etc) intensity, spectrum, exposure duration, and axes of application.

3.4.2.10 *Operating Life*

The accelerometer shall be capable of operating within the requirements of this specification for _______ h.

3.4.2.11 *Other*

Include any other appropriate operative environmental conditions such as fungus, salt spray, etc.

3.5 Reliability

3.5.1 Reliability Program

The reliability program shall be in accordance with _______.

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

3.5.2 Mean Time Between Failure (MTBF)

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

4. 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.

4.1 Classification of Tests

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

1) *Acceptance tests* are those performed on accelerometers submitted for acceptance under contract
2) *Qualification tests* are those performed on accelerometers submitted for qualification as a satisfactory product
3) *Reliability tests* are those performed to demonstrate the reliability specified in 3.5

4.2 Acceptance Tests

Acceptance tests shall consist of individual and sample tests.

4.2.1 Individual Tests

Each accelerometer shall be subjected to the following tests described under 4.7, Test Methods:

The list of individual tests shall 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. Those tests frequently specified as Individual Tests are listed below.

	Paragraph Title	*Paragraph Number*
(1)	Examination of product	4.7.1.1
(2)	Seal	4.7.1.3
(3)	Impedance	4.7.1.4
(4)	Dielectric strength	4.7.1.5
(5)	Insulation resistance	4.7.1.6
(6)	Electrical interface tests	4.7.2.2
(7)	Scale factor and bias	4.7.2.4
(8)	Short term stability	4.7.2.5
(9)	Repeatability	4.7.2.7
(10)	Input axis misalignment	4.7.2.9
(11)	Centrifuge input range test	4.7.2.11
(12)	Turn-on Hysteresis	4.7.2.13
(13)	Velocity storage	4.7.2.15

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

4.2.2 Sampling Plan and Tests

4.2.2.1 *Sampling Plan*

Accelerometers selected shall be subjected to the tests specified in 4.2.2.2.

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.

4.2.2.2 *Sampling Tests*

Accelerometers selected in accordance with 4.2.2.1 shall be subjected to the following tests described under 4.7, Test Methods:

The procuring organization shall specify those tests which shall be performed on accelerometers selected in accordance with the sampling plan, 4.2.2.1. Those 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.

	Paragraph Title	*Paragraph Number*
(1)	Individual tests	4.2.1
(2)	Weight	4.7.1.2
(3)	Warm-up time	4.7.2.3
(4)	Static multipoint test	4.7.2.10
(5)	Precision centrifuge test	4.7.2.12
(6)	Threshold, resolution, and dead zone	4.7.2.14
(7)	Magnetic leakage	4.7.2.18
(8)	Temperature (high, low)	4.7.3.3.3

4.2.3 Rejection and Retest

When a unit from the production run fails to meet the specification requirements, the procuring organization shall be notified of the failure. The cause of the failure shall be determined, and rejection and retest shall be accomplished in accordance with the following plan. [Describe Rejection and Retest Plan.] After corrections have been made, the complete test under which failure occurred and also any tests which might be affected by the corrective measures taken shall be defined and approved by the procuring organization. The unit shall complete the retest without further failure before it will be considered to have passed the test. For operational and production reasons, individual tests may be continued pending the investigation of the failure.

4.2.4 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.

4.3 Qualification Tests

4.3.1 Qualification Test Samples

A quantity 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 uniquely identified as required by the procuring organization.

4.3.2 Qualification Test Methods

The procuring organization shall specify from 4.7, Test Methods, those tests which shall be performed on the qualification test samples. It is usual to require all the individual tests as listed in 4.2.1, selected sampling tests from 4.2.2.2, sensitivity test from 4.7.2.8, long term stability from 4.7.2.6, and all of the environmental tests in 4.7.3.

4.4 Reliability Tests

The MTBF requirements shall be demonstrated by testing _______ production units for _______ hours minimum each and a minimum time of _______ hours combined.

A demonstration test plan may be prepared to define test conditions, types of tests, failures, etc. As an alternate to demonstration testing, MTBF may be calculated. In some cases, it may be desirable to combine the reliability tests with the life tests.

4.5 Standard Test Conditions

4.5.1 Ambient Environment

The conditions listed below define the requirements for the test environment. They are not intended as environmental tests, which are described in 4.7.3.

4.5.1.1 *Atmospheric Conditions*

1) Pressure _______ ± _______ [Pa, lbf/in^2]
2) Ambient temperature _______ ±_______ °C
3) Relative humidity _______ to _______ %

4.5.1.2 *Other Conditions*

Specify other test area environmental conditions as required (for example, magnetic field, radiation, vibration).

4.5.2 Installation Requirements

4.5.2.1 *Mounting Fixture(s)*

The mounting fixture(s) design requirements shall be specified (for example, alignment for reference axes, surface(s) conditioning, thermal considerations, simulation of in-service installation).

4.5.2.2 *Electrical Interconnections*

The electrical interconnections may be specified in a schematic (included as a figure) or as a separate engineering drawing. Several schematics may be required for the various test arrangements required. Each schematic shall indicate such things as: grounding, test points, circuit protection, precautionary notes, allowable lead length, shielding, etc. The detailed test procedures shall ensure that all electrical parameters are set within the allowable tolerances specified for the electrical interface.

4.5.2.3 *Operating Temperature*

The operating temperature shall be in accordance with 3.2.1.7.

4.6 Test Equipment

> The selection of test equipment should be based on accuracy requirements compatible with the performance specifications. Similarly, the bandpass of the measuring devices should be chosen so as to provide information within the frequency spectrum of interest for the tests. All special purpose and commercial test equipment shall be listed by name, model, part number, or performance requirement.

4.7 Test Methods

4.7.1 Nonoperative Tests

These methods are intended to assure the conformance of the accelerometer to the nonoperative mechanical and electrical requirements.

1) Unless otherwise specified, all nonoperating tests shall be performed in a normal laboratory environment as described in 4.5.1.
2) After examination the accelerometer shall be mounted on a simple mounting fixture that will minimize the chances for accidental mechanical damage.
3) The electrical leads, if required, shall be brought out to a junction box or equivalent device that will minimize the chance of accidental electrical damage due to shorting across leads, etc. Terminal designations shall be as shown in the electrical schematic.

> Care must be taken in the choice of the junction box and the size and length of leads in order to avoid affecting the characteristics of the accelerometer circuits.

4.7.1.1 *Examination of Product*

The accelerometer shall be examined visually for proper identification markings, surface finish, workmanship, and dimensional conformance to the outline drawing No _______.

4.7.1.2 *Weight*

Measure the weight of the accelerometer. The weight shall conform to the requirements of 3.2.1.5.

4.7.1.3 *Seal*

The purpose of this test is to determine that the accelerometer is properly sealed.

> This procedure is written to accommodate either fluid or gas filled instruments. The appropriate subparagraphs, below, should be chosen.

4.7.1.3.1 *Test Equipment*

The following test equipment is required for this test.

1) *Fluid-Filled Accelerometer*
   Binocular microscope

Vacuum enclosure

2) *Gas-Filled Accelerometer*

Leak detector or immersion fluid (specify)
Vacuum enclosure

4.7.1.3.2 *Test Method*

1) *Fluid-Filled Accelerometer.* After thorough cleaning of all surfaces, the accelerometer shall be placed in a vacuum enclosure at _______ ± _______ Pa and at an accelerometer temperature of _______ ± _______ °C for a minimum period of _______ min. The accelerometer shall then be removed and visually examined for evidence of leakage at a magnification of _______.
2) *Gas-Filled Accelerometer.* The accelerometer shall be placed in a vacuum enclosure at _______ ± _______ Pa and _______ °C accelerometer temperature. External gas leakage shall then be measured using a leak detector. Or, the accelerometer shall be submerged in fluid and placed in a vacuum enclosure at _______ ± _____ Pa and _____ ± _____ °C temperature for a period of _____ min. The presence or absence of a flow of bubbles after _____ min shall be noted. Care must be taken to distinguish bubbles due to leakage, from those due to adsorbed gases on the outer surface.

4.7.1.3.3 *Test Results*

The seal integrity shall conform to the requirements of 3.2.1.6.

> In some cases other procedures may be more appropriate, such as the use of fluorescent tracers in fluids or the measurement of weight loss.

4.7.1.4 *Impedance*

The purpose of this test is to measure the impedance of the accelerometer's electrical interface circuits.

4.7.1.4.1 *Test Equipment*

The following test equipment is required for this test:

Impedance measuring equipment
Resistance measuring equipment

4.7.1.4.2 *Test Method*

Measure the impedances of each circuit listed below:

> Appropriate circuits at the accelerometer's electrical interface shall be selected for impedance or resistance tests, or both. In some cases it may be necessary to measure the impedance while operating.

4.7.1.4.3 *Test Results*

Measured impedances shall conform to the requirements of 3.2.2.1.

4.7.1.5 *Dielectric Strength*

The purpose of this test is to ascertain that the separate accelerometer circuits are isolated from each other and from the case by measuring the leakage current between these circuits and between the circuits and the case.

4.7.1.5.1 *Test Equipment*

The following test equipment is required for this test. Adjustable ac high voltage source equipped with voltage and current measuring capabilities.

4.7.1.5.2 *Test Method*

Apply _____ ± _____ V rms at _____ Hz between mutually isolated circuits and between each circuit and the accelerometer case. The test voltage shall be raised from zero to the specified value as uniformly as possible, at a rate of _____ V rms/s. The test voltage shall then be gradually reduced to zero. During each test the current meter shall be monitored and the maximum leakage current recorded.

4.7.1.5.3 *Test Results*

The measured leakage current(s) shall conform to the requirements of 3.2.2.2.

4.7.1.6 *Insulation Resistance*

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

4.7.1.6.1 *Test Equipment*

The following test equipment is required for this test: megohmmeter.

4.7.1.6.2 *Test Method*

Apply _____ ± _____ V dc for a period of _____ ± _____ s between mutually isolated circuits and between each circuit and the accelerometer case.

4.7.1.6.3 *Test Results*

The measured insulation resistance shall conform to the requirements of 3.2.2.3.

4.7.2 Operative Tests

These tests are intended to determine the accelerometer performance characteristics.

> In the tests which follow, the accelerometer output measurement test equipment and technique may significantly influence the test results. Specify the sequence of operations required to bring the accelerometer and test equipment to operating condition for each test setup.

4.7.2.1 *Test Setup*

4.7.2.1.1 *Mounting Position No 1*

1) Unless otherwise specified, the accelerometer shall be operated under the standard test conditions of 4.5.
2) With the rotation axis of the dividing head horizontal within _____ arc seconds, attach the mounting fixture to the face plate of the dividing head so the accelerometer when mounted will satisfy the requirements of paragraph (3).
3) With the dividing head set at 0° ± _____ arc seconds, mount the accelerometer on the reference mounting surface(s) so the input reference axis is horizontal within _____ arc seconds, the positive pendulous reference

axis points upward, the output reference axis is parallel to the rotation axis of the head within _____ arc minutes and the positive input reference axis points upward when the head is rotated to the 90° position.

4) With the dividing head set at 90°, the accelerometer and the immediate environment (including the dividing head) shall be allowed to reach thermal equilibrum as evidenced by the stability of the accelerometer output being within _______ p/s for _______ measurements spaced _______ min apart before proceeding with the test.

4.7.2.1.2 *Mounting Position No 2*

1) Unless otherwise specified, the accelerometer shall be operated under the standard test conditions of 4.5.
2) With the rotation axis of the dividing head horizontal within _____ arc seconds, attach the mounting fixture to the face plate so the accelerometer when mounted will satisfy the requirements of paragraph (3).
3) With the dividing head set at 0° ± _____ arc seconds, mount the accelerometer on the reference mounting surface(s) so that the input reference axis is horizontal within _____ arc seconds, the positive output reference axis points downward, the pendulous reference axis is parallel to the rotation axis of the head within ______ arc minutes and the positive input reference axis points upward when the head is rotated to the 90° position.
4) With the dividing head set at 90°, the accelerometer and the immediate environment (including the dividing head) shall be allowed to reach thermal equilibrium as evidenced by the stability of the accelerometer output being within _______ p/s for _____ measurements spaced _______ min apart before proceeding with the test.

4.7.2.2 *Electrical Interface Tests*

4.7.2.2.1 *Purpose*

The purpose of this test is to determine that all of the operational electrical interface functions are within their allowable tolerances.

4.7.2.2.2 *Test Equipment*

The following equipment specified in 4.6 is required for this test.

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and measure its output

> Specify additional test equipment required to make measurements at the electrical interface such as: variable power supplies, variable frequency supplies, oscilloscopes, electronic counters, ammeters, precision voltmeters, wattmeters, etc.

4.7.2.2.3 *Test Setup*

The accelerometer test setup shall be in accordance with mounting position No 1 as specified in 4.7.2.1.1.

> Other positions may be specified during the test to evaluate interface functions with various values of *g* as an input.

4.7.2.2.4 *Test Methods*

Specify the test methods which are required to determine that the functions at the electrical interface are within their allowable tolerances. For example:

1) Measure input current(s)
2) Measure test point wave shapes
3) Measure output signal wave shapes
4) Measure test point wave shapes with input line voltages at the allowable extremes
5) Measure output signal wave shape characteristics with input line voltages at the allowable extremes
6) Measure phase relations between critical signals
7) Measure distortion of critical signals, etc

4.7.2.2.5 *Test Results*

The measured test results shall conform to the requirements of 3.2.2.1.

4.7.2.3 *Warm-Up Time*

4.7.2.3.1 *Purpose*

The purpose of this test is to determine the time required for the accelerometer output to come within a specified value of the steady state or final indicated output following power turn on in a specified ambient environment.

4.7.2.3.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output
3) Equipment required to establish the specified ambient environment

4.7.2.3.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.1.

The mounting position(s) selected should be determined by the application. A plus or minus 1 *g* input is recommended unless another input is more suitable to the application.

4.7.2.3.4 *Test Method*

1) Set the dividing head at 90°
2) Establish the ambient thermal environment at ______ ± ______ °C; allow ______ min for the accelerometer to reach thermal equilibrium
3) Energize the accelerometer
4) Record the accelerometer output as a function of time until a steady state is reached

4.7.2.3.5 *Test Results*

The accelerometer output shall conform to the requirements of 3.3.3.

4.7.2.4 *Scale Factor and Bias*

This test describes one method of determing scale factor and bias, another is described in 4.7.2.10.

4.7.2.4.1 *Purpose*

The purpose of this test is to determine the bias K_0, and the scale factor K_1.

4.7.2.4.2 *Test Equipment*

The following equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output

4.7.2.4.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.1.

4.7.2.4.4 *Test Method*

1) Rotate the dividing head to the 900 position (input reference axis up) within ______ arc minutes. Record the accelerometer output as E_{90}.
2) Rotate the dividing head to the 270° position (input reference axis down) within ______ arc minutes. Record the accelerometer output as E_{270}.
3) Calculate K_1 and K_0 using the following algebraic equations:

$$K_1 = \frac{E_{90^\circ} - E_{270^\circ}}{2} \qquad (\text{p}/\text{s})/g$$

$$K_0 = \frac{E_{90^\circ} + E_{270^\circ}}{2K_1} \qquad g$$

The bias and scale factor obtained by the above method includes the effects of the second order term K_2 and the third term K_3, respectively. (Refer to 6.3.)

An alternate method of measuring bias is to obtain accelerometer outputs at the other two cardinal positions. This value represents the bias with (nominally) no acceleration applied along the input axis, and is

$$K_0' = \frac{E_{0^\circ} + E_{180^\circ}}{2K_1} \qquad g$$

where E_0 and E_{180} are the accelerometer, outputs measured in the two horizontal positions. The two positions must be 180° apart within one arc second for each 2.5 μg allowable uncertainty in the bias measurement. The effect of K_2 is excluded by this method.

4.7.2.4.5 *Test Results*

The scale factor and bias shall conform to the requirements of 3.3.4.1 and 3.3.5.1, respectively.

4.7.2.5 *Short Term Stability*

4.7.2.5.1 *Purpose*

The purpose of this test is to determine the short-term stability of the accelerometer bias K_0 and scale factor K_1.

4.7.2.5.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output

4.7.2.5.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.1.

4.7.2.5.4 *Test Method*

1) Stabilize the accelerometer at the standard operating conditions specified in 4.5
2) Determine and record the bias and scale factor using the procedure of 4.7.2.4
3) Repeat step (2) ______ times per day for ______ [h, d] of continuous operation; measurements to be made at least ______ [min, h apart
4) Determine the rms deviation of the bias and scale factor from their mean values

4.7.2.5.5 *Test Results*

The accelerometer short term stability shall conform to the requirements of 3.3.4.3 and 3.3.5.2.

> In some applications it may be desirable to modify the test to determine the stability of additional parameters such as input axis misalignment.

4.7.2.6 *Long Term Stability*

4.7.2.6.1 *Purpose*

The purpose of this test is to determine the long term stability of the accelerometer's bias K_0 and scale factor K_1.

4.7.2.6.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output

4.7.2.6.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.1.

4.7.2.6.4 *Test Method*

1) Stabilize the accelerometer at the standard operating conditions specified in 4.5
2) Determine and record the bias and scale factor using the procedure of 4.7.2.4

3) Repeat step (2) ______ times per day for ______ d of continuous operation; measurements to be made at least ______ [min, h] apart
4) Obtain the best fit linear curves to the bias and scale factor data points by the method of least squares; determine the rms deviation of the data points from the best fit lines

4.7.2.6.5 *Test Results*

The accelerometer long term stability shall conform to the requirements of 3.3.4.4 and 3.3.5.3.

> In some applications, it may be desirable to modify the test to determine the stability of additional parameters such as input axis misalignment.

4.7.2.7 *Repeatability*

4.7.2.7.1 *Purpose*

The purpose of this test is to determine the repeatability of the bias K_0 and the scale factor K_1 with cool downs to the specified temperature.

4.7.2.7.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test.

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output

4.7.2.7.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.1.

4.7.2.7.4 *Test Method*

1) Stabilize the accelerometer at the standard operating conditions specified in 4.5
2) Determine and record the bias and scale factor using the procedure of 4.7.2.4
3) Deenergize and cool the accelerometer to ______ ± ______ °C; soak at least ______ h
4) Repeat steps (1), (2), and (3) ______ times

4.7.2.7.5 *Test Results*

The repeatability shall conform to the requirements of 3.3.4.5 and 3.3.5.4.

> Other changes in environmental conditions may be specified as desired.

4.7.2.8 *Sensitivity*

4.7.2.8.1 *Purpose*

The purpose of the sensitivity test is to determine the changes in accelerometer scale factor K_1 or bias K_0, or both, caused by variations in the following:

1) Input voltage(s)
2) Power input frequency(ies)
3) Operating temperature

4) External magnetic fields (dc or ac, or both)
5) Pressure

For some applications, it may be desirable to increase or reduce the number of test conditions to be varied and to test for the sensitivity of other accelerometer parameters such as input axis misalignment.

4.7.2.8.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output
3) Equipment required to produce the excition variations and environmental changes

4.7.2.8.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.1.

4.7.2.8.4 *Test Method*

This test is performed by varying each parameter individually while maintaining all other test conditions constant per the requirements of 4.5. An example illustrating sensitivity to pickoff excitation voltage is presented below.

1) *Pickoff Excitation Voltage*
   a) Determine the accelerometer scale factor and bias per 4.7.2.4 with the pickoff excitation voltage set at ______ ± ______ V
   b) Change the pickoff excitation voltage to ______ ± ______ V and repeat the test

Other parameter variations — repeat the test described in 4.7.2.8.4 (1) for each parameter listed in 4.7.2.8.1.

Select the appropriate parameter change for each test.

Generally the conditions of environmental exposure should be specified such as rate of temperature and pressure changes and the direction of the magnetic fields. Care must be taken to separate or eliminate the effect of changes in test equipment characteristics caused by variations in environment.

4.7.2.8.5 *Test Results*

The test data shall be reduced in order to determine the sensitivity coefficients. An example of an accelerometer sensitivity coefficient calculation for pickoff excitation voltage is as follows.

1) Scale factor sensitivity to variations in pickoff excitation voltage equals

$$\frac{100\ (K_{1a} - K_{1b})}{K_1\ (V_a - V_b)} \qquad \%/\mathrm{V}$$

where

V_a = maximum excitation voltage
V_b = minimum excitation voltage
K_1 = scale factor
K_{1a} = scale factor measured with V_a applied

K_{1b} = scale factor measured with V_b applied

2) Bias sensitivity to variations in pickoff excitation voltage equals

$$\frac{K_{0a} - K_{0b}}{V_a - V_b} \qquad g/\mathrm{V}$$

where

K_{0a} = bias measured with V_a applied
K_{0b} = bias measured with V_b applied

Determine the other sensitivity coefficients in a similar manner.

3) The sensitivity coefficients shall meet the requirements specified in 3.3.4.6 and 3.3.5.5.

Note that if a particular sensitivity is non-linear, the result obtained from the above procedure can be misleading. It may be desirable to obtain more data points in order to determine such characteristics as linearity, maximum slope, or hysteresis.

4.7.2.9 *Input Axis Misalignment*

4.7.2.9.1 *Purpose*

The purpose of this test is to determine the misalignment of the input axis with respect to the input reference axis (IRA). The IRA is defined by external marks or mounting surfaces, or both, on the accelerometer case.

4.7.2.9.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its outputs

4.7.2.9.3 *Test Setup — Mounting Position No 1*

The test setup shall be in accordance with 4.7.2.1.1.

4.7.2.9.4 *Test Method — Mounting Position No 1*

1) With the dividing head set at 0°, record the accelerometer output as E_{0°
2) Rotate the dividing head 180° ± _______ arc seconds and record the accelerometer output as E_{180°
3) Calculate the misalignment angle δ_o using the following equation:

$$\delta_o = \frac{E_{0^\circ} - E_{180^\circ}}{2K_1} \qquad \text{rad}$$

where δ_o is the misalignment angle of the input axis with respect to the input reference axis about the output reference axis in radians, and K_1 is the scale factor in (p/s)/g.

4.7.2.9.5 *Test Setup — Mounting Position No 2*

The test setup shall be in accordance with 4.7.2.1.2.

4.7.2.9.6 *Test Method — Mounting Position No 2*

1) With the dividing head set at 0°, record the accelerometer output as $E_{0°}$
2) Rotate the dividing head 180° ± _______ arc seconds and record the accelerometer output as $E_{180°}$
3) Calculate the misalignment angle δ_p using the following equation:

$$\delta_p = \frac{E_{0^\circ} - E_{180^\circ}}{2K_1} \qquad \text{rad}$$

where δ_p is the misalignment angle of the input axis with respect to the input reference axis about the pendulous reference axis in radians.

> The misalignment angles as obtained above include angular errors of the mounting fixture, dividing head errors, and errors in mounting as well as the misalignment between the input reference axis and the input axis. There is no way of distinguishing between a misalignment and a cross axis sensitivity. An alternate method is to align the IRA parallel to the horizontal dividing head rotation axis, and to obtain measures of indicated acceleration at each of the four cardinal case positions.

4.7.2.9.7 *Test Results*

The misalignment angles shall conform to the requirements of 3.3.6.

4.7.2.10 *Static Multipoint Test*

> See Appendix B for a discussion of the multipoint test. Because of the limited acceleration range 2*g*, the static multipoint test may not determine the nonlinear and cross coupling coefficients with sufficient accuracy. Other test techniques may be utilized to determine these coefficients, for example, the precision centrifuge test.

4.7.2.10.1 *Purpose*

The purpose of this test is to determine the linearity of the accelerometer input/output function over the test range of ± 1*g*.

4.7.2.10.2 *Test Equipment*

The following equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixtures
2) Electronic equipment required to operate the accelerometer and to measure its output

4.7.2.10.3 *Test Setup, Position No 1*

The test setup shall be in accordance with 4.7.2.1.1.

4.7.2.10.4 *Test Method — Mounting Position No 1*

1) Record the accelerometer output E_j at dividing head angles θ_j. The tolerance on the setting of the angles is ± _____ arc seconds. Measurements will be made at _____°, _____°, _____°, _____° and _____°

> Angles θ_j are chosen to provide approximately equal increments of acceleration in all four test quadrants and to include the 90° and 270° positions (that is, input axis (IA) up and IA down).

2) The normalized input X can be expressed in units of g:
   $X_j = 1\ g \sin(\theta_j + \beta)$
   where

   X_j = acceleration input, in g
   θ_j = table angle, in radians
   β = input axis misalignment in plane of rotation, in radians

3) Assume: $E_j = C_0 + C_1 X_j$
   where

   E_j = accelerometer output, in pulses per second
   C_0 = bias, in pulses per second
   C_1 = scale factor, in (p/s)/g

4) Then: $E_j = C_0 + C_1 \sin(\theta_j + \beta)$.
   Assuming β is constrained by test setup to less than 1 mrad and utilizing the small angle approximations for the sine and cosine functions gives:
   $E_j \cong C_0 + C_1 \sin\theta_j + C_1\beta \cos\theta_j$
5) By the method of least squares estimate C_0, C_1, and $C_1\beta$
6) Calculate β from the values obtained for C_1 and $C_1\beta$ and then compute X_j by means of the equation given in paragraph (2)
7) Normalize the indicated acceleration E_j into units of g by computing the two point scale factor from the 90° and 270° test data

$$Y_j = \frac{E_j}{K_{1(2p)}} \qquad g$$

$$K_{1(2p)} = \frac{E_{90^\circ} - E_{270^\circ}}{2} \qquad (\mathrm{p/s})/g$$

8) Compute $Y_j - X_j$ and plot this difference against X_j
9) Examine the resultant plot to estimate the form of the accelerometer input/output function

Refer to Appendix B, Section B4, for a discussion of this procedure.

10) Fit the selected model equation, including a new estimate of β, to the original test data by the method of least squares.

4.7.2.10.5 *Test Setup Position No 2*

The test setup shall be in accordance with 4.7.2.1.2.

4.7.2.10.6 *Test Method — Mounting Position 2*

Repeat 4.7.2.10.4 utilizing the new mounting position.

4.7.2.10.7 *Test Results*

1) Using the coefficients obtained from the tests taken in the two mounting positions, compute the final estimates of each of the model equation coefficients, the unbiased estimate of the standard deviation of the residuals, and the standard errors of the coefficients.
2) The best estimate of the lower model equation coefficients shall conform to the requirements paragraphs as noted:

K_0	3.3.5
K_1	3.3.4
δ_o	3.3.6
δ_p	3.3.6

δ_o and δ_p can be estimated by removing the known misalignment between the appropriate reference axis and the dividing head angular readout from the applicable β estimate. The best estimate of the higher order coefficients K_2, K_3, K_{ip}, and K_{io} should be examined for consistency with their respective requirements. The resulting coefficient standard errors are related to uncertainties associated with the test and, as stated in 4.7.2.10, may be inconsistent with specified requirements.

4.7.2.11 *Centrifuge Input Range Test*

4.7.2.11.1 *Purpose*

The purpose of this test is to establish that the instrument input acceleration range is equal to or greater than the specified value.

4.7.2.11.2 *Test Equipment*

The following equipment specified in 4.6 is required for this test:

1) Mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output
3) Centrifuge

4.7.2.11.3 *Test Setup — Mounting Position A*

1) Unless otherwise specified, the accelerometer shall be operated under the standard test conditions of 4.5 for operative closed loop tests
2) The axis of rotation of the centrifuge shall be vertical within _____ arc minutes
3) Attach the accelerometer to the mounting fixture on the centrifuge arm with the input reference axis normal to the centrifuge axis within _____ arc minutes and pointing toward the rotation axis (positive input acceleration); determine and record the nominal radius from the centrifuge axis to the effective center of mass for angular velocity within _____ cm
4) The accelerometer and the immediate environment shall be allowed to reach thermal equilibrium as evidenced by the stability of the accelerometer output within _____ pps for _____ measurements spaced _____ min apart before proceeding with the test

4.7.2.11.4 *Test Method — Mounting Position A*

1) Apply a centripetal acceleration of _____ ± _____ g
2) Record the accelerometer output

4.7.2.11.5 *Test Setup — Mounting Position B*

Same as 4.7.2.11.3, above, except that the direction of the input reference axis shall be reversed (negative input acceleration).

4.7.2.11.6 *Test Method — Mounting Position B*

1) Apply a centripetal acceleration of _____ ± ____ *g*
2) Record the accelerometer output

4.7.2.11.7 *Test Results*

The accelerometer outputs shall conform to the requirements of 3.3.2.

4.7.2.12 *Precision Centrifuge Test*

4.7.2.12.1 *Purpose*

The purpose of this test is to determine the magnitude of the acceleration-sensitive model equation coefficients K_2 and K_3.

> Precision centrifuge tests are also applicable for the determination of cross coupling terms of the model equation. When measuring these coefficients, additional orientations of the accelerometer with respect to the centripetal acceleration vector are required. Centrifuge testing is generally not required for accelerometers with low input ranges (for example, less than ± 2*g*).

4.7.2.12.2 *Test Equipment*

Same as 4.7.2.11.2 except use a precision centrifuge and timing equipment to measure the centrifuge period.

4.7.2.12.3 *Test Setup — Mounting Position A*

1) Unless otherwise specified, the accelerometer shall be operated under the standard test conditions of 4.5
2) The axis of rotation of the centrifuge shall be vertical within _____ arc seconds
3) Attach the accelerometer to the mounting fixture on the centrifuge arm with the input reference axis normal to and pointing toward the centrifuge rotation axis within _____ arc seconds (positive input acceleration); determine and record the nominal radius from the centrifuge axis to the effective center of mass for angular velocity.
4) Starting procedure

> State sequence of operations required to bring accelerometer and test equipment to operating conditions.

4.7.2.12.4 *Test Method — Mounting Position A*

1) Set the centrifuge angular rate to a value equivalent to a centripetal acceleration at the effective center of mass for angular velocity of _____ *g*, nominally
2) Measure and record the average accelerometer output and the centrifuge period
3) Repeat steps (1) and (2) at nominal centripetal acceleration levels of _____, _____, _____, …, and _____ *g*

4.7.2.12.5 *Test Setup — Mounting Position B*

Same as 4.7.2.12.3, above, except that the direction to the input reference axis shall be reversed (negative input acceleration).

4.7.2.12.6 *Test Method — Mounting Position B*

Same as 4.7.2.12.4, above.

4.7.2.12.7 *Test Results*

Perform an analysis of the input versus indicated acceleration data in order to obtain values of the acceleration sensitive model equation coefficients and test residuals. The resulting coefficients shall conform to the requirements of 3.3.7.

> The measurement precision is directly related to the test accuracy desired, and careful attention must be given to these considerations when designing a centrifuge test. In some cases it may be necessary to measure the arm compliance (arm bending and change in arm length) which occurs between the test acceleration levels. Equipment to perform these measurements is usually provided as part of the centrifuge apparatus. The test procedure or analysis, or both, must be designed to minimize the impact of these effects as well as uncompensated changes in centrifuge radius and the accelerometer attitude relative to gravity which might occur between the various orientations used during the test. Errors in the derived values of the model equation coefficients may occur if these effects are not removed or compensated.

> Residuals (differences between the actual data points and the fitted curves) may be examined in order to verify that the accelerometer response reasonably reflects the model equation utilized.

4.7.2.13 *Turn-On Hysteresis*

4.7.2.13.1 *Purpose*

The purpose of this test is to determine the displacement hysteresis associated with moving the pendulum from either stop to the operating null position as a result of power turn on.

4.7.2.13.2 *Test Equipment*

The following test equipment is required for this test.

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output
3) Equipment required to establish the specified ambient environment

4.7.2.13.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.2.

4.7.2.13.4 *Test Method*

1) Set the dividing head at 0°
2) Energize the accelerometer
3) Rotate the dividing head to 90°
4) Remove the accelerometer power for _____ s, and then restore the accelerometer power
5) Rotate the dividing head smoothly to 0°
6) Measure and record the accelerometer output for _____ s
7) Rotate the dividing head to 270°
8) Repeat (4) through (6)
9) Calculate the turn-on hysteresis Hy:

$$\text{Hy} = \frac{E_{01} - E_{02}}{K_1} \qquad g$$

where

E_{01} = accelerometer output at 0° after turn on at 90°, in pulses per second

E_{02} = accelerometer output at 0° after turn on at 270°, in pulses per second

K_1 = scale factor obtained from 4.7.2.4

4.7.2.13.4 *Test Results*

The accelerometer turn-on hysteresis shall conform to the requirements of 3.3.12.

4.7.2.14 *Threshold, Resolution, and Dead Zone*

4.7.2.14.1 *Purpose*

The purpose of this test is to determine if the changes in accelerometer output are greater than the specified values for given changes in input acceleration level.

4.7.2.14.2 *Test Equipment*

The following equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output

4.7.2.14.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.2. Care should be taken to rotate the dividing head slowly and smoothly between positions.

4.7.2.14.4 *Test Method — Threshold*

1) Rotate the dividing head to the 0° position (zero *g* input) within _______ arc seconds and record the accelerometer output E_0
2) Rotate the dividing head + _______ arc seconds in steps of _______ arc seconds and record at each step the accelerometer output E_j
3) Rotate the dividing head — _______ arc seconds in steps of _______ arc seconds from the 0° position and record at each step the accelerometer output E_j
4) Calculate the indicated changes in acceleration at each input angle

$$\Delta A_{\text{ind}} = \frac{E_0 - E_j}{K_1} \qquad g$$

where

K_1 = scale factor obtained from 4.7.2.4.

E_0 = accelerometer output at 0° ποσιτιον, ιν πυλσεσ περ σεχονδ

E_j = accelerometer output at the *j*th test position, in pulses per second

5) Calculate the input acceleration at each input angle

$$A_{\text{input}} = g \sin \theta \qquad g$$

where θ is the input angle

6) Tabulate A_{input} and ΔA_{ind} for each input angle

Threshold is the smallest input acceleration at which ΔA_{ind} is at least 50 percent of the input. Record threshold for both positive and negative inputs.

4.7.2.14.5 *Test Method — Resolution*

1) Rotate the dividing head to the 90° position (one g input) within _______ arc minutes ($E_{90°}$)
2) Rotate the dividing head + _______ arc minutes in steps of _______ arc minutes and record at each step the accelerometer output (E_j)
3) Rotate the dividing head — _______ arc minutes in steps of _______ arc minutes from the 90° position and record at each step the accelerometer output (E_j)

Other additional input acceleration levels may be utilized if desired.

4) Calculate the indicated changes in acceleration at each input angle

$$\Delta A_{ind} = \frac{E_{90°} - E_j}{K_1} \qquad g$$

where
K_1 = scale factor obtained from 4.7.2.4
E_{90} = accelerometer output at 90° ποσιτιον, ιν πυλσεσ περ σεχονδ
E_j = accelerometer output at the jth test position, in pulses per second

5) Calculate the change in input acceleration (from 90°) at each input angle

$\Delta A_{input} = g \Delta\theta \cos\theta$

where
θ = angle between the positive input axis and the horizontal, in degrees
$\Delta\theta$ = angular increment from the angle θ, in radians

6) Tabulate ΔA_{input} and ΔA_{ind} for each input angle; resolution is the smallest ΔA_{input} at which ΔA_{input} is at least 50% of the ΔA_{input}; record resolution for both directions of input rotation
7) Repeat steps (1) through (6) at the 270° position (minus one g input)

4.7.2.14.6 *Test Method — Dead Zone*

1) Rotate the dividing head to the angle which produces zero indicated output pulses during a period of _______ s

A digital accelerometer instrumented with a pulse rate output per input acceleration scaling can resolve no less than one pulse. Each output pulse represents an increment of velocity. It would theoretically be necessary to wait an infinite time period to define zero indicated acceleration. For this test, a measurement period corresponding to a detectable acceleration of 50% of the specified dead zone is recommended.

$$\text{measurement period} = \frac{\begin{array}{c}\text{minimum unit of}\\ \text{velocity increment } [g \cdot \text{s},\ \text{m/s}]\end{array}}{\text{desired acceleration resolution } [g,\ \text{m/s}^2]}$$

2) Rotate the dividing head clockwise in increments of _______ arc seconds; continue until three pulses occur during the measurement period

3) Rotate the dividing head counterclockwise in increments of _______ arc seconds; at each angle record the number of output pulses during a period of _______ seconds; and continue three pulses of the opposite sign to those detected in step (2) above are detected
4) Calculate the absolute value of the dead zone as follows: dead zone = $g\ [(\sin \theta_3 - \sin \theta_2) - \delta_p (\cos \theta_3 - \cos \theta_2)]$
where
δ_p = misalignment angle determined by the method described in 4.7.2.9.6
θ_2, θ_3 = the angles in degrees determined in (2) and (3) above, respectively.

4.7.2.14.7 *Test Results*

Threshold, resolution, and dead zone shall conform to the requirements of 3.3.9, 3.3.10, and 3.3.11, respectively.

4.7.2.15 *Velocity Storage*

4.7.2.15.1 *Purpose*

The purpose of this test is to determine the maximum velocity stored in the accelerometer for normal operation and to verify that minimum velocity storage requirements are met.

4.7.2.15.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Shock machine with shock recording instrumentation
2) Dividing head and mounting fixture
3) Electronic equipment required to operate the accelerometer and to measure its output
4) Digital recorder for recording each output pulse in real time and associated readout and data processing equipment

4.7.2.15.3 *Test Setup — Normal Operation*

The test setup shall be in accordance with 4.7.2.1.2.

4.7.2.15.4 *Test Method — Normal Operation*

1) Rotate the dividing head to the 0° position (zero g input) within _______ arc seconds
2) Record accelerometer output pulses in real time for a period of _______ s
3) Compute the average acceleration output of the accelerometer over the specified measurement period
4) Compute velocity versus time using the acceleration computed in step (3) above
5) Compare indicated velocity (summation of output pulses) with the computed velocity of step (4) above after each pulse recorded during the measurement period (normal velocity storage is the peak difference)

> Other or additional input acceleration levels may be utilized if desired.

4.7.2.15.5 *Test Setup — Overrange Operation*

1) Mount the accelerometer on the shock machine such that its input axis is parallel to the direction of applied shock within _______ °
2) Program the shock machine for desired shock profile

4.7.2.15.6 *Test Method — Overrange Operation*

1) Energize the accelerometer. The accelerometer and the immediate environment shall be allowed to reach thermal equilibrium as evidenced by the stability of the accelerometer output being within _______ p/s for _______ measurements spaced _______ min apart before proceeding with the test
2) Compute the average acceleration during the _______ s measurement period prior to the application of the shock
3) Using the average acceleration computed in step (2) above, compute the velocity to a point in time _______ s after the application of the shock
4) Compare indicated velocity (summation of output pulses) computed velocity _______ s after the application of the shock. The difference shall not exceed _______ output pulses

> If the accelerometer satisfactorily stores the overrange velocity input produced by the initial shock impulse, the total indicated velocity gained or lost by the instrument as a result of the total shock profile will be zero. The test is preferably run on a vertical axis shock machine. If the motion and sensing axes are horizontal, large errors may occur as a result of alignment instability in the shock machine.

5) If the requirements of paragraph (4) above are met, record the value of the positive shock profile (integral of positive acceleration versus time) exceeding the input range of the accelerometer, as overrange velocity storage

4.7.2.15.7 *Test Results*

The accelerometer velocity storage for normal and overrange operation shall conform to the requirements of 3.3.13.1 and 3.3.13.2, respectively.

4.7.2.16 *Frequency Response*

4.7.2.16.1 *Purpose*

The purpose of this test is to determine the equivalent linear amplitude and phase response of the accelerometer.

4.7.2.16.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output
3) Equipment required to establish the specified ambient environment; a transfer function analyzer

4.7.2.16.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.2.

4.7.2.16.4 *Test Method*

> This current-torque test method is valid only for input frequencies which are low compared with acceleration torquing transition frequencies. This method is not possible for accelerometers which do not have a torquer test point and is of limited accuracy for accelerometers which have a high torquer impedance. In these cases, a vibratory or other physical input is recommended.

1) Set the dividing head at 0°

2) Insert a sinusoidal torquing current of _______ ± _______ mA peak, _______ ± _______ Hz across the torquer winding (or self-test torquer)

This driving current should be provided by a floating current source.

3) Connect the transfer function analyzer to the digital output
4) Measure and record the output amplitude and phase with respect to the driving signal
5) Repeat at _______, _______, _______, and _______ Hz
6) Compute the amplitude response in decibels and the phase lag for the above frequencies, using the first frequency [step (4)] as the reference

4.7.2.16.5 *Test Results*

The accelerometer frequency response shall conform to the requirements of 3.3.14.

4.7.2.17 *Self-Test Scale Factor*

4.7.2.17.1 *Purpose*

The purpose of this test is to determine the scale factor of the self-test circuit.

4.7.2.17.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Dividing head and mounting fixture
2) Electronic equipment required to operate the accelerometer and to measure its output
3) DC current supply

4.7.2.17.3 *Test Setup*

The test setup shall be in accordance with 4.7.2.1.2 except that the dividing head shall be set at 0°.

4.7.2.17.4 *Test Method*

1) Apply _______ ± _______ mA dc to the self-test circuit; record the accelerometer output as E_1

Specify a current which will not damage the accelerometer.

2) Reverse the polarity of the applied self-test current; record the accelerometer output as E_2
3) Calculate the self-test scale factor K_s by

$$K_s = \frac{E_1 - E_2}{2I_s} \qquad (\mathrm{p/s})/\mathrm{mA}$$

where

I_s = self-test current, in milliamperes
E_1, E_2 = accelerometer outputs, in pulses per second

4.7.2.17.5 *Test Results*

The self-test scale factor shall conform to the requirements of 3.3.16.

4.7.2.18 *Magnetic Leakage*

4.7.2.18.1 *Purpose*

The purpose of this test is to determine the magnitude of the magnetic field(s) emanating from the accelerometer.

4.7.2.18.2 *Test Equipment*

The following test equipment specified in 4.6 is required for this test:

1) Electronic equipment required to operate the accelerometer
2) Magnetic field measuring equipment
3) Nonmagnetic mounting fixture

> The earth's magnetic field will influence the measurements. If this effect is significant, shielding or compensation should be specified.

4.7.2.18.3 *Test Setup*

Secure the nonmagnetic mounting fixture to a suitable base. Install the accelerometer.

4.7.2.18.4 *Test Method*

1) Stabilize the accelerometer at the standard test conditions of 4.5
2) Measure the magnetic leakage in all directions at a distance of _______ m from the entire surface of the accelerometer package(s)
3) Record the maximum leakage and location

4.7.2.18.5 *Test Results*

The leakage shall conform to the requirements of 3.2.2.6

4.7.3 Environmental Tests

4.7.3.1 *Purpose*

The purpose of these tests is to verify that the accelerometer performs as specified during or before and after, or both, exposure to environments in excess of the standard operating condition, but within the specified environmental limits.

4.7.3.2 *Test Equipment*

The following test equipment must be included for each environmental test:

1) Equipment for providing the specified environment
2) Means of measurement of environment and time
3) Adaptation of accelerometer to environmental equipment such as special holding fixtures, cables, etc
4) Equipment for each accelerometer test, chosen from 4.7.1 and 4.7.2

4.7.3.3 *Test Procedure and Results*

Detail the procedure for the control of the environment, including tolerances and rates of change, integrated with the procedure for the accelerometer test. Caution notes on overload limits on the environmental intensity applied to the accelerometer can be specified if required. Compliance with the specification performance requirements should be demonstrated prior to, during if appropriate, and upon completion of the environmental test sequence.

Procedures for most environmental tests are well covered by existing industry, government, and military documents such as MIL-E-5272, Environmental Testing, Aeronautical and Associated Equipment. Rather than duplicate samples of existing procedures, the present standard provides (in Fig 3) assistance in selecting the accelerometer parameters which will be most important to measure in each environment. This selection is made based on the expected environmental sensitivities of the accelerometer and the cost-effectiveness of the testing.

The application of the accelerometer will determine which tests or combinations of tests, are to be performed and their sequence. The table is intended as a guide for selection of the accelerometer test which should be conducted in association with the environmental tests which are chosen dependent on the application of the accelerometer. In some cases it may be desirable to combine environments in order to simulate the expected operating conditions.

4.8 Data Submittal

The format for all data organization and the method of submittal shall be specified.

5. Preparation for Delivery

Give detailed procedures for: (1) preservation and packaging, (2) packing, and (3) marking of shipping containers. A common United States specification covering preservation and packaging is MIL-P-116. Other organizations use different supporting documents.

6. Notes

6.1 Intended Use

Describe application if it is considered necessary or helpful.

6.2 Ordering Data

Procuring documents should specify the title, number, and date of this specification. In addition, the following, or other items, should be specified as applicable:

1) Level of packaging and packing desired
2) Mode of shipment required
3) Whether sampling plan tests are to be conducted
4) Number of preproduction samples to be submitted for qualification testing
5) Data package

	Accelerometer Tests																								
Environmental Tests	4.7.1.1 Examination of Product	4.7.1.2 Weight	4.7.1.3 Seal	4.7.1.4 Impedance	4.7.1.5 Dielectric Strength	4.7.1.6 Insulation Resistance	4.7.2.2 Electrical Interface	4.7.2.3 Warm-up Time	4.7.2.4 Scale Factor and Bias	4.7.2.5 Short Term Stability	4.7.2.6 Long Term Stability	4.7.2.7 Repeatability	4.7.2.8 Sensitivity	4.7.2.9 Input Axis Misaligment	4.7.2.10 Static Multipoint Test	4.7.2.11 Centrifuge Input Range Test	4.7.2.12 Precision Centrifuge Test	4.7.2.13 Turn-on Hysteresis	4.7.2.14 Threshold, Resolution and Dead Zone	4.7.2.15 Velocity Storage	4.7.2.16 Frequency Response	4.7.2.17 Self-Test Torquer Scale Factor	4.7.2.18 Magnetic Flux Leakage	Monitor Indicated Acceleration	Comment
4.7.3.3.1 Electromagnetic Interference							D		O															D	
4.7.3.3.2 Electromagnetic Compatibility							D		O															D	
4.7.3.3.3 Temperature (High-Low)	N,O				N	N	N,O,D	D	N	N,O			D	N	N,O					D				D	
4.7.3.3.4 Thermal Shock	N,O		N,O				N,O		N	N,O				N	N,O										
4.7.3.3.5 Vibration	N,O		N,O	N,O	N,O	N,O	N,O,D		N,O	N,O				N,O	N,O				N,O		D			D	
4.7.3.3.6 Mechanical Shock	N,O		N,O	N,O	N,O	N,O	N,O		N	N,O				N	N,O				N,O					D	
4.7.3.3.7 Pressure (High Low)	N,O						N,O,D		N,O				D	N,O	N,O										
4.7.3.3.8 Magnetic Fields							D		O				D	O									N,O	D	
4.7.3.3.9 Humidity	N					N																			
4.7.3.3.10 Acceleration	N,O						N,O,D		N	N,O				N	N,O	O	D								
4.7.3.3.11 Acoustic Noise			O	O	O	O	D		N,O	O				N,O	O				O					D	
4.7.3.3.12 Operating Life	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	D	
4.7.3.3.13 Storage Life	N		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N		
4.7.3.3.14 Nuclear Radiation	N,O	N,O	N,O	N,O	N,O	N,O	N,O	N,O	N,O	N,O				N,O	N,O				N,O	N,O	N,O			D	
4.7.3.3.15 Thermal Radiation							N,O,D		N,O					N,O	N,O									D	
4.7.3.3.16 Other																									

Code:

O Accelerometer tests conducted before and after specified environment and accelerometer operated during environment.

N Accelerometer tests conducted before and after specified environment and accelerometer not operated during environment.

D Accelerometer tests conducted during specified environment and accelerometer is operating or non-operating as applicable.

Figure 3—Suggested Digital Accelerometer Environmental and Test Combinations

6.3 Model Equation

A model equation of an accelerometer is defined as a series which mathematically relates the output to the components of acceleration applied parallel and normal to the sensor’s input reference axis. Two example equations with each term expressed in units of *g* are:

$$A_{\text{ind}} = \frac{E}{K_1} = K_0 + a_i + K_2 a_{\text{i}}^2 + K_3 a_{\text{i}}^3 + \delta_o \mathrm{a}_p + K_{ip} a_i a_p - \delta_p a_o + K_{io} a_i a_o \qquad (1)$$

(conventional higher order nonlinearity and cross coupling model)

or

$$A_{\text{ind}} = \frac{E}{K_1 \zeta_{+} + K_1' \zeta_{-}} = K_0 + a_i + \delta_o \mathrm{a}_p - \delta_p a_o \qquad (2)$$

(asymmetrical scale factor model)

where

A_{ind} = acceleration indicated by the accelerometer, in *g*
E = output, in pulses per second
a_i = applied acceleration[1] component along the positive input reference axis, in *g*
a_p = applied acceleration[1] component along the positive pendulous reference axis, in *g*
a_o = applied acceleration[1] component along the positive input reference ence axis, in *g*
K_0 = bias, in *g*
K_1 = scale factor for Eq (1) or scale factor for $a_i > 0$, Eq (2), in (p/s)/*g*
K_1' = scale factor for $a_i < 0$, in (p/s)*g*
K_2 = second order nonlinearity coefficient, in g/g^2
K_3 = third order nonlinearity coefficient, in g/g^3
δ_{o}, δ_p = misalignment of the input axis with respect to the input reference axis about the output and pendulous axes, respectively, in radians
K_{ip}, K_{io} = cross coupling coefficients, in (*g*/*g*)/cross *g*
ζ+ = 1 and ζ_ 0 for $a_{\text{i}} > 0$
ζ+ = 0 and ζ_ 1 for $a_{\text{i}} < 0$

---

[1] Applied acceleration refers only to nongravitational acceleration since an accelerometer cannot sense the acceleration of free fall. For an earthbound accelerometer, the attractive force of gravity acting on the proof mass must be treated as an applied upward acceleration of 1 *g*.

In general, only one model equation representative of the design would be specified. The coefficients of the model equation may be functions of other variables such as voltage, temperature, time, angular velocity, angular acceleration, etc. Some of the above terms may be deleted or others added as appropriate for the type of accelerometer and its applications, for example, in a spinning vehicle, angular accelerations and rates can introduce significant errors in the output of a strapdown accelerometer. In some cases it may be desirable to model some coefficients with sufficient accuracy that they may be used to compensate the accelerometer output. In these cases, modeling uncertainties such as test repeatability and coefficient standard error should be considered. Only a sufficient number of terms should be used that will adequately describe the response.

In those cases where the forcing function is the local gravity vector, it should be noted that the magnitude of gravity varies with location, including the effect of altitude, and it is necessary to normalize the measured coefficients to a standard value of gravity or other unit of acceleration, when comparing data obtained at different test locations.

6.4 Definitions

The following definitions are provided for convenience in using this standard. Additional definitions are found in ANSI/IEEE Std 100-1977 .

binary pulse width modulation torquing: A torquing technique in which the time between (positive, negative) torquing transitions is constant.

binary torquing: System with two stable torquing states (for example, positive and negative.

clock reference: Basic system timing reference.

effective center of mass for angular acceleration: That location at which the accelerometer exhibits minimum sensitivity to angular acceleration about an axis parallel to the output axis.

effective center of mass for angular velocity: That location at which the accelerometer exhibits minimum sensitivity to angular velocity.

output pulse: A pulse which represents the minimum unit of velocity increment ($g \cdot$s, m/s).

ternary torquing: System with three stable torquing states (for example, positive, negative and off).

unit of acceleration — *g*: The symbol g denotes a unit of acceleration equal in magnitude to the local value of gravity at the test site unless otherwise specified.

velocity storage: The velocity information which is stored in the accelerometer as a result of its dynamics.

velocity storage, normal: The velocity information that is stored in the accelerometer during the application of an acceleration within its input range.

velocity storage, overrange: The velocity information that can be stored in the accelerometer during the application of an acceleration exceeding its input range.

Annex A

Accelerometer Dynamic Block Diagram

(Informative)

(These Appendixes are not a part of IEEE Std 530-1978, Standard Specification Format Guide and Test Procedure for Linear, Single-Axis, Digital, Torque-Balance Accelerometer.)

This appendix presents a typical block diagram for the dynamic response of the accelerometer, when operating in the closed loop mode of operation. An idealized linear second order model is assumed for the acceleration sensor's pendulum. The symbols used in Fig A.1 are defined as follows:

K_t = torquer scale factor, in [N·m/A, dyn·cm/A]
R = torquer resistance, in ohms
L = torquer inductance, in henries
s = Laplacian operator
J = moment of inertia of pendulum about the output axis, in [N·m/(rad/s^2), dyn·cm/(rad/s^2]
C = damping torque coefficient, in [N·m/(rad/s), dyn·cm/(rad/s)]
K_e = pendulum elastic restraint, in [N·m/rad, dyn·cm/rad]
$K_{\mathrm{po}}(s)$ = transfer function of pickoff, in V/rad
$T_i(s)$ = Laplace transform of driving torque, in [N·m, dyn·cm]
$\theta_{\mathrm{po}}(s)$ = Laplace transform of angular displacement of pendulum with respect to case, in radians
$V_{\mathrm{po}}(s)$ = Laplace transform of pickoff output voltage, in volts
$a(t)$ = applied acceleration along the input axis, in *g*
$A(s)$ = Laplace transform of applied acceleration $a(t)$, in *g*
p = pendulousity, in [N·m/*g*, dyn·cm/g]
$T_r(s)$ = Laplace transform of capture torque, in [N·m, dyn·cm]
$T_e(s)$ = Laplace transform of error torque, in [N·m, dyn·cm]

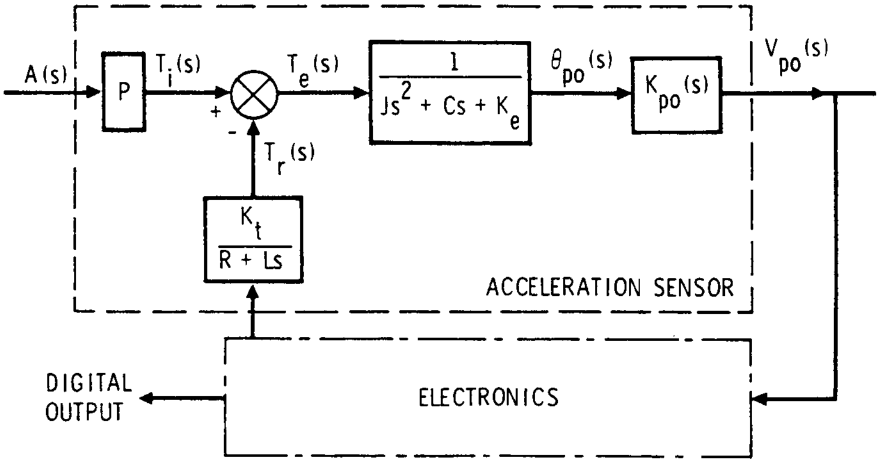


Figure A.1—Block Diagram for Closed Loop Operation

Annex B

Notes on Accelerometer Static Multipoint Testing and Data Reduction

(Informative)

B.1 Introduction

The purpose of this appendix is to present a discussion of the multipoint test and suggested data, as described in [1].[2] This approach offers potential pitfalls. This simple test is a very useful technique for estimating the input/output function of an accelerometer. The resulting data can be easily reduced with the aid of a small digital computer.

B.2 Discussion

Traditionally, Fourier analysis techniques have been utilized to reduce multipoint test data, as described in [1]. This approach offers relative ease of coefficient computation, but it suffers from a number of disadvantages.

1) The procedure limits the form of the model equation to a smooth curve which contains a bias, scale factor, and error terms consisting of coefficients times powers of combinations of input and cross accelerations. The terms associated with this curve cannot, singly or in combination, directly model unconventional nonlinearities such as scale factor or bias asymmetries, or both, which are sometimes observed in the output of digital accelerometers.
2) The test data is biased to the plus and minus 1 *g* ends of the input scale because the data is taken at equal increments of angle.
3) Deleting "bad" data points invalidates the simplified data reduction procedure. Therefore, if one or more of the data values are inconsistent with the remainder of the data (for example, if they are in error), "corrected" values must be supplied.

The test procedure described herein departs from the traditional Fourier analysis approach in order to gain a number of important advantages. The test angle increments are not constrained to be equal. This allows the input data to be approximately equally spaced in acceleration to facilitate detection of nonlinearities such as asymmetries in scale factor and bias. If desired, the test can be conducted so as to emphasize certain regions within the ± 1 *g* range in order to more carefully examine discontinuities. In addition, a small number of "bad" data points can be detected and removed and the remaining measurements resubmitted to the fitting routine with minimal impact on the results.

The approach is to assume that the input/output function is represented by a *simple straight line*. The reduction then proceeds with a technique designed to identify the form of observable higher order nonlinearities. This observation leads to an improved analytical model which then can be fitted to the data to obtain the final estimates for the coefficients. Ideally, the resulting model is that with the simplest form which "best" fits the data utilizing a minimum number of terms. Obviously, selecting the "best" fit involves subjective considerations and, depending on the characteristics of the data noise, more than one model may fit the data about equally well. In some cases, other test techniques may be needed to resolve these situations.

B.3 Suggested Test Method

The suggested test procedure is basically outlined in [1]. The main difference relative to that of the reference is that test angles should be initially chosen which provide nominally equal increments of acceleration with the desired granularity between data points. Generally, the test angles are selected at equal nominal input amplitudes in all four

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[2] The numbers in brackets correspond to those of the references listed in Section B.6 of this appendix.

test quadrants, and the input axis (IA) up and down positions are included although these constraints are not mandatory.

Since the sensor mounting orientation on the dividing head controls which cross axis experiences the component of acceleration that is perpendicular to the input axis, it is necessary to perform the multipoint test with each cross axis parallel to the table axis in order to detect all of the significant model equation coefficients. Thus a minimum of two test orientations are required.

B.4 Data Reduction Method

This section describes a recommended technique for reduction of multipoint test data. The approach is to subtract a straight line from the input/output data and then examine the differences plotted against input to estimate the form of the nonlinearity. With this information, a more complex model is selected which can then be fitted to the input/output data to obtain best estimates of the coefficients. The residuals and estimates of the coefficient uncertainties can also be computed.

B.4.1 Computaton of Acceleration Input

The first step in the data reduction process is to obtain an estimate of the test input axis misalignment β which is then used to compute the acceleration input at each test position X. The discussion which follows assumes that the dividing head sensor alignment is set so that nominally zero degrees corresponds to IA horizontal and 90° corresponds to IA up. An estimate of the IA misalignment is obtained by least squares fitting the following equations to the data:

$$E = \mathrm{C}_0 + C_1 \sin\theta + C_1\beta\cos\theta \tag{B-1}$$

where

E = accelerometer output, in accelerometer output units
θ = test angle, in radians
C_0 = bias, in accelerometer output units
C_1 = scale factor, in accelerometer output units per g
β = total test IA misalignment, in radians

Obtain the normalized input acceleration at each test position by means of the following equation:

$$X_j = 1\ g \sin(\theta_j + \beta) \qquad g \tag{B-2}$$

where X_j is the acceleration input associated with the jth test position, in g, and β is the estimate of the total test IA misalignment obtained above.

B.4.2 Normalization of Indicated Acceleration and Initial Identification of Nonlinearity

The next step in the data reduction process is to normalize the indicated acceleration E into units of g. This is done by computing the two point scale factor $K_{1(2P)}$ from the test data taken IA up and IA down (90° and 270°).

$$K_{1(2P)} = \frac{E_{90^\circ} - E_{270^\circ}}{2} \quad \text{accelerometer output units per } g \tag{B-3}$$

The two point scale factor is used to normalize E as follows:

$$Y_j = \frac{E_j}{K_{1(2P)}} \qquad g \tag{B-4}$$

The multipoint data originally obtained as a list of E_j with corresponding θ_j has now been converted to Y_j and X_j, both expressed in units of g.

In order to observe any nonlinearities present in the input/output data, compute the quantity $Y_j — X_j$ and plot it against X_j. It can be shown that this plot represents the two point calibration line (obtained from the $\theta_{90°}$ and $\theta_{27°}$ points) rotated to the horizontal along with related rotations of the other data values (see [2]). The geometric relationship between the data points and the two point calibration line has not been distorted, however, the vertical range has been greatly reduced because the dominant response of the instrument (1.000000X) has been subtracted from the output. The remainder is small (ideally zero) and can be plotted on a greatly expanded scale for examination. An example depicting this process is shown in Fig B.1.

An ideal accelerometer with no output noise will have a ($Y — X$) versus X plot which is a horizontal straight line. If noise is present, the $(Y — X)_{90°}$ and $(Y — X)_{270°}$ points will lie on a horizontal line as before, by definition, and the other points will be scattered randomly about this line. These cases, along with other examples of nonlinearity forms, are shown in Fig B.2. If a bad data point is present, it will show up as being inconsistent with the other points and can be eliminated from the data file. In this case, the value of β should be re-estimated, and X_j and $(Y_j — X_j)$ recomputed and plotted. If the bad point happens to be either $E_{90°}$ or $E_{270°}$, other test data can be used instead for the normalization of Y.

Within the limitations imposed by the noise present in the data, examination of the plot of ($Y — X$) versus X should provide insight as to the possible forms of nonlinearity present in the input/output function. The observed nonlinearities are then expressed as coefficients and used to modify the original linear model to form a revised model equation, which is then fitted to the original data pairs.

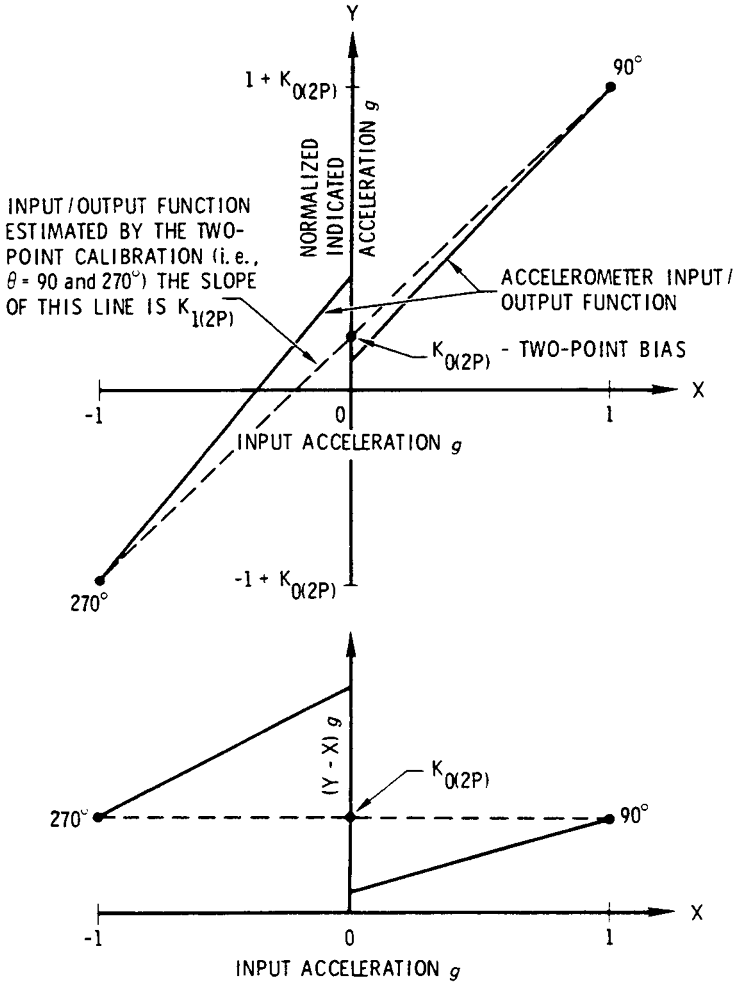

Figure B.1—Noise-Free Example Which Illustrates the Geometric Relationship Between the Original Input/Output Function and the (*Y* — *X*) Versus *X* Plot (Scale Factor and Bias Asymmetries are Present in the Example Input/Output Function.)

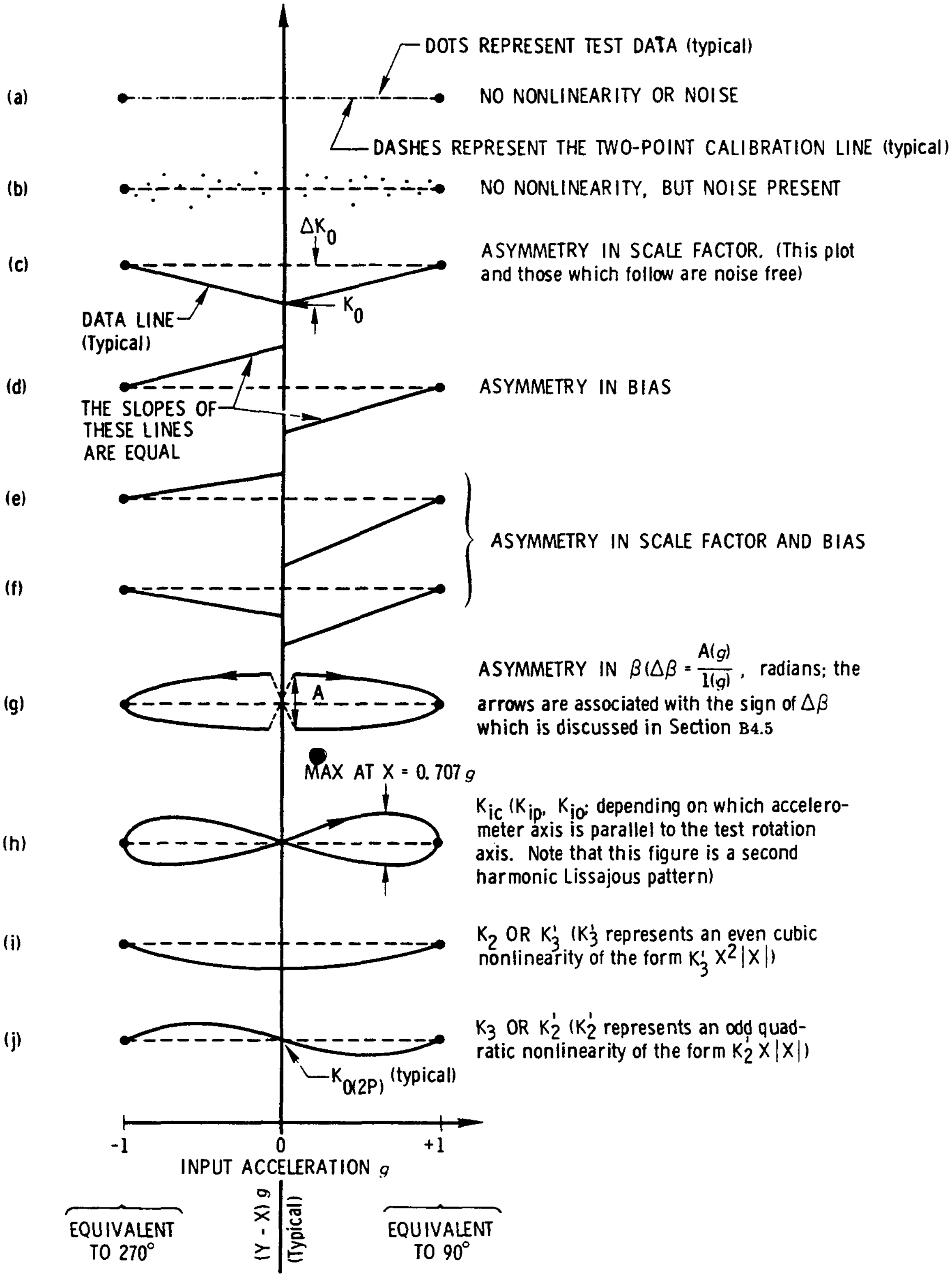

Figure B.2—Examples of (*Y* — *X*) Versus *X* Plots Illustrating Linearity and Various Forms of Nonlinearity

B.4.3 Selection of the Model Equation

Table B.1 presents a listing of suggested nonlinear models to be used with the various forms of (Y — X) versus X plots illustrated in Fig B.2. Note that in some instances, several forms of nonlinearity can be observed simultaneously in the test data. In those cases, the appropriate terms should be combined into a single nonlinear model. The example presented in B.4.4 depicts this situation. Refs [3] and [4] describe a procedure which generates the least squares simultaneous equations involving the selected model equation coefficients and the test data. Solution of these equations is usually done by matrix inversion. As part of the analysis, the residuals (E_j — $\hat{E}j$) should be computed and plotted against X_j. This plot should be examined for systematic functions of X which might suggest further alterations to the form of the model.

In the event that data noise precludes positive identification of the form of the nonlinearity, alternate forms may be selected, and the resulting model equations separately fitted to the data. Examination of the resulting residual plots and rms residual values may provide insight as to the model which “best” expresses the input/output function. Note that if the form of the model cannot be estimated from the plot of (Y — X) versus X because of noise, a number of models will fit the data better than a straight line (that is, lower rms residuals). However, little confidence can be placed in the resulting nonlinear coefficients.

Table B.1—List of Suggested Nonlinear Models to be Utilized with the (*Y* — *X*) Versus *X* Plots Shown in Fig B.2

The + and — coefficient subscripts indicate the sign of the input with which they are to be used, (that is, C_{1+} is to be associated with $X \geq 0$, etc.) β should be refitted with each model chosen.

Fig B.2 Item	Nonlinearity	Suggested Model Equation
(a) & (b)	linear	$Y_j = C_0 + C_1 X_j$; $X_j = \sin(\theta_j + \beta)$ (X_j typical, except as noted otherwise)
(c)	scale factor asymmetry	$Y_j = C_0 + C_{1+}, X_j + C_{1-} X_j$
(d)	bias asymmetry	$Y_j = C_{0+} + C_{0-} + C_1 X_j$
(e) & (f)	scale factor and bias asymmetry	$Y_j = C_{0+} + C_{0-} + C_{1+} X_j + C_{1-} X_j$
(g)	IA alignment asymmetry	$Y_j = C_0 + C_1 X_j$; $X_j = \sin(\theta_j + \beta_+ + \beta_-)$
(h)	cross coupling term	$Y_j = C_0 + C_1 X_j + C_{ic} X_j a_{cj}$ $a_{cj} = \pm \cos(\theta_j + \beta)$ (sign of cosine depends on the accelerometer orientation)
(i)	“even” curved nonlinearity	$Y_j = C_0 + C_1 X_j + C_2 X_j^2$, or $Y_j = C_0 + C_1 X_j + C'_3 X_j^2 \lvert X_j \rvert$
(j)	“odd” curved nonlinearity	$Y_j = C_0 + C_1 X_j + C_3 X_j^3$, or $Y_j = C_0 + C_1 X_j + C'_2 X_j \lvert X_j \rvert$

It is often possible to roughly estimate the magnitude of the nonlinearities directly from the plot of ($Y - X$) versus X. For example, if the ($Y - X$) versus X plot is similar to that shown in Fig B.2(c), the true positive scale factor (slope) exceeds the two point scale factor by $\Delta K_0/1g$ in units of g/g. The negative slope is less than the two point slope by the same amount. Similar techniques can be utilized to directly estimate other forms of nonlinearity.

B.4.4 Example

Fig B.3 presents a computer-derived plot of ($Y - X$) versus X based on actual data taken in a conventional 24 point multipoint test (that is, $\Delta\theta = 15°$). The nominal test angles associated with each data point are printed on the figure. The test proceeded increasing from an angle of 15° on around and ended at 345° as indicated by the arrows, and the data points are connected by straight lines to facilitate observation of the $(Y - X)$ versus X pattern. In this case, the data taken at test angles of 0° and 180° were deleted from the file because there was a readout difficulty associated with the pulse rebalance loop which rendered these points inconsistent with the other 22 values. Examination of the plot readily suggests that asymmetries in scale factor and bias are present as depicted in Fig B.2(f). Comparing this plot with that of Fig B.2(g) further suggests the presence of asymmetry in input axis alignment. Here is an example where three forms of nonlinearity are present and simultaneously observable. Based on this insight, a model of the form listed below was subsequently fitted to the data in the least squares sense:

$$\begin{aligned} E_j &= C_{0+} + C_{0-} + C_{1+} X_j + C_{1-} X_j \\ X_j &= \sin(\theta_j + \beta_+ + \beta_-) \end{aligned} \tag{B-4}$$

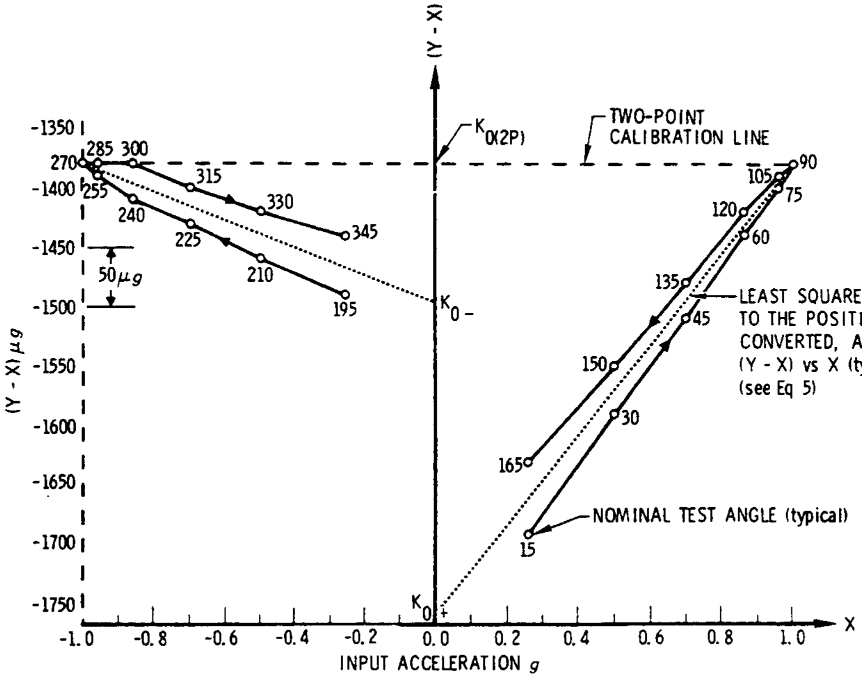

Figure B.3—Plot of ($Y - X$) Versus X for Actual Data Taken from a 24 Point Test (Asymmetries in Scale Factor Bias and Input Axis Alignment are Clearly Visible. Two Lines Representing Least Squares Fits to Each Half of the Data are Plotted on the Figure.)

The rms of the residuals associated with this model is 2.4, μg, which is equivalent to less than 1/20 of the vertical scale spacing on Fig B.3. The plot of residuals versus X is presented in [2], and examination of it suggests that increasing the model complexity is unwarranted.

The normalized results obtained from fitting the model expressed by Eq 4 are tabulated below:

	K_0 (mg)	K_1 (g/g)	β (μrad)	Residual (μg)
Postive	–1.755	1.000373	–733	2.4
Negative	–1.495	0.999886	–684	
$\lvert\Delta\rvert$	0.260	0.000487	49	–

Note that the asymmetries are significant. The two biases are 260, μg apart, the two scale factors differ by 487 ppm, and the input axis alignment shifts 49 μrad or about 10 arc seconds between the positive and negative halves of the data. Note that the fitted model characterizes only the test data at hand. In this case, for example, it does not express the input/output function in the input region between +0.25 and − 0.25 g. The two fitted straight lines represented by $K_{0+} + K_{1+} X$ and $K_{o-} + K_{1-} X$ are plotted relative to the $(Y - X)$ versus X data presented in Fig B.3. As discussed previously, these could have been roughly estimated directly from the figure. Similarly, the size of the input axis alignment asymmetry could also be estimated by measuring the width of the extrapolated ellipse patterns where they intersect the vertical axis.

Note that if the two-point calibration were used to characterize the input/output function of this instrument, the positive scale factor and bias would be in error by 373 ppm and 373 μg, respectively. Similarly, the negative values would be in error by 114 ppm and 113 μg, respectively.

B.4.5 Correction for Input Axis Misalignment

The previous discussion in B.4.1 describes the technique of correcting the input acceleration for the total IA misalignment β. This section outlines the necessity for that procedure. The value of test input X must be corrected for the misalignment β because serious distortion of the $(Y - X)$ versus X plot would otherwise result. As described in [2], an uncorrected misalignment β relative to the table angular readout results in an elliptically shaped Lissajous pattern associated with β which is added to the apparent input/output function. The resulting plot of $(Y - X)$ versus X would contain the same ellipse rotated so that its major axis is horizontal. A misalignment of 1 mrad, which is typical for the test, would produce an ellipse in the $(Y - X)$ versus X plot with a vertical amplitude of 2000 μg, which, in most instances, is much larger than the nonlinear effects that we desire to observe. Therefore, it is important to remove this error source from the data.

If input axis asymmetry is present, its magnitude can be estimated as indicated in Fig B.2(g) and the sign associated with this effect can be determined in the same manner relative phase is obtained from a Lissajous pattern. Similar techniques can be utilized to determine the magnitude and sign of a K_i, term, as illustrated in Fig B.2(h).

Note that the first estimate of β is obtained by fitting a linear model plus a single misalignment to the test data [see Eq (B-1)]. When significant nonlinearities are present, this model is incorrect and an error in the estimate of β may be introduced. Therefore, it is important to refit β along with the other coefficients of the improved nonlinear model when making the final coefficient estimates.

B.5 Other Comments

Least squares fitting has been assumed in the previous discussion because it is commonly used in engineering practice. In order to fit models to multipoint data in the presence of data scatter or “noise,” it is desirable that the test be overdetermined (more data points are taken than the number of coefficients desired). As a rough “rule of thumb,” the number of data points should exceed the number of fitted coefficients by a factor of at least four. Generally, a larger excess is preferable.

Common techniques for judging the goodness of fit for a model are to examine the plot of residuals versus X and to compute and consider the rms value of the residuals, as described above. Another technique is to compute the estimate of the standard deviation of the individual coefficients themselves. Of these, by far the most important is to carefully examine the residual plot.

Where possible, it is desirable to obtain data from other tests to check the multipoint test results. Precious centrifuge tests can be used to obtain the higher order nonlinearities (K_2 and K_3, for example). This method typically suffers from test errors associated with radius arm and input axis attitude uncertainties, which result in unknown test-induced bias and scale factor asymmetries, and, hence, this form of nonlinearity usually cannot be detected in centrifuge data. Similarly, with present precision accelerometers, it is unlikely that higher order nonlinearities such as K_2 and K_3 can be detected with a multipoint test. At the time of this writing, precision accelerometers typically exhibit second- and third-order nonlinearities (K_2 and K_3), less than 2 $\mu g/g^2$ and 0.1 $\mu g/g^3$, respectively, which would be almost impossible to detect in the presence of data noise in the range of 2-5μg rms, which is typical for the test. However, the results from the multipoint and the centrifuge tests can be compared to reinforce conclusions regarding the input/output function nonlinearity. For example, an "even" nonlinearity observed in multipoint testing as either scale factor asymmetry or K_2 can be compared with the centrifuge result for K_2 to assist in the resolution.

B.6 References

[1] IEEE Std 337-1972, Specification Format Guide and Test Procedure for Linear, Single-Axis, Pendulous, Analog Torque Balance Accelerometer, Paragraph 10.3.5 and Appendix B, Static Multipoint Test.

[2] FURHMAN, T. A. An Improved Technique for Estimating Accelerometer Linearity from Multipoint Data, A Collection of Technical Papers. *AIAA Guidance and Control Conference Proceedings*, Aug 1977, p 530.

[3] SPIEGEL, M. R. "Theory and Problems of Statistics," *Schaum's Outline Series*. New York: McGraw-Hill, 1961, Chapter 13 and Appendix VIII.

[4] MENDENHALL and SCHEAFFER, *Mathematical Statistics with Applications*. Duxbury Press, 1973, Chapter 11.