The Basics of Accelerometer Calibration

Calibration Overview

What is calibration?

- Verifies amplitude response and system linearity over the intended range of use
- Provides physical meaning to the electrical output
- Typical Manufacturer calibration includes:
  - Reference sensitivity
  - Frequency response
  - Output bias level or supply voltage
  - Transverse sensitivity
  - Resonant frequency
  - Time constant

Calibration Overview

- **Why calibrate?**
  - To ensure the sensor performs according to the specification and to provide meaning to the electrical output
- **Why recalibrate?**
  - Good measurement practice that helps to ensure accurate results and that the sensor is still “healthy”.
    - Reference sensitivity, frequency response, output bias level, transverse sensitivity, resonant frequency and time constant
  - Often required by ISO 9001, QS9000 or contractual reasons
- **“Do-it-yourself” decision**
  - Risk vs. Reward

Calibration Overview: Standards

What are the standards?

- ISO 9001 Company Quality Management System
- ISO 17025 Calibration Laboratory Quality System
  - Identifies the general requirements for the competence of calibration laboratories
  - Accreditation bodies include A2LA, ACLASS, NVLAP, etc
- ISO 16063 Methods for the Calibration of Vibration and Shock Transducers
  - 16063 Part 11. Primary vibration calibration by laser interferometry
  - 16063 Part 13. Primary shock calibration by laser interferometry
  - 16063 Part 21. Vibration calibration by comparison method
  - 16063 Part 22. Shock calibration by comparison method

Measurement Uncertainty

- **Calibration data is fairly meaningless without knowing the measurement uncertainty**
- **Measurement Uncertainty often misstated**
  - May not include component from reference standard
  - May not be compliant with relevant standard
    - For example, neglect shaker transverse or drift
  - May not use coverage factor of k=2
- **Systemic Component**
  - *Generally speaking – the measurement accuracy*
- **Random Component**
  - *Generally speaking – the measurement precision*

Examples of Systemic Uncertainty

- Reference and Signal Conditioner Uncertainty
- Transverse Motion of Exciter
- Reference Sensitivity "Drift"
- Measurement Channel Inaccuracies

Examples of Random Uncertainty

- **Mounting and Cabling**
  - Torque Variation
  - Cable Strain Relief
  - Accelerometer Base Strain Sensitivity
- **Relative Motion Between SUT and Reference**
- **Operator Technique**
- **Electrical Noise**
- **Lab Conditions**
  - Temperature
  - Humidity
  - Pressure

Examples of Uncertainty Budget

- Excerpt from The Modal Shop's published ISO 17025 A2LA certified uncertainty budget

Table 7: *Uncertainty Budget*

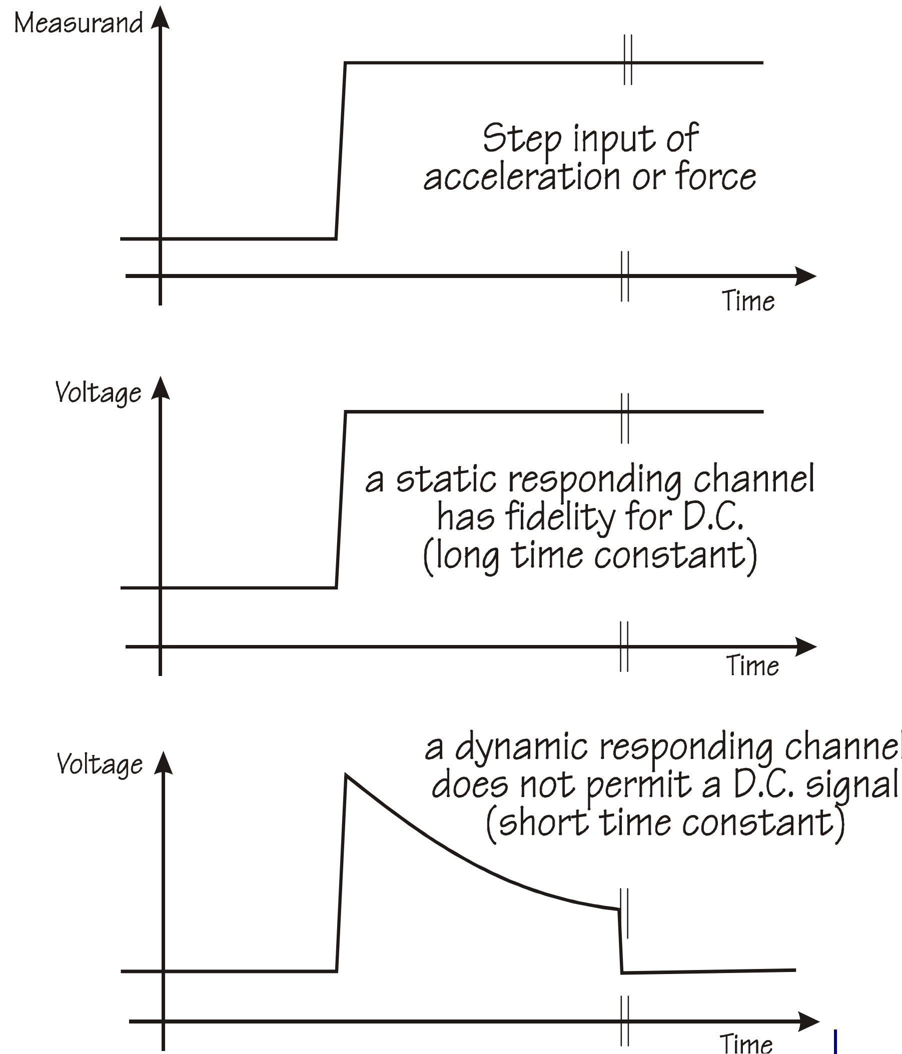
Uncertainty Component	Relative Uncertainty Contribution						
	10 Hz to 99 Hz	100 Hz	101 Hz to 920 Hz	921 Hz to 5000 Hz	5001 Hz to 10,000 Hz	10k Hz to 15k Hz	15k Hz to 20k Hz
Primary standard calibration	0.25	0.10	0.25	0.50	0.75	1.50	2.00
Primary standard stability	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Ratio Error	0.31	0.29	0.29	0.29	0.29	0.29	0.29
Random (Type A)	0.30	0.09	0.14	0.10	0.18	0.24	0.63
Combined Standard Uncertainty (%) u_c	0.51	0.33	0.42	0.59	0.83	1.55	2.04
Expanded Uncertainty (%) U (k=2)	1.02	0.66	0.84	1.18	1.66	3.10	4.08

Table 8: *Published Best Expanded Uncertainty, k = 2.*

Published Uncertainty (%) U (k=2)	**1.15**	**0.75**	**1.00**	**1.35**	**1.85**	**3.30**	**4.30**

Calibration

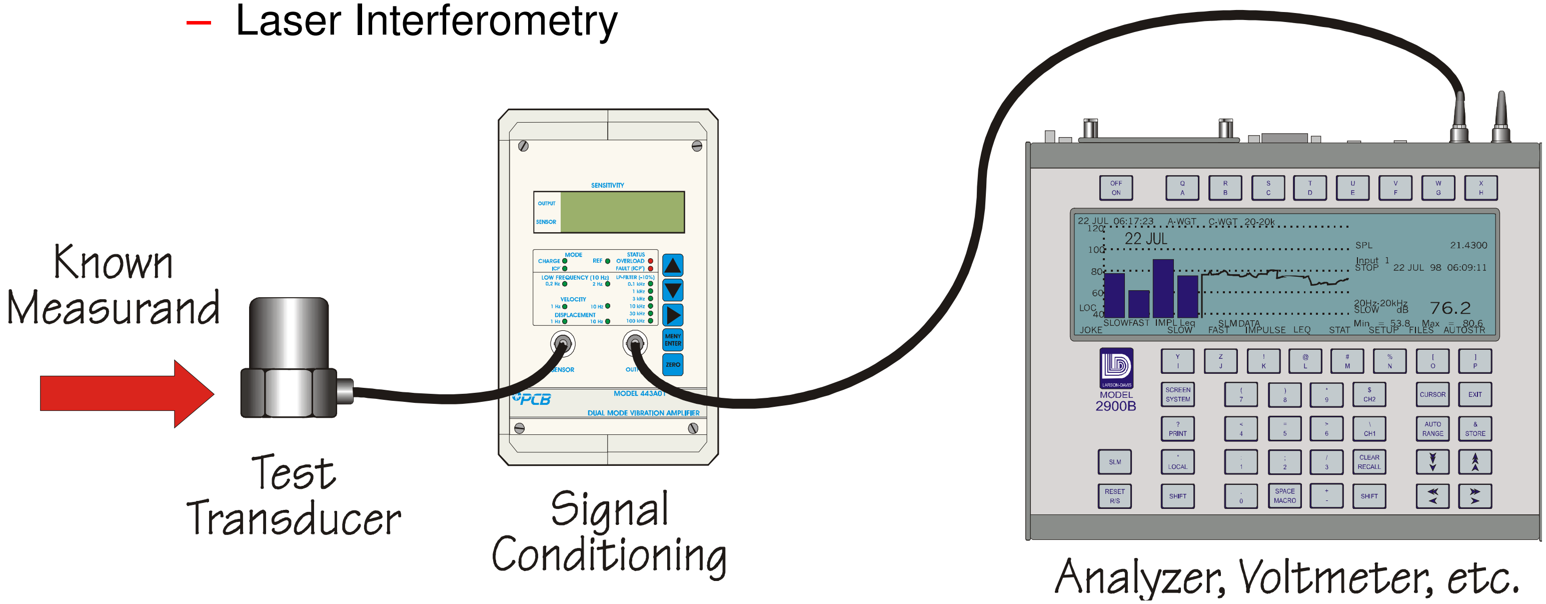
- Static versus Dynamic Calibration



Calibration Methods

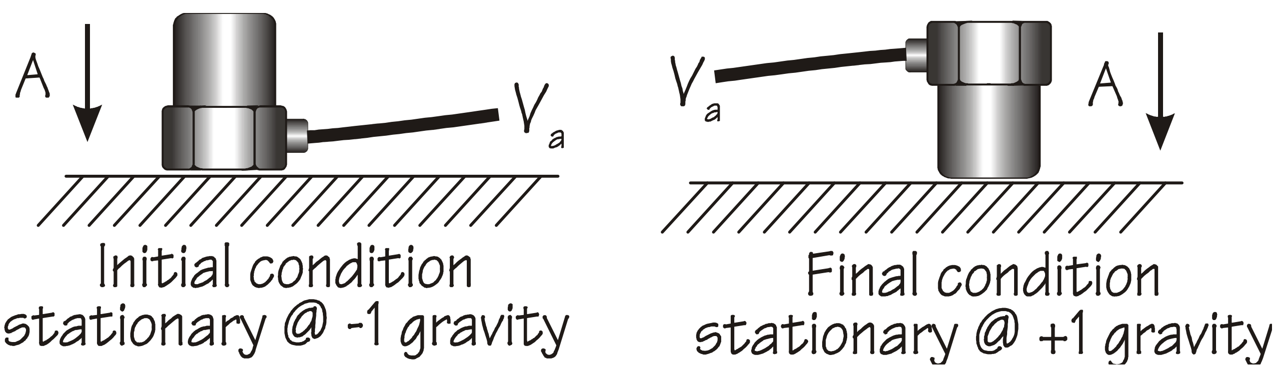
Absolute Methods

- Test where the sensor is subjected to a known, accurate and reliable standard of nature
  - Drop Test/Gravity Inversion Test
  - Gravimetric
  - Laser Interferometry

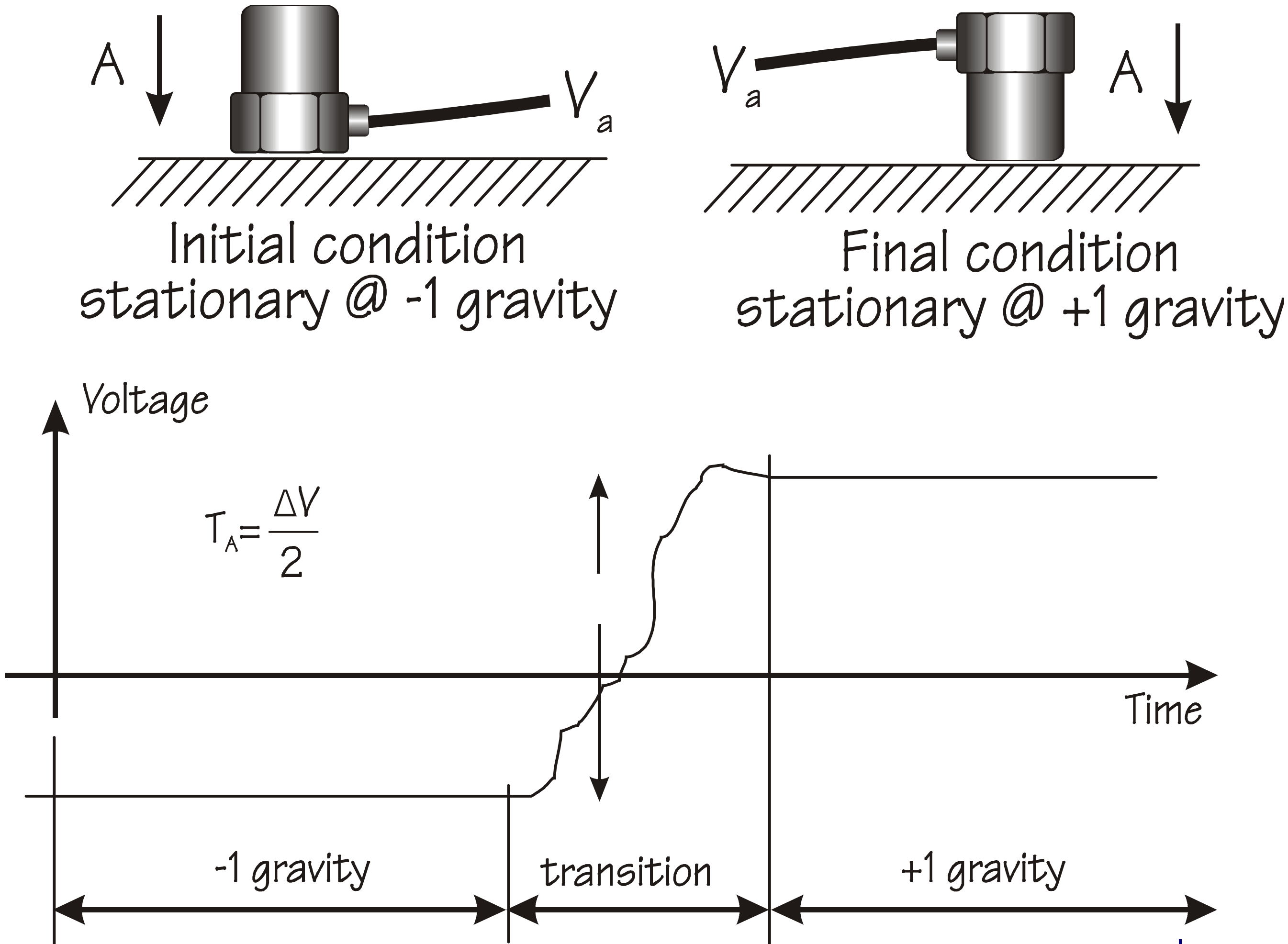


Calibration: Inversion Test

- Sensor is rotated 180 Degrees in the Earth's gravity so that it experiences a 2g (-1 g to +1 g) step function
  - Requires long DTC or DC response for accurate results
  - Signal Conditioning and readout device must be DC coupled

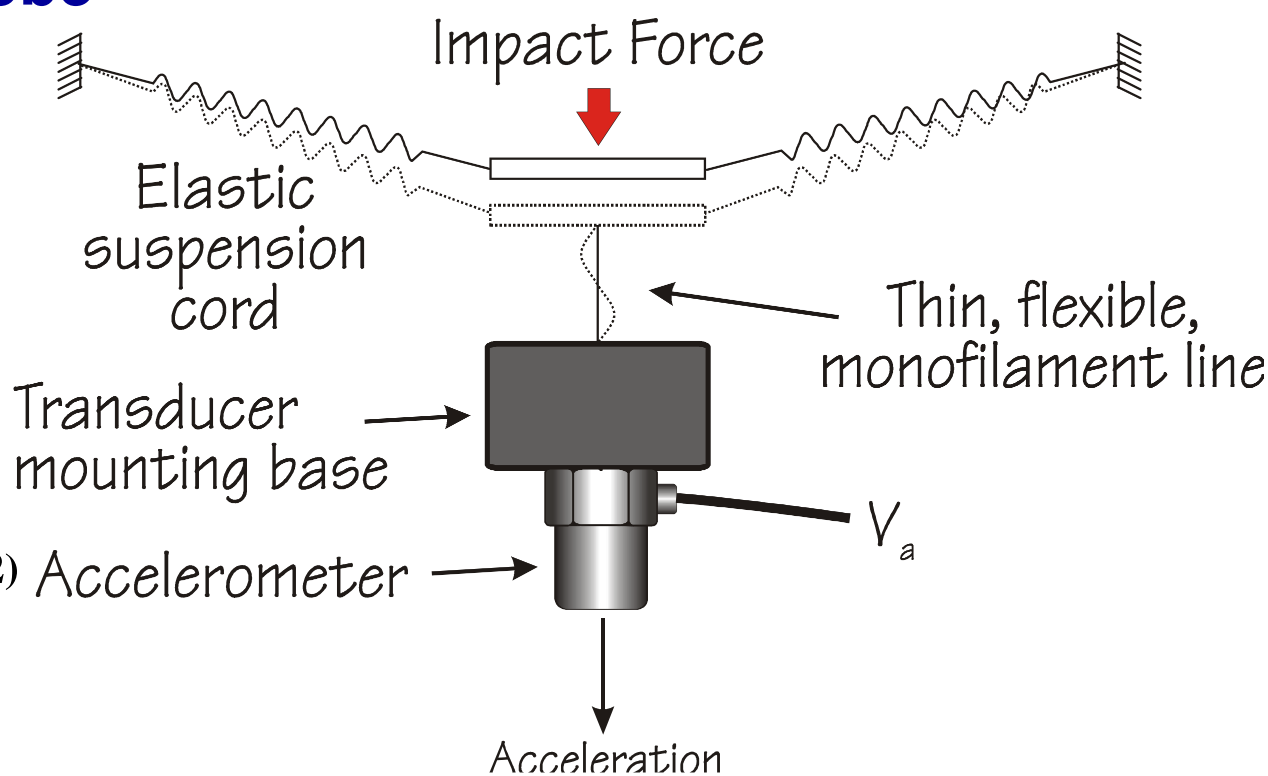


Calibration: Inversion Test



Calibration: Drop Test

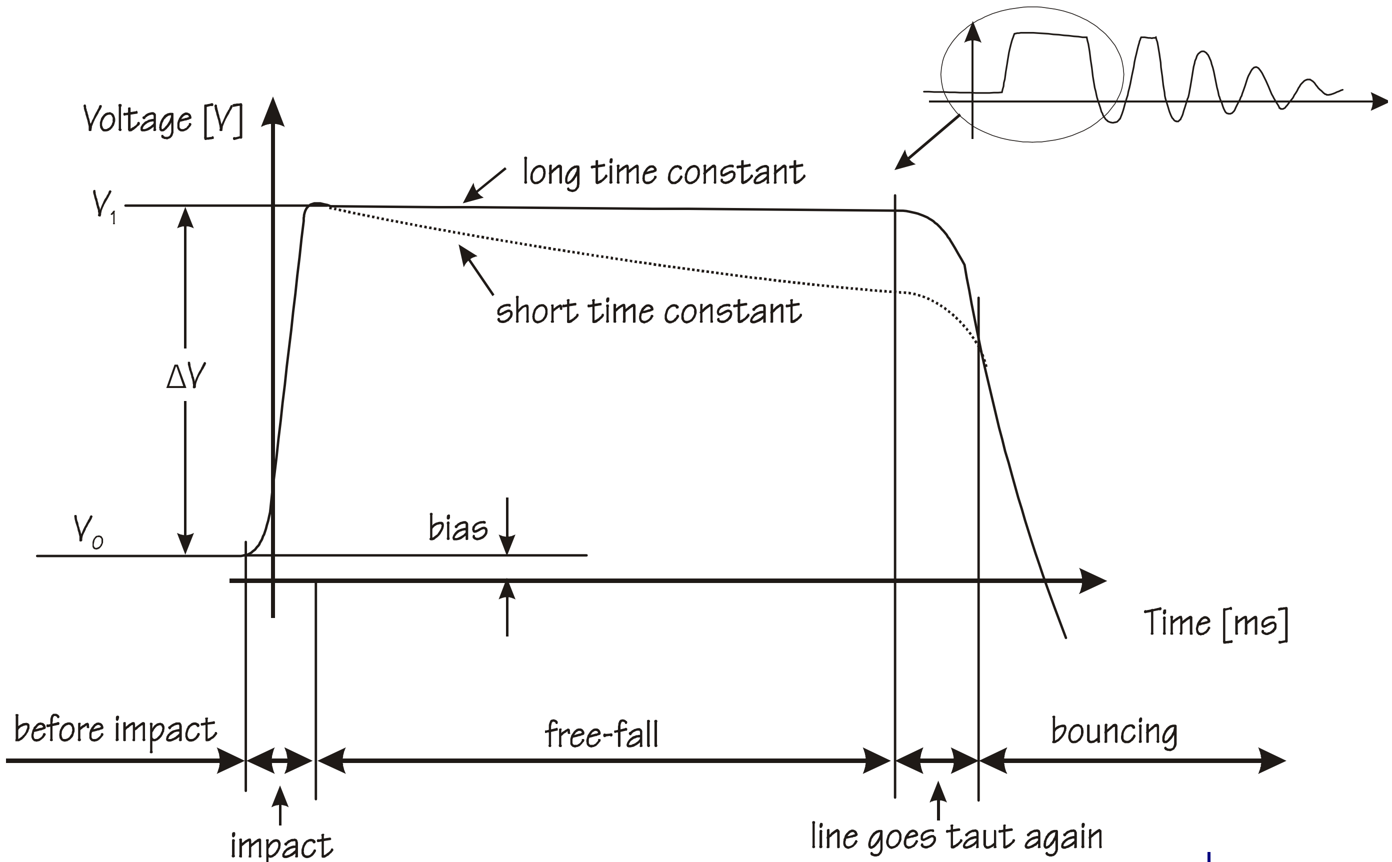
- Accelerometer is allowed to free-fall in Earth's gravity which varies by approximately +/-0.25% around the globe



Earth's Gravity (9.80665 m/s2)
0 Deg Latitude: 9.789 m/s2
90 Deg Latitude: 9.832 m/s^2
Altitude Correction: -3 mm/s^2 per 1000 m above sea level

Calibration: Drop Test

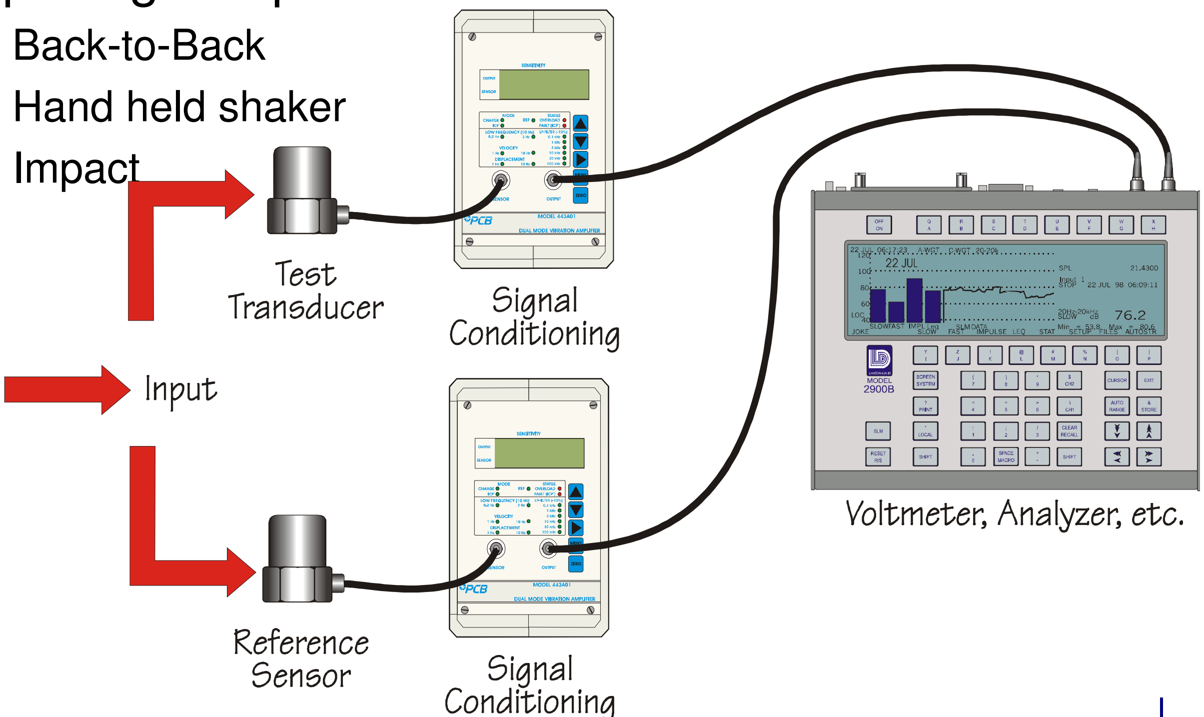
- Step function output (mV) divided Earth's gravity (1 g) equals the sensitivity of the accelerometer



Calibration Methods

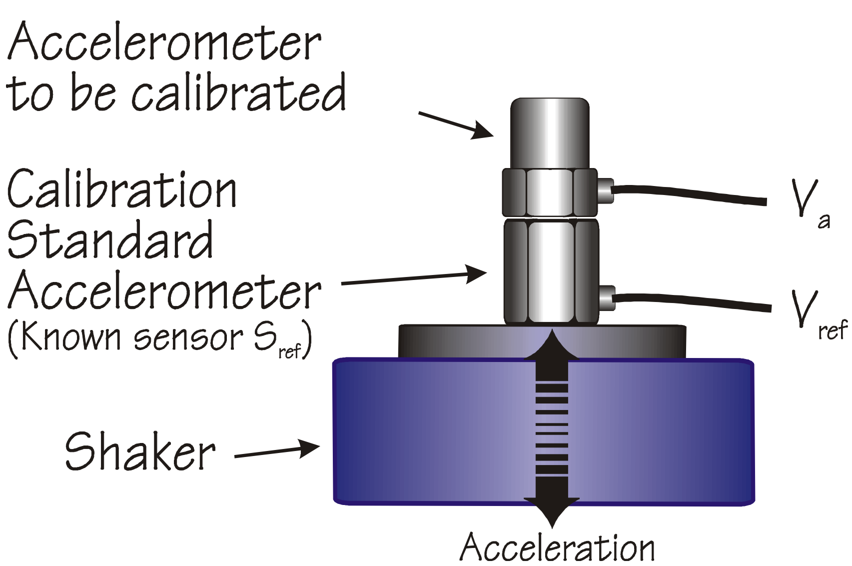
Relative Methods

- Test where the sensor and *calibrated reference* are subjected to the *identical input acceleration.* The ratio of the output signals provides the calibration factor.
  - Back-to-Back
  - Hand held shaker
  - Impact



Calibration: Comparison

- Test sensor mounts "back-to-back" with a reference accelerometer that has been previously calibrated by primary means or by a recognized laboratory



$$A_a = A_{ref}$$

$$\frac{V_a}{S_a} = \frac{V_{ref}}{S_{ref}}$$

$$S_a = S_{ref}\frac{V_a}{V_{ref}}$$

Calibration: Comparison

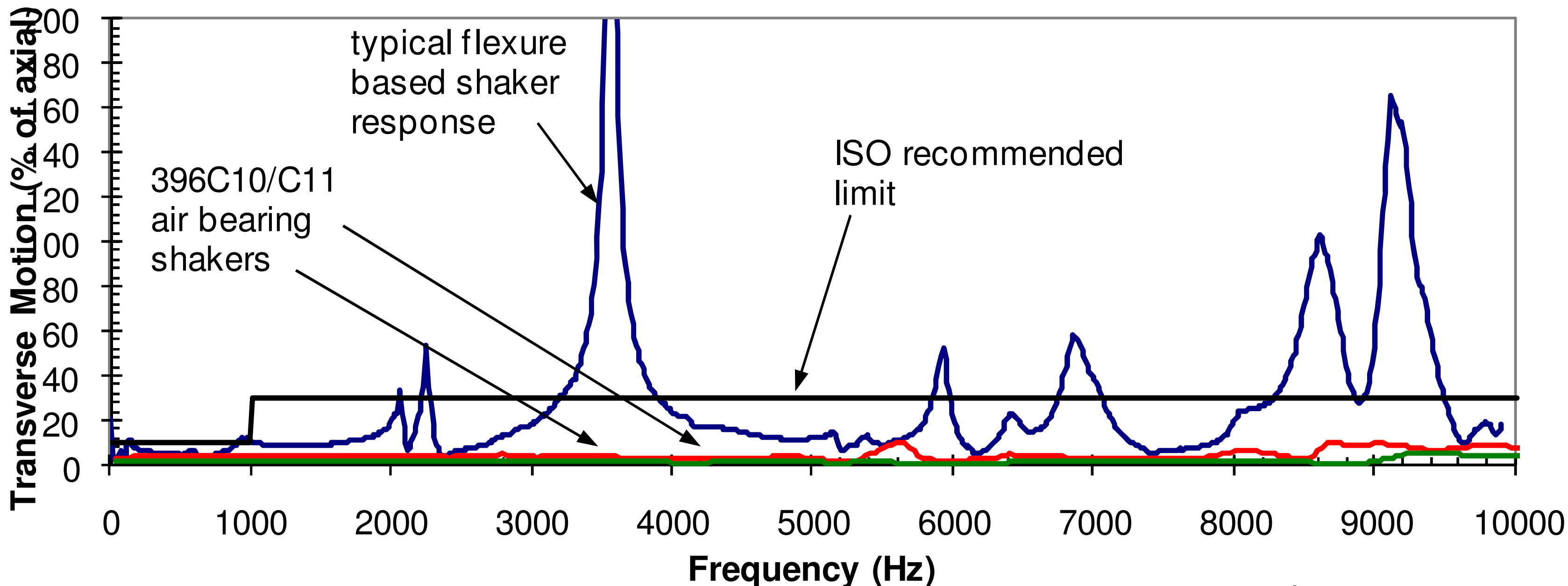
- **ISO 16063 Part 21**
  - Vibration calibration by comparison to a reference transducer
- **Most common of all calibration system types**
  - Typically used by manufacturers and metrology labs
- **Reference transducer can be either external "piggyback" or internal to exciter**
- **Approximate uncertainty, including both systematic and random errors:**
  - 1 to 20 Hz : +/-3%
  - 20 to 5000 Hz : +/-1.5%
  - 5000 to 10000 Hz : +/-3%
  - >10000 Hz : +/-4.5%

Important Considerations for Reference

- Reference Accelerometer is typically the largest single component of the system uncertainty budget
- Consider calibrating reference directly to Laser Primary for improved uncertainty
- Quartz as piezoelectric material provides natural, stable characteristics
- ICP technology provides low noise susceptibility, particularly at low frequencies
- Shear mode construction eliminates base strain
- Hermetic sealing for humidity insensitivity

Important Considerations for Exciter

- **Transverse bending and rocking motion of shaker causes significant measurement error**
- **Calibration air-bearing shakers meeting ISO 16063 recommendations eliminate this error**

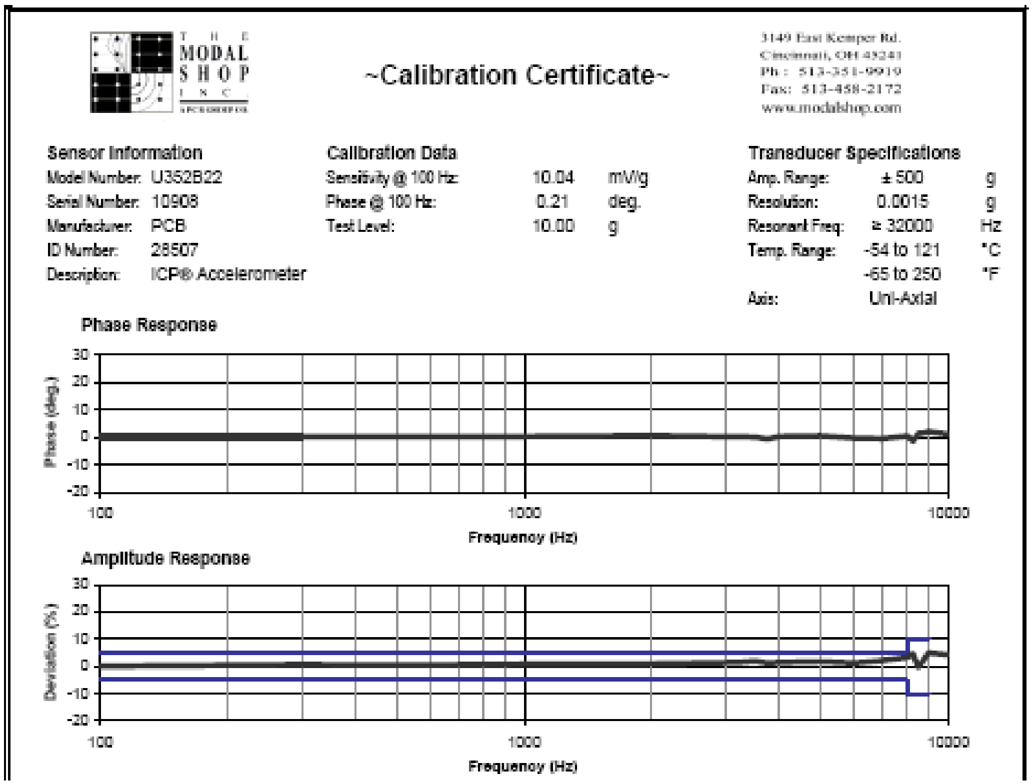


TMS

PCB PIEZOTRONICS INC.

Important Considerations for Exciter

- Uncertainty often misstated due to neglecting transverse motion effects, often as much as 3-5%



THE MODAL SHOP INC.

~Calibration Certificate~

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Cincinnati, OH 45241
Ph: 513-351-9919
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Sensor Information

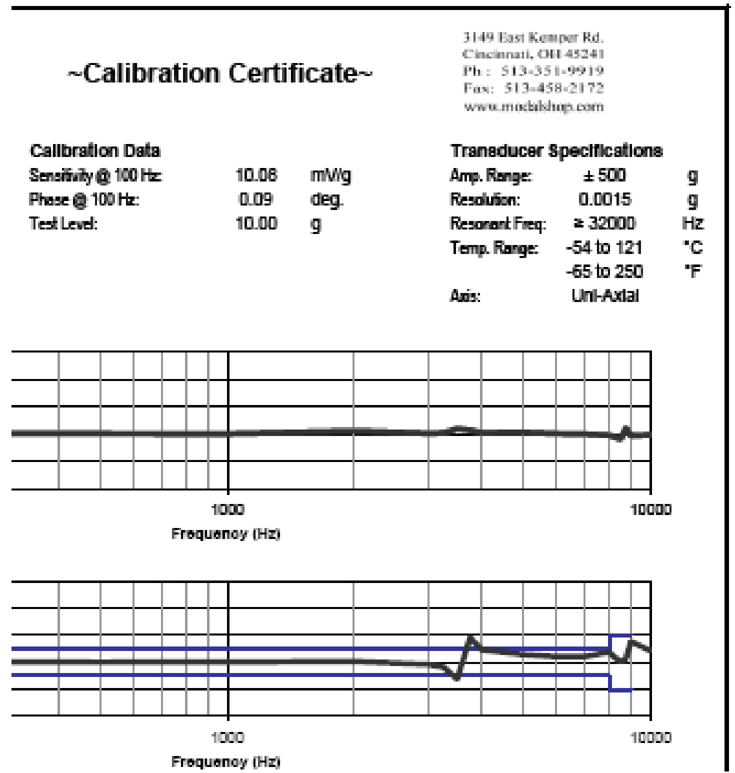
Model Number:	U352B22
Serial Number:	10908
Manufacturer:	PCB
ID Number:	28507
Description:	ICP® Accelerometer

Calibration Data

Sensitivity @ 100 Hz:	10.04	mV/g
Phase @ 100 Hz:	0.21	deg.
Test Level:	10.00	g

Transducer Specifications

Amp. Range:	± 500	g
Resolution:	0.0015	g
Resonant Freq:	≥ 32000	Hz
Temp. Range:	-54 to 121	°C
	-65 to 250	°F
Axis:	Uni-Axial	



~Calibration Certificate~

3149 East Kemper Rd.
Cincinnati, OH 45241
Ph: 513-351-9919
Fax: 513-458-2172
www.modalshop.com

Calibration Data

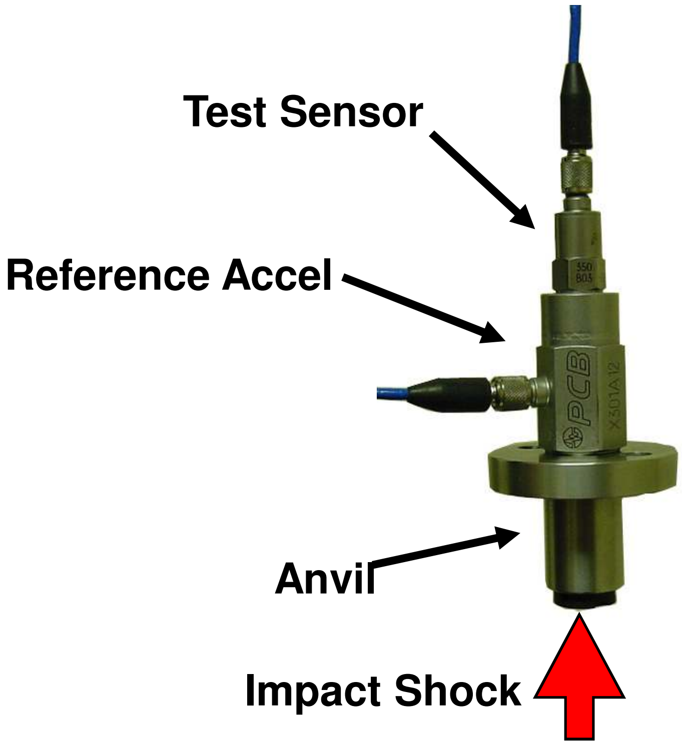
Sensitivity @ 100 Hz:	10.08	mV/g
Phase @ 100 Hz:	0.09	deg.
Test Level:	10.00	g

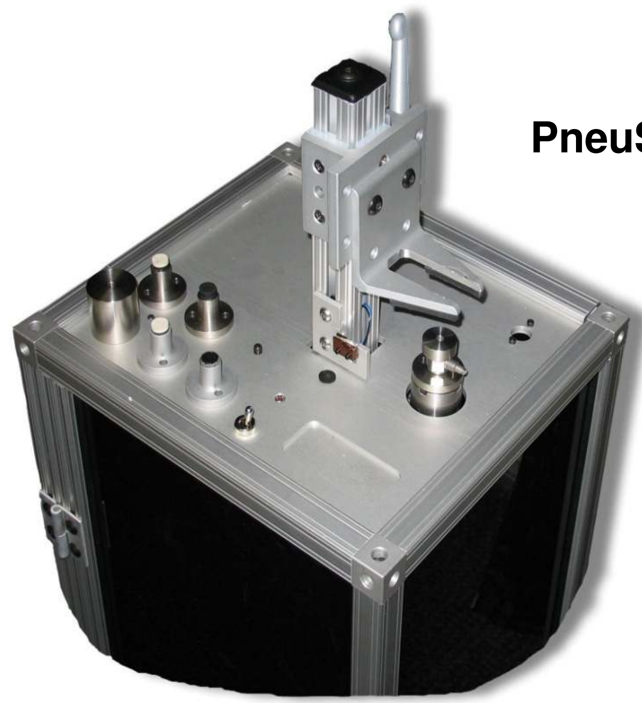
Transducer Specifications

Amp. Range:	± 500	g
Resolution:	0.0015	g
Resonant Freq:	≥ 32000	Hz
Temp. Range:	-54 to 121	°C
	-65 to 250	°F
Axis:	Uni-Axial	

Shock Calibration: Comparison

- Test sensor mounts "back-to-back" with a reference accelerometer and anvil, struck with a pneumatically operated projectile

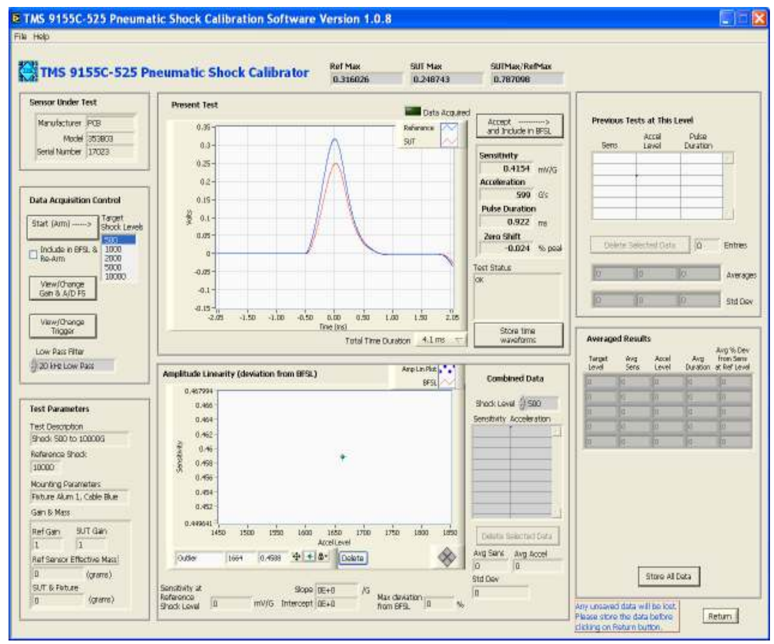




PneuShock™ shock tower

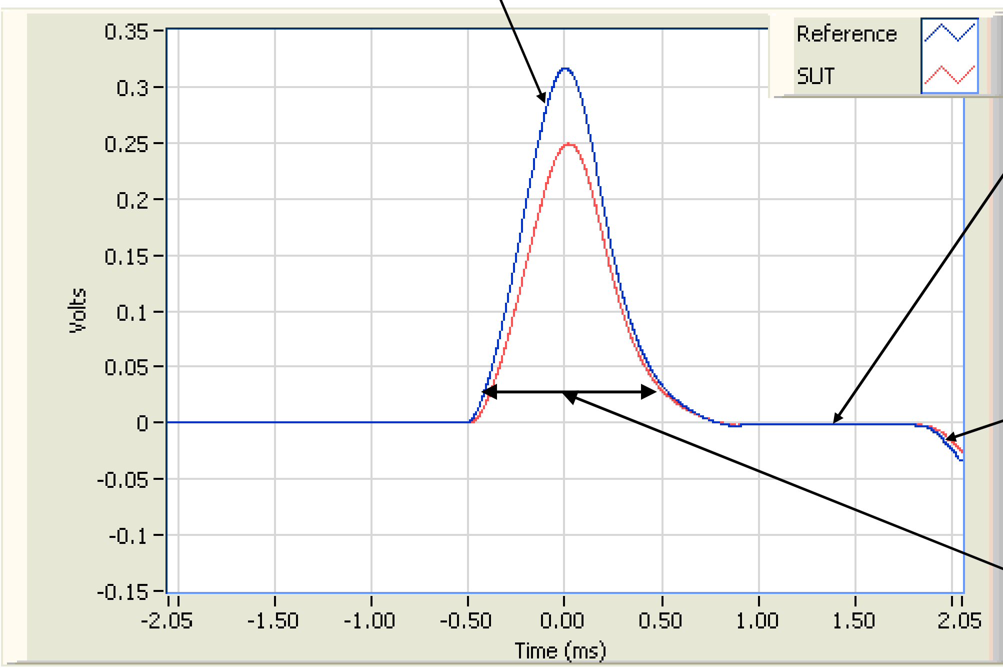
Calibration: Shock

- ISO 16063 Part 22 shock calibration by comparison to a reference transducer
- Measures transient (impact) acceleration levels up to 10,000 g to calculate sensitivity
- Verifies amplitude linearity and performance of sensor at intended test levels



Typical Shock Pulse ~640g

Compare peaks to get sensitivity



Zero shift is apparent during free fall

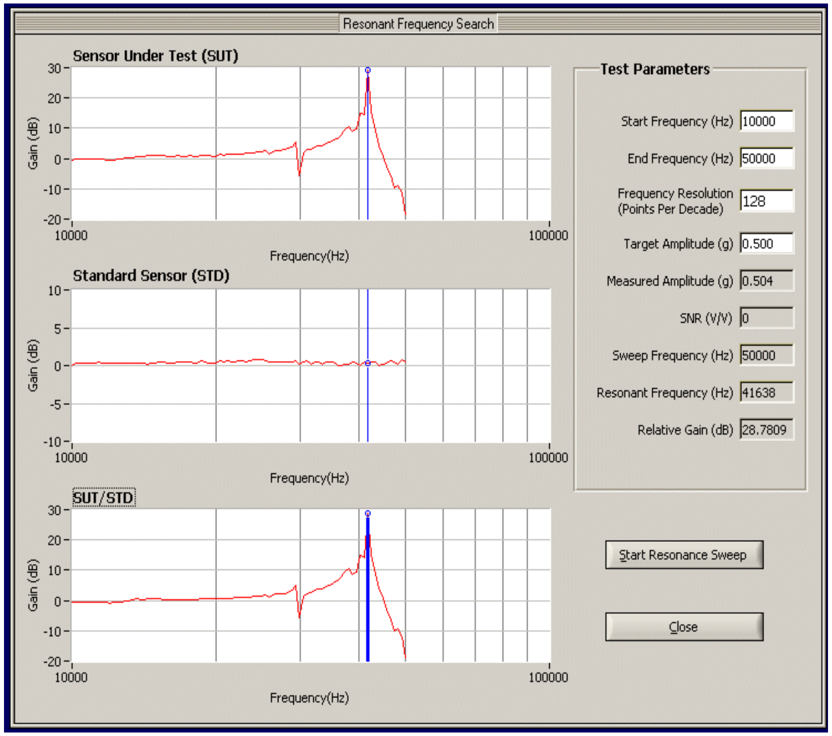
Deceleration by "fingers"

Duration – should be ~5x resonance

Duration of free fall is set by height of "fingers"

Calibration: Resonance

- **Back-To-Back Calibration – Resonance Test**
  - Stepped sine FRF measurement of test sensor to reference standard identifies the unit's mounted resonant frequency
- **Verifying consistency of sensor's mounted resonant frequency provides additional assurance of sensor health**



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Calibration: Handheld Check

Handheld Calibrator

- Quick, easy field check and/or calibration of entire system from sensor through cable to analysis equipment
- Provides a fixed g force via a built-in servo-stabilization
- Battery operation provides for portable use, while DC adapters allows for extended operation
- A handheld shaker is relative to an internal reference in shaker

Calibration: Field Check

Portable Vibration Calibrator

- Quick, easy field check and/or calibration of entire system from sensor through cable to analysis equipment
- Provides selectable amplitude and frequency settings for in-situ cal from 7 Hz to 10 kHz
- Integral reference accelerometer provides traceability through comparison method
- Supports acceleration, velocity and displacement

Know Your Calibration House

Laboratory Qualifications

- OEM (Original Equipment Manufacturer)
  - Advantages of using an OEM
    - OEM is capable of checking all functions of the instrument
    - OEM has knowledge of latest changes
    - One Stop Shopping OEM is able to upgrade instrument at customer request and provide calibration services
- Accredited Laboratory
  - Has been audited by A2LA, NVLAP or other approved organization to ISO Guide 25, ANSI Z540 or ISO 17025
  - Per QS-9000, non -OEM Laboratories must be accredited to one of the above standards.

Know Your Calibration House

- **Traceability**
  - The ability to show that a standard or an instrument has been calibrated or certified by a higher order standard which is then calibrated by a still higher order, and on and on, thus the standard or instrument is eventually related back to the established national standards.

Know Your Calibration House

- **Customer Responsibilities**
  - Verify that the Laboratory is qualified to calibrate the instrument being submitted
  - Verify that the Quality System is adequate through audits - onsite or written
  - Communicate any needs or requirements when the Laboratory is being evaluated to determine if your needs will be met