Technical Advances in a Commercial Off-The-Shelf Accelerometer Calibration System

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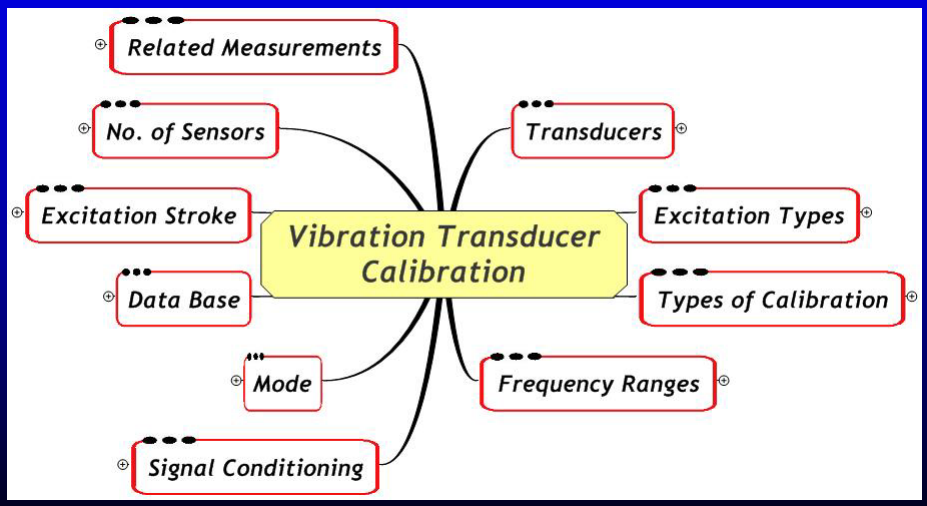
MB Dynamics *Innovating and Delivering Solutions ...Vibration and Shock*

How Important is Vibration Transducer Calibration?

Issue or Problem	Result or Effect
↗ Undetected bad accelerometers	↗ Failed test items and tests
↗ Sensitivity is not correct	↗ In-accurate, un-reliable and non-repeatable test data
↗ Bad test data	↗ Wrong engineering decisions
↗ Improper calibration process and poor records	↗ Failed audits
↗ Outside vendors charge much to calibrate accelerometers	↗ High cost

Family of Calibration Products



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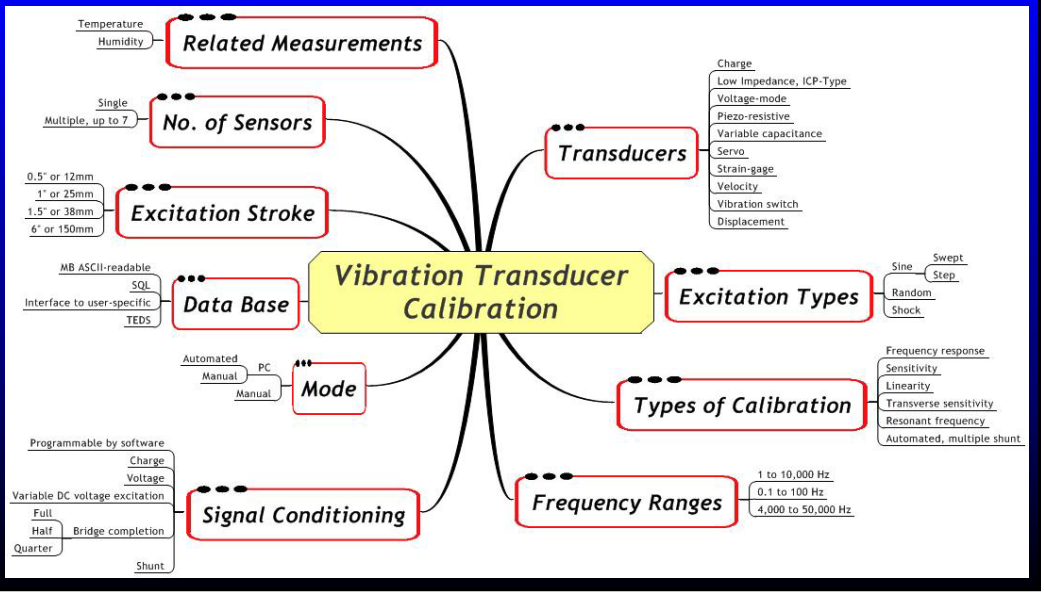


Key Features of MB Family

- Lowest Expanded System Uncertainty on the market (0.6% @ 95%)
- Broad frequency range: 1 to 10,000 Hz
- Long stroke (1" or 25 mm) p-p and highest acceleration (40 g's pk)
- Accelerometers: charge, voltage, low-impedance, piezo-resistive, strain gage, variable capacitance, servos
- Velocity & displacement transducers; heavy accelerometers: ≈ 1 kg
- Step sine, swept sine, linearity
- Desktop unit -- minimal floor space required
- Simple to use; no instruments; minimizes human error
- Low frequency (optional): 0.1 - 200 Hz; 6" (150 mm) stroke
- Random vibration calibration (optional)
- Shock calibration (optional): 40 g's and 5 to 0.5 msec (up to 3,000 g's)
- Heavy transducers & switches (optional): up to 10 lbs. (4.5 kg)

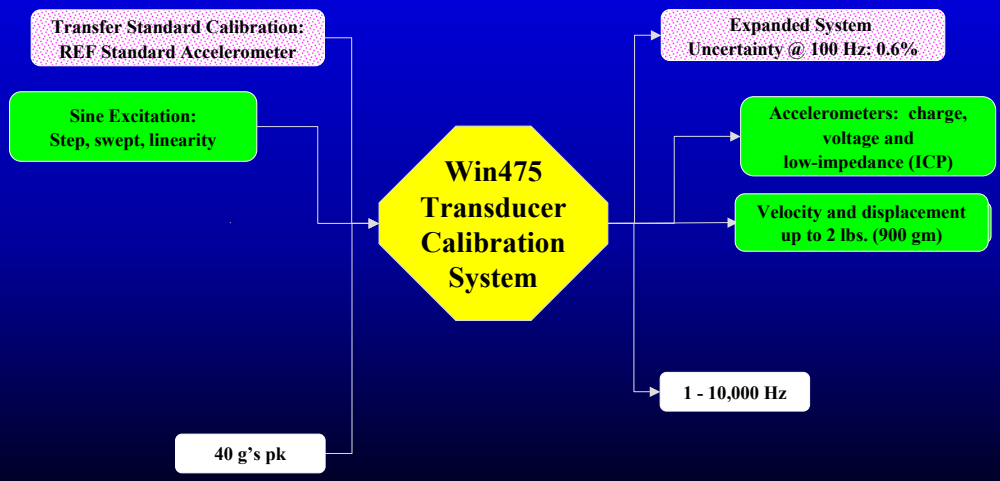
Worldwide Installations

COMPANY	WHERE INSTALLED		QTY	YEAR	SO#
AFPS, INC (GM Harrison Div)	Amherst	NY	1	1992	92382
AMTEC Gage Verification Lab (aka Redstone)	Huntsville	AL	1	1997	96300
AT&T Technology	Union City	NJ	1	1990	18586
Aviall Inc (aka Ryder Airlines)	Ft Worth	TX	1	1993	93406
BAMSI	Marshall Space Flight Ctr	AL	1	1997	96183
BMW	Coles Hill, WARKS	ENGLAND	1	2001	201141
Boeing Commercial Airline Group	Seattle	WA	1	1995	95012
Breed Technologies	Detroit	MI	1	2000	200214
Burle Industries	Lancaster	PA	1	2001	201120
Carderock Div/NSWC	Suffolk	VA	1	1996	96209
CATIC602	Xi'an	China	1	2002	201275
CATIC HK623	Xi'an	China	1	2004	204003
Chrysler Corp Tech Center	Auburn Hills	MI	1	1997	97026
Chrysler Corp (Stress Lab)	Auburn Hills	MI	1	1992	92166
Chung Shan Inst of Science & Technology	Taiwan	ROC	1	1992	92049
Consumers Energy	Jackson	MI	1	1997	96383
DaimlerChrysler	Auburn Hills	MI	1	2003	203062
Delphi Harrison Thermal Sys/GM (AFPS)	Lockport	NY	1	1998	98117
Duke Energy	Huntersville	NC	1	2002	202064
EG&G Mound Labs	Miamisburg	OH	1	1989	91678
Entek IRD Int'l	Columbus	OH	1	1998	98135
Entergy	Russellville	AK	1	2001	201021
Ford Safety	Dearborn	MI	1	2003	203273
Govt of India (Electronics Test & Develop Ctr)	Bangalore	INDIA	1	1992	92242
Govt of India (Gas Turbine Research Establish.)	Bangalore	INDIA	1	1991	91365
GE Transportation Systems	Erie	PA	1	2004	204046
General Motors R&D Center	Warren	MI	1	1994	94219
Grand Prairie Accessory Services	Grand Prairie	TX	1	2003	203292
Hyundai Electronics	Seoul	KOREA	1	1995	95378
LDW	Melvindale	MI	1	2003	203081
Lockheed Martin	Moorestown	NJ	1	2001	201208
Lockheed Martin	Ocala	FL	1	1997	95363
Loral Space Systems	Palo Alto	CA	1	1991	90306
Loral Aerospace (Aeronutronic Div)	Rancho Santa Magarita	CA	1	1990	18527
Milano Bros.		ITALY	1	1993	93393

Worldwide Installations

COMPANY	WHERE INSTALLED		QTY	YEAR	SO#
Millstone Nuclear Power Station		CT	1	2000	200338
National Metrology	Pretoria	S. AFRICA	1	1996	96387
Pratt & Whitney Aircraft	East Hartford	CT	1	1994	94164
Pratt & Whitney Aircraft	East Hartford	CT	1	2002	202163
QD (Qingda)	Xi'an	CHINA	1	2003	202150
Rockwell – Rocketdyne Divison	Canoga Park	CA	1	1990	18498
SAC (Shenyang Aircraft)		HONG KONG	1	2002	202136
SAIC (Science Applications Int'l Corp)		SINGAPORE	1	1997	97111
Sandia Laboratories	Albuquerque	NM	1	2004	204060
South Carolina Electric & Gas	Jenkinsville	SC	1	1993	93327
Texas Instruments, Inc.	Attleboro	MA	1	1995	95373
Tongji University		CHINA	1	2001	200193
Toyo Corporation	Tokyo	JAPAN	1	1991	91564
Trane Southside Works	Lacrosse	WI	1	1997	97122
TRW Vehicle Safety	Washington	MI	1	1996	96176
US Air Force – AFMETCAL Systems Inc	Heath	OH	33	1997	97246
US Air Force – AFMETCAL Systems Inc	Heath	OH	26	1998	97246A
US Army Redstone	Huntsville	AL	1	1992	92062
US Army Redstone	Corpus Christi	TX	1	2000	200142
US Army TMDE Activity	Corpus Christi	TX	1	1991	91873
US Army TMDE Support Center	Aberdeen Proving Grounds	MD	1	1992	91873
US Army - Aberdeen	Aberdeen Proving Grounds	MD	1	2001	201340
US Army - Aberdeen	Aberdeen Proving Grounds	MD	1	1999	99082
US Army - White Sands	White Sands Missille Range	NM	1	1999	99228
US Navy - Naval Air Eng Center	Lakehurst	NJ	1	1990	18529
US Navy - Naval Air Test Center	Patuxent River	MD	4	1989	18336
US Navy - SIMA San Diego (Seal Beach)	San Diego	CA	1	1996	96314
US Navy - Bremerton (Puget Sound)	Yokosuka	JAPAN	1	1993	93326
Vitec	Cleveland	OH	1	2001	201102
Westinghouse Savannah River Co	Aiken	SC	1	1998	98188
Westinghouse Savannah River Co	Aiken	SC	1	1993	93237
	TOTAL MB 475 SYSTEMS TO DATE:		**122**		

"WIN475-Standard" System



What's Really Important?

Experienced Users Agree:

1. The lowest possible uncertainty -- and a reasonable price
2. Minimize reproducibility variation in measurements
3. Broad frequency range
4. Easy to use
5. Throughput
6. Professional reports and simplified recordkeeping
7. Reliable equipment and instrumentation

Terminology

Transfer Standard Approach: *calibrating an unknown transducer by comparing its sensitivities over an operating frequency range to those of a known transducer*

System Transfer Uncertainty (STU): *error introduced by all of the instrumentation and equipment used to perform this comparison (except the Reference Standard Accelerometer)*

Reference Standard Accelerometer Uncertainty (REF): *uncertainty of the known or reference transducer, shown on its Calibration Certificate*

Expanded System Uncertainty (ESU): *the cumulative error inherent in the measurement system used to calibrate a transducer; combines the uncertainty of the instrument / system and the uncertainty of the REF*

Uncertainties of "Win475-Standard"

Specification	MB "*Win475-Standard*" System Uncertainty
System Transfer Uncertainty (STU) @ 95 % confidence level (excludes REF Uncertainty):	
• 100 Hz or 159 Hz	0.25 %
• 5 Hz to 2000 Hz	0.25 %
• 2,000 Hz to 8,000 Hz	0.25 %
• 9,000 Hz to 10,000 Hz	0.5 %
• 1 Hz to 2 Hz	1.0 %
• 3 Hz to 4 Hz	0.5 %
Reference Standard Accelerometer Uncertainty (REF) @ 95% confidence level:	Absolute Calibration
• 1 Hz to 2,000 Hz	0.5 %
• 2,000 Hz to 10,000 Hz	1.0 %
Expanded System Uncertainty (ESU) @ 95 % confidence level:	
• 5 Hz to 2000 Hz	0.6 %
• 2,000 Hz to 8,000 Hz	1.1 %
• 9,000 Hz to 10,000 Hz	1.2 %
• 1 Hz to 2 Hz	1.2 %
• 3 Hz to 4 Hz	0.8 %

MB Strengths → Low Uncertainty

- **Sophisticated signal processing (FFT techniques and narrow-band tracking filter) - lesser systems use simple, less accurate RMS-detection method**
- **Precision, matched dual channel signal conditioner**
- **Proprietary software error algorithm detects deviations in system electronics and compensates for them, improving low frequency amplitude measurements & high frequency phase measurements**

System Transfer Uncertainty

- **REDSTONE CHECK includes all errors due to electrical & mechanical noise, shaker sine wave distortion, cross-axis motion, accelerometer base strain and mass compensation effects, errors from instrumentation, environmental effects, errors from data acquisition/signal processing, etc.**
- **Requires 3 mV Peak or 7 pico-coulombs Peak of signal from each accelerometer to assure System Transfer Uncertainty specs**
- **Requires accelerometer resolution less than 1/50 of the measured amplitude to assure System Transfer Uncertainty specs**

System Transfer Uncertainty

- **Procedure for measuring System Transfer Uncertainty:**

  The REDSTONE CHECK

  Step 1 use a known transducer, REF A, to calibrate an unknown one, REF B

  Step 2 use REF B as the known transducer, with sensitivity values from Step 1, and calibrate REF A

  Step 3 for REF A, compute the % differences in sensitivity at each frequency from the known values given in Step 1 and those from Step 2

- **System Transfer Uncertainty is the maximum difference at any frequency in a defined frequency range**

Reference Standard Uncertainty

- **Uncertainty of Reference Standard Accelerometer is provided by accelerometer supplier or Standards lab as part of its calibration report**

- **Calibration must be traceable to a National Standards lab following prescribed, published calibration procedures**

- **Reference Accelerometer Uncertainty is expressed over defined frequency ranges dependent on measurement uncertainties of the Standards lab**

Expanded System Uncertainty

- Compute as the square root of the sum of the squares of
  - *System Transfer Uncertainty*
  - *Reference Standard Accelerometer Uncertainty*
- Publishing the "best" component uncertainty distorts true System Transfer Uncertainty (ex: spec says "5 digit DVM" but last 3 digits vary wildly - meaningless)
- Computing System Transfer Uncertainty from component uncertainties requires identical frequency ranges, common environmental conditions, consistent calibration procedures for components sourced from different suppliers, etc.

CONCLUSION: Measure transfer uncertainty, don't compute from component uncertainties

Uncertainty Summary

- Win475 supports a Test Accuracy Ratio (TAR) of 4:1
- Users maintain a TAR of 4:1 while calibrating 5% devices
- Win475 can be used to comply with ANSI / NCSL Z540-1-1994, ISO 9000 (ANSI / ASQC Q90 Series), ISO/IES 17025, ISO 16063-1 and ISO 5347
- The smaller the System Transfer Uncertainty the more leeway a lab has to absorb higher Human Error

MB Win475 has
Highest Proven Transfer Uncertainty and the
Broadest Frequency Range
at the
Most Affordable Price
of any calibration system

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7. **Reliable equipment and instrumentation**

Reproducibility

Reproducibility: the variation in the average of the measurements made by different people using the same measuring instrument when measuring the identical characteristics on the same item

Sources of reproducibility variation from different people:

- **Different skills and different levels of training**
- **Varying care and attention to detailed procedures**
- **Inconsistent preparation of accel contacting surfaces & inconsistent torques**
- **Different environmental conditions from time to time**
- **Dirty connectors, damaged cables, accelerometer cable whip, and failure to properly secure accelerometer cables (especially charge mode devices)**
- **Uncontrollable & inevitable mistakes by human beings!**

Steps Taken by MB to Minimize Reproducibility Variation

- Highly automated software system- simply select DUT from list!
- "Self Check" and "Accuracy Check" assure that the calibration system itself is OK
- Signal conditioner has no knobs or switches that can get set incorrectly due to boredom or lack of attention
- Real time display of waveforms
- Manual mode helps find sources of human error
- Easy-to-follow documentation helps to "do it right"
- Password protection of set-up files

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Broad Frequency Range

- **"Win475-Standard" has very broad frequency range (1 Hz - 10 kHz)**
  - CAL 50 exciter has 25 mm of stroke and a stiff armature that allows it to be used as low as 1 Hz and up to 10kHz
  - Much more expensive systems have a minimum frequency for the shaker of 10 Hz or even 20 Hz (they require the user to do a second calibration run for accelerometers that are used below 10 Hz, and most are)
  - Achieve 1.2% Expanded System Uncertainty as low as 1 Hz. This allows the desirable 4:1 ratio for a 5% device being calibrated, even at 1 Hz.
- **"Win475-Low Frequency" System, 0.1 Hz to 200 Hz**
  - CAL 20 exciter has 150 mm of stroke that allows it to be used as low as 0.1 Hz
  - Excellent performance on low sensitivity DUTs that must be accurately calibrated < 10 Hz, and for sub 1.0 Hz calibrations, especially on heavy DUTs

CAL20 Exciter Options

CAL20 Vertical-only mode

- 0.2 Hz to 200 Hz
- 6" of stroke p-p (150 mm)
- Max. DUT: 1.1 lb (<500 gm)
- 7 g's on 0.25 lbs DUT (125 gm)

CAL20 Horizontal-only mode

- 0.1 Hz to 100 Hz
- 6" of stroke p-p (150 mm)
- Max. DUT: 10 lb (4.5 kg)
- 0.5 g's on 6.6 lbs DUT (3 kg)

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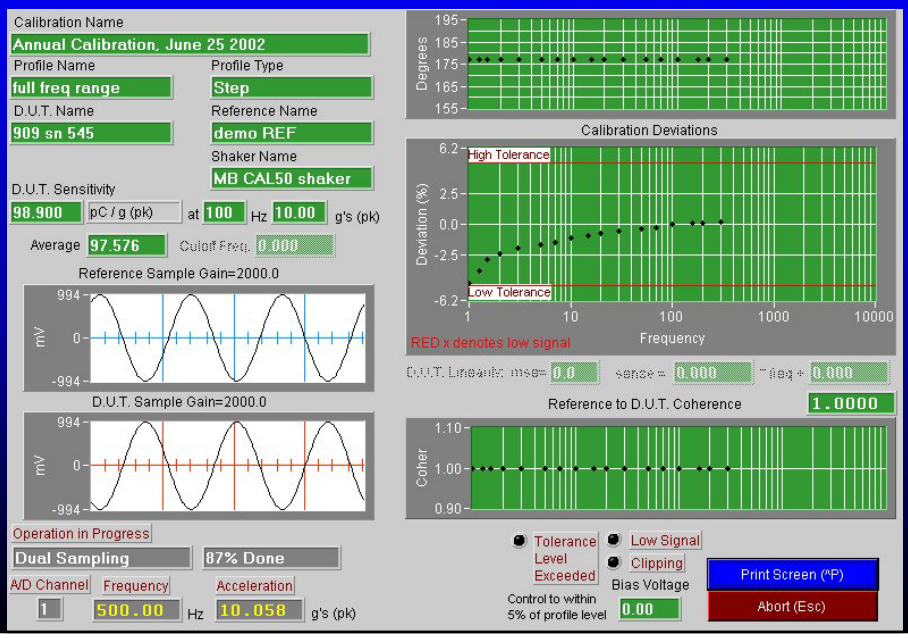
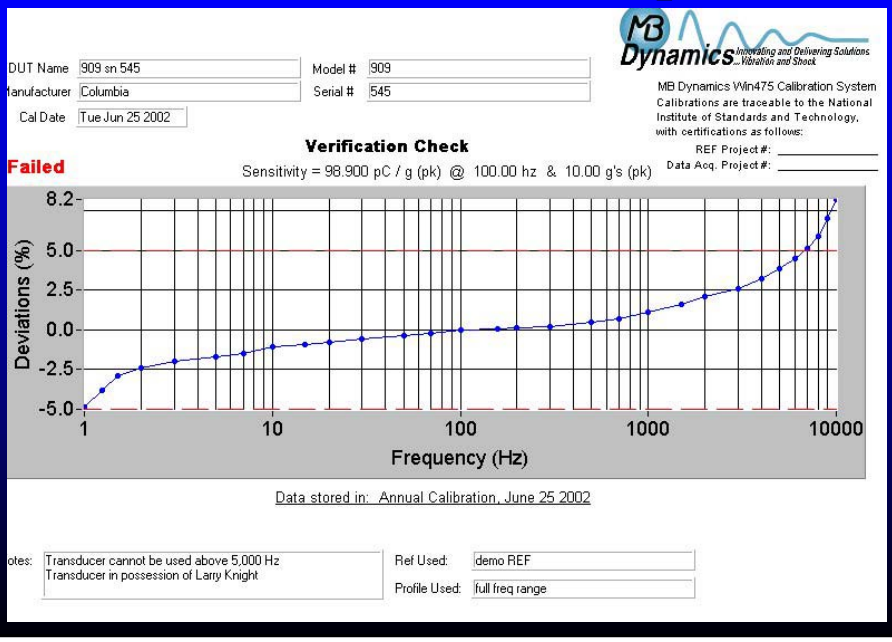
Other MB Features

- Calibrations in 3-5 minutes, typical
- Reliable equipment & instrumentation:
  - Minimal hardware & electronics: software does the work
  - Minimal hardware & electronics: one Model 405 vs. many boxes/instruments
  - Normal calibrations use small fraction of shaker / amplifier force capacity
  - World-class plug-in board supplier: National Instruments
- NIST traceability
- Many report formats (customizable)
- Real time display of waveforms
- Compact desktop package (very space efficient)
- Outputs to all Windows compatible printers; ASCII output; calibrate next DUT while printing report from last DUT
- English and SI units

SINE Run-Time Screen



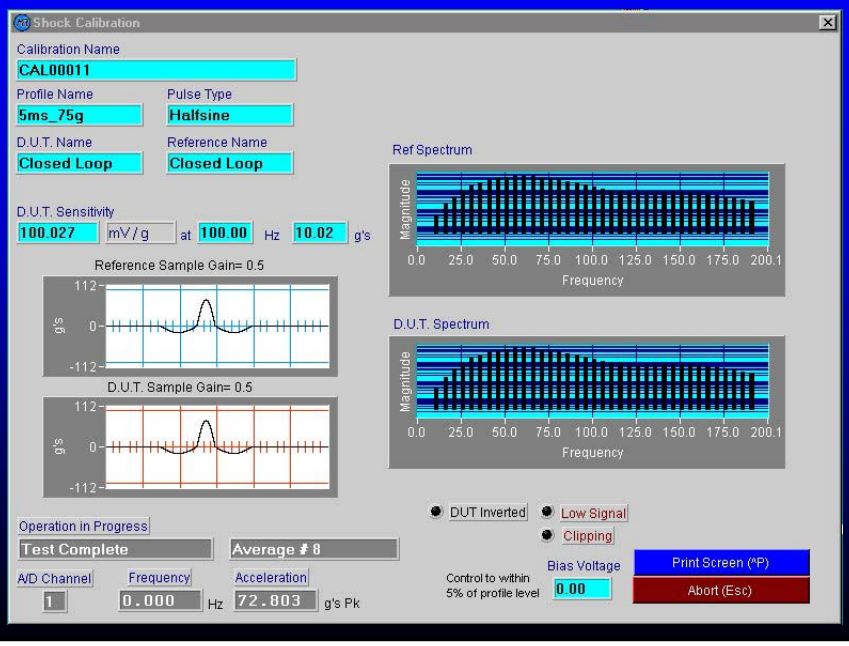
SINE Calibration Report



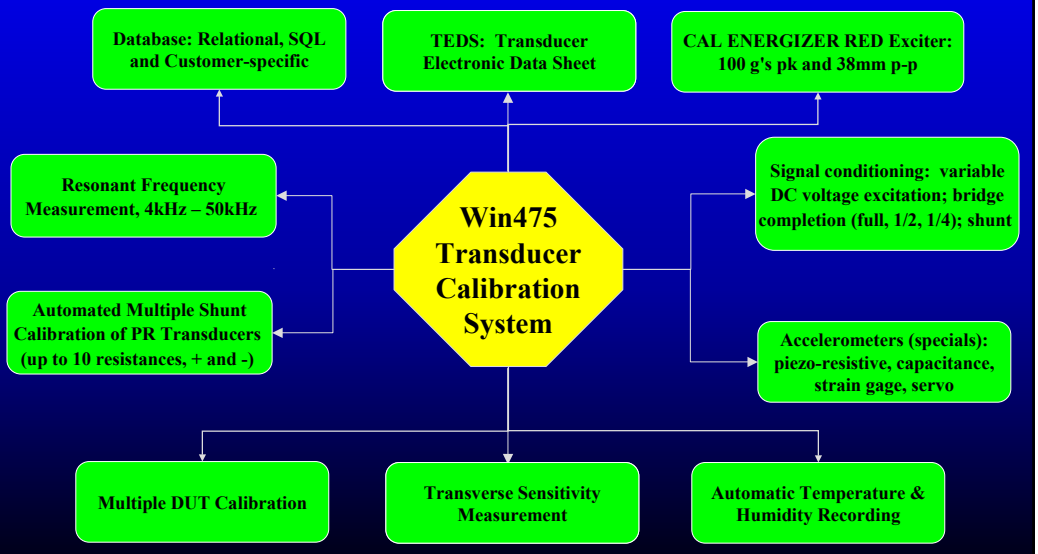
RANDOM Vibration Calibration Option

- Computes nominal sensitivity at single frequency and amplitude
- Computes deviations from this nominal sensitivity via FFT methods
- Calibration deviations computed at traceable frequencies defined by the REF accelerometer
- Computes phase of DUT with respect to the REF
- Uses flat random energy for the calibration profile
- Multiple calibration profiles are available with pre-set bandwidths and adjustable amplitudes
- Common look and feel of setup screens and plotting routines as in SINE module
- Add-on software module to standard Win475 Calibration System; no other hardware required

SHOCK Run-Time Screen



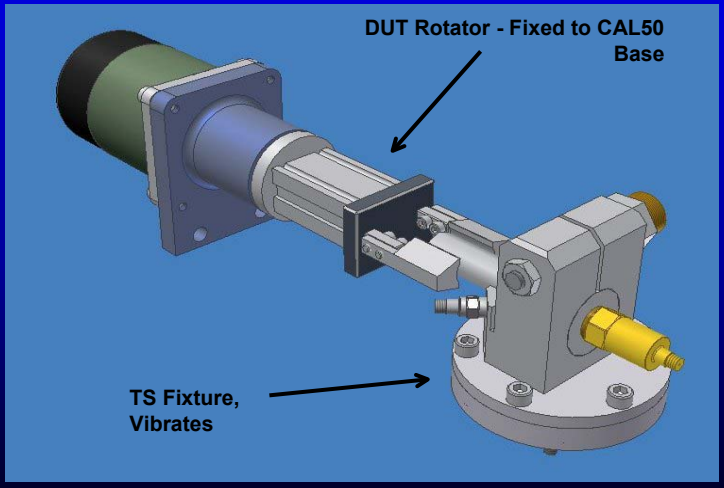
WIN475 Special Features



Transverse Sensitivity Measurement

- Transverse Sensitivity of a vibration sensor is defined as the output due to an acceleration perpendicular to sensing axis. This is expressed either as a % of the nominal sensitivity or as a sensitivity in mV/g, pC/g, mV/ips, or mV/m/s.
- A specification of "2 % transverse sensitivity" on a 100 mV/g accelerometer means when that accelerometer experiences 1 g pk. of vibration perpendicular to its sensing axis, its output is an error term of ∗ 2 mV.
- This output due to perpendicular vibration varies with the radial direction of the vibration about the accelerometer's sensing axis.
- By specification, when this accelerometer is vibrated at 1 g pk in any radial direction perpendicular to its sensing axis, the output would not exceed 2 mV.
- The purpose of this MB ***Win475-TS*** Transverse Sensitivity Calibration System is to automatically make controlled measurements to determine:
  - the maximum transverse sensitivity, and
  - its radial direction, or its polar coordinates about the transducer's sensing axis

TS Fixture & DUT Rotator - Automated



Comparing MB Win475-TS to ISO 5347-11

ISO 5347-11	MB Win475-TS
"The limits of uncertainty applicable are <10% of reading."	Uncertainty of transverse sensitivities in mV/g or pC/g can be within <10% of reading with /10 mV or 20 pC of output.
"Vibrator fixture shall mount the accelerometer at different angles about its sensing axis, preferably for continuous rotation over at least 180°."	Standard met; no exception.
"The transverse acceleration of the vibrator fixture shall be < 2% of the vibration in the intended direction . . . Achieved by proficient fixture design and by testing at selected frequencies."	Standard met; no exception.
"Amplitude in m/s^2 of 1, 2, 5, 10, 20, 50, or their multiples of ten"	Amplitude of 250 m/s^2 provides higher output perpendicular to sensing axis.
"Frequency in Hz: 20, 40, 80, 315, 630, 1250, 2500, 5000"	Frequencies: 5 to 2500 Hz, user-selectable
"sensitivity can be a function of frequency"	Standard met; no exception.

Comparing MB Win475-TS to ISO 16063-1

ISO 16063-1	MB Win475-TS
"transverse sensitivity ratio (TSR) is usually determined at a single frequency below 500 Hz."	Multiple frequencies are user-selectable between 5 to 2500 Hz; not limited to one frequency as with resonant beam apparatus
"motion shall be 100 times the motion in the direction of the sensing axis"	***Win475-TS*** computes the motion in DUT sensing axis and deducts it from transverse sensitivity measurements; ***Win475-TS*** does not require meeting the 100 X guideline in order to achieve specified performance
"transducer is mounted and rotated about its sensing axis through 360º, in increments of 45º or less"	Standard met; no exception.
"transverse sensitivity measurements on accelerometers indicate no detectable frequency dependence up to about 2000 Hz"	Assumptions in Standard can be validated up to 2500 Hz

Win475 Calibration System - Summary

- System Transfer Uncertainty as good as 0.25%
- Standard System has very broad frequency range (1 Hz - 10 kHz)
- Low Frequency Option down to 0.1 Hz (uses 150 mm stroke shaker)
- High throughput: shortens calibration turnaround time
- Excellent, flexible reports (includes phase plots - important for modal)
- Simple to use; no instruments; reduces human error
- Costs less than other systems (ex: B&K / Endevco)