The current status of Acoustics, Ultrasound and Vibration measurement standards at NMIJ/ AIST

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1. Introduction

NMIJ has four research institutes. Acoustics and Ultrasonics Standards Group is involved in the Research Institute for Measurement and Analytical Instrumentation. Vibration and Hardness Standards Group is involved in the Research Institute for Engineering Measurement.

Acoustics and Ultrasonics Standards Group is responsible for the development, supply and maintenance of acoustic and ultrasonic standards. Acoustic standards are essential for precise measurement of audible sound, airborne ultrasound and infrasound. Acoustic measurements are closely related to human hearing, noise pollution and safety evaluation. Ultrasonic standards are essential for the precise measurement of ultrasonic power, ultrasonic pressure and ultrasonic field parameters. Ultrasonic measurements are related to medical diagnostics, treatments, and industrial applications.

Vibration and Hardness Standards Group is responsible for the development, supply and maintenance of vibration and acceleration standards, hardness standards and material impact strength standards necessary in order to ensure the safety and quality control of transport equipment and structures. Vibration and acceleration standards cover vibration acceleration, shock acceleration and angular velocity.

Activities of the above two groups include integrating opinions from domestic stakeholders such as government, academic organizations and industries, and reflecting their opinions to international arrangements. We hold an annual meeting in order to share the information on global technical trends and to exchange opinions.

2. Acoustics

Established calibration services

Quantity	Calibration and Measurement Capabilities			Participated international comparison
	Instrument or Artefact	Measurement conditions Independent Variable	Expanded Uncertainty (k = 2)	

Pressure sensitivity level	Measurement microphone, LS1P (Laser pistonphone method)	$1\ \text{Hz} \le f \le 2\ \text{Hz}$	0.2 dB	
		$2\ \text{Hz} < f \le 20\ \text{Hz}$	0.1 dB	
	Measurement microphone, LS1P (Coupler reciprocity method)	$20\ \text{Hz} \le f \le 4\ \text{kHz}$	0.04 dB	CCAUV.A-K1 CCAUV.A-K2 CCAUV.A-K5 APMP.AUV.A-K1
		$4\ \text{kHz} < f \le 8\ \text{kHz}$	0.05 dB	
		$8\ \text{kHz} < f \le 10\ \text{kHz}$	0.15 dB	
		$10\ \text{kHz} < f \le 12.5\ \text{kHz}$	0.17 dB	
	Measurement microphone, LS2aP (Coupler reciprocity method)	$20\ \text{Hz} \le f < 25\ \text{Hz}$	0.07 dB	CCAUV.A-K3 CCAUV.A-K6 APMP.AUV.A-K3
		$25\ \text{Hz} \le f < 31.5\ \text{Hz}$	0.06 dB	
		$31.5\ \text{Hz} \le f < 40\ \text{Hz}$	0.05 dB	
		$40\ \text{Hz} \le f \le 12.5\ \text{kHz}$	0.04 dB	
		$12.5\ \text{kHz} < f \le 16\ \text{kHz}$	0.05 dB	
		$16\ \text{kHz} < f \le 20\ \text{kHz}$	0.12 dB	
Free-field sensitivity level	Measurement microphone, WS1 (Comparison in a free field)	$20\ \text{Hz} \le f < 6.3\ \text{kHz}$	0.2 dB	
		$6.3\ \text{kHz} < f \le 8\ \text{kHz}$	0.3 dB	
		$8\ \text{kHz} < f \le 12.5\ \text{kHz}$	0.4 dB	
	Measurement microphone, WS2 (Comparison in a free field)	$20\ \text{Hz} \le f < 6.3\ \text{kHz}$	0.2 dB	
		$6.3\ \text{kHz} < f \le 8\ \text{kHz}$	0.3 dB	
		$8\ \text{kHz} < f \le 20\ \text{kHz}$	0.4 dB	
	Measurement microphone, WS3 (Comparison in a free field)	$20\ \text{Hz} \le f < 31.5\ \text{Hz}$	0.6 dB	
		$31.5\ \text{Hz} \le f \le 1.6\ \text{kHz}$	0.4 dB	
		$1.6\ \text{kHz} < f \le 8\ \text{kHz}$	0.5 dB	
		$8\ \text{kHz} < f \le 20\ \text{kHz}$	0.8 dB	
	Measurement microphone, WS3 (Reciprocity in a free field)	$20\ \text{kHz} \le f \le 100\ \text{kHz}$	1.0 dB	
	Sound calibrator	$31.5\ \text{Hz} \le f < 63\ \text{Hz}$	0.09 dB	CCAUV.AUV.A-S1
		$63\ \text{Hz} \le f \le 8\ \text{kHz}$	0.08 dB	

Sound pressure level		$8\ \text{kHz} < f \leq 12.5\ \text{kHz}$	0.10 dB	
		$12.5\ \text{kHz} < f \leq 16\ \text{kHz}$	0.14 dB	
Free-field response level	Sound level meter	$20\ \text{Hz} \leq f \leq 2\ \text{kHz}$	0.2 dB	
		$2\ \text{kHz} < f \leq 6.3\ \text{kHz}$	0.3 dB	
		$6.3\ \text{kHz} < f \leq 12.5\ \text{kHz}$	0.5 dB	
Sound power level	Reference sound source	$100\ \text{Hz} \leq f < 125\ \text{Hz}$	0.8 dB	
		$125\ \text{Hz} \leq f < 160\ \text{Hz}$	0.6 dB	
		$160\ \text{Hz} \leq f < 250\ \text{Hz}$	0.5 dB	
		$250\ \text{Hz} \leq f \leq 2.5\ \text{kHz}$	0.4 dB	
		$2.5\ \text{kHz} < f \leq 5\ \text{kHz}$	0.5 dB	
		$5\ \text{kHz} < f \leq 8\ \text{kHz}$	0.6 dB	
		$8\ \text{kHz} < f \leq 10\ \text{kHz}$	0.9 dB	

The number of accredited labs：8 laboratories

The number of calibration services to accredited labs：23 calibration services from Sep. 2017 to present

Latest peer-review assessment

The latest peer-review assessment was carried out in March 2018 and we obtained accreditation on 29th March 2019. The accredited scope is shown in the above table.

Current CMC

Quantity	Calibration and Measurement Capabilities				Approved on
	Instrument or Artefact	Measurand Level or Range	Measurement conditions / Independent Variable (Optional)	Expanded Uncertainty (Level of Confidence Approximately 95 %)	
Pressure sensitivity level	Measurement microphone, LS1P		63 Hz	0.05 dB	1st Aug. 2004
			80 Hz to 4 kHz	0.04 dB	
			5 kHz	0.05 dB	

			6.3 kHz to 8 kHz	0.06 dB	

Activities (conferences and ISO committee, APMP etc.) [Sep. 2017 to present]

IEC TC29

- R. Horiuchi attended TC 29 meeting in Ottawa in 2018 as a head of Japanese delegates.

APMP TCAUV

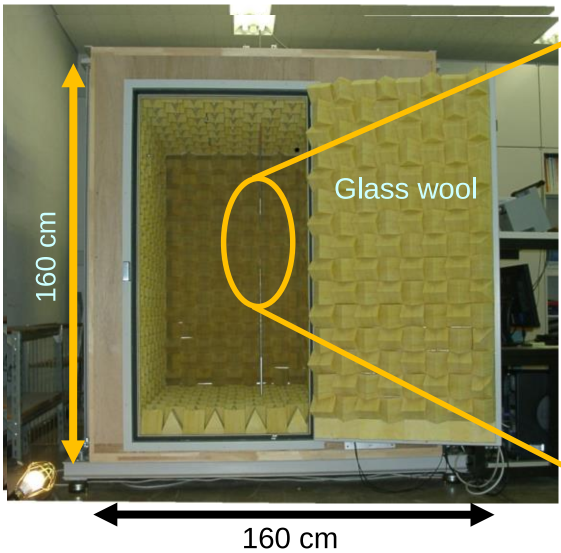
- R. Horiuchi attended APMP TCAUV meeting in India in 2017.
- R. Horiuchi attended APMP TCAUV meeting in Singapore in 2018.
- R. Horiuchi attended APMP Mid-year meeting in Cebu, Philippines in 2019 as a TCAUV chair.

Research activities

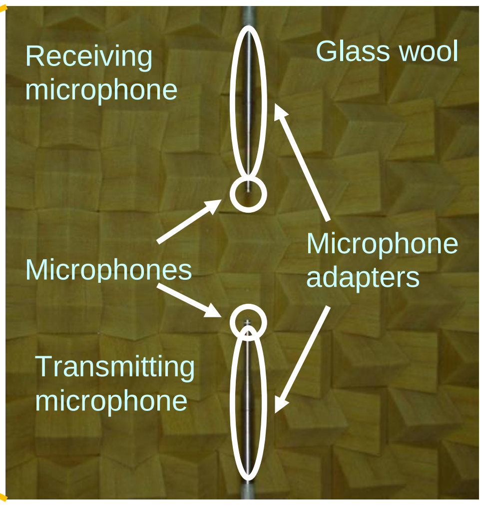
- Frequency range expansion for calibration of reference sound sources at frequencies down to 50 Hz and up to 20 kHz
- Precise and practical measurements of noise radiated from drones
- Measurements of airborne ultrasound emitted from electrical appliances
- Development of primary acoustic standard of pressure sensitivity level at frequencies lower than 1 Hz
- Development of optical sound measurements

Calibration facilities

Facility name	Pressure sensitivity calibration system
Range	20 Hz to 20 kHz
Exp. uncertainty	0.04 dB to 0.17 dB for LS1P, 0.04 dB to 0.12 dB for LS2P
In compliance with	IEC 61094-2

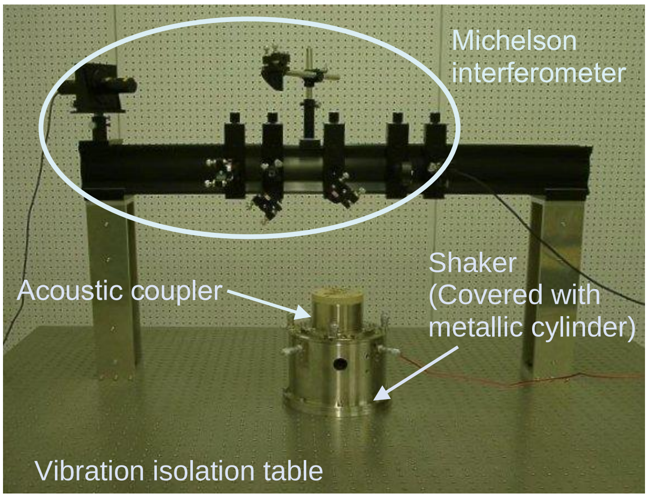


Anechoic box



Configuration of setting up the microphones

Facility name	Free-field sensitivity calibration system for airborne ultrasound
Range	20 kHz to 100 kHz
Exp. uncertainty	1.0 dB
In compliance with	IEC 61094-3



Facility name	Pressure sensitivity calibration system for infrasound
Range	1 Hz to 20 Hz
Exp. uncertainty	0.1 dB to 0.2 dB
In compliance with	None

Facility name	Sound power level calibration system
Range	100 Hz to 10 kHz with 1/3 octave-band steps
Exp. uncertainty	0.4 dB to 0.9 dB
In compliance with	ISO 6926

References

[1] K. Yamada, H. Takahashi and R. Horiuchi, “Availability of reference sound sources for qualification of hemi-anechoic rooms based on deviation of sound pressure level from inverse square law”, IEICE Trans. on Fundamentals, Vol. E101 A, No. 1, pp.211-218 (2018.1).

[2] H. Takahashi and R. Horiuchi, “Uncertainty analysis on free-field reciprocity calibration of WS3 microphones”, J. Acoust. Soc. Am., Vol. 144, No. 4, pp.2584-2597, (2018.10)

3. Ultrasound

Established calibration service

Item	Method	Calibration range Independent Variable	Expanded uncertainty (*k*=2)	Participated international comparison
Ultrasonic power	Radiation force balance	1 mW – 15 W (0.5 MHz – 15 MHz) 1 mW – 500 mW (15 MHz – 20 MHz)	5 % – 12 %	CCAUV.U-K3.1 APMP.AUV.U-K3
	Calorimetry	15 W – 100 W (1 MHz – 3 MHz)	9 %	
Hydrophone sensitivity	Reciprocity	0.1 MHz – 1 MHz	10 % – 13 %	
	Laser interferometry	0.5 MHz – 20 MHz	6.1 % – 8.8 %	CCAUV.U-K4
		21 MHz – 40 MHz	13 % – 17 %	
Ultrasonic field parameters	Plane scan using hydrophone	0.5 MHz – 20 MHz	Peak rarefactional instantaneous acoustic pressure: 7 % – 10 % Spatial-peak temporal-average intensity: 14 % – 20 % Spatial-average temporal-average intensity in 6 dB beam area: 14 % – 21 %	

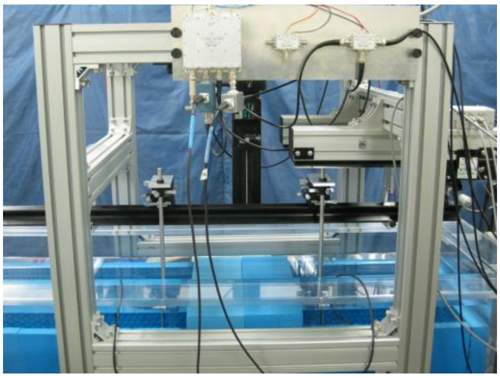
The number of calibration service to user of ultrasonic transducer or hydrophone:

27 (FY2017), 23 (FY2018) [Note: Japanese fiscal year is from April to March.]

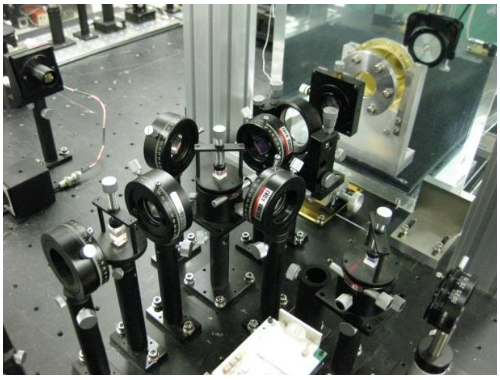
Radiation force balance

Water bath for calorimetry

Fig. U1: Ultrasonic power calibration system

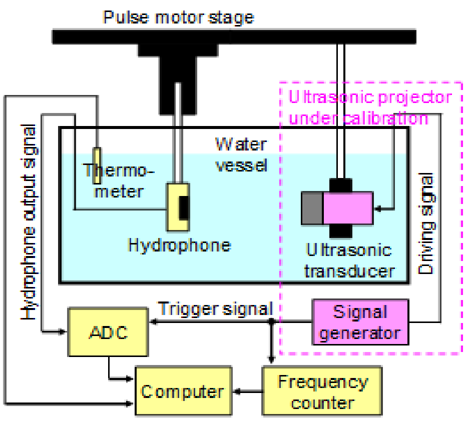


Reciprocity

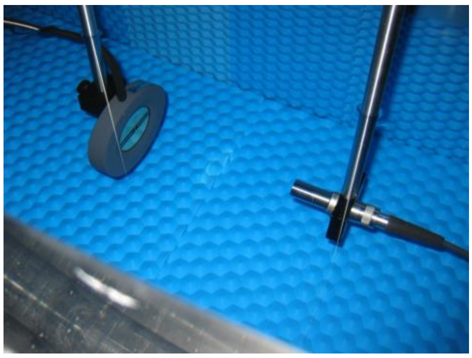


Laser interferometry

Fig. U2: Hydrophone sensitivity calibration system



Block diagram



Inside water vessel

Fig. U3: Ultrasonic field parameters calibration system

Activities [September 2017 to August 2019]

APMP TCAUV workshop on medical ultrasound metrology (Beijing, September 2018)

- T. Uchida, "Hydrophone calibration by laser interferometer in NMIJ"
- T. Uchida, "High ultrasonic power standard by calorimetric method in NMIJ"

APMP TCAUV initiative project: Pilot study comparison of ultrasonic power up to 100 W (Planned from 2019, Participants: NMIJ, NIM, KRISS)

- T. Uchida prepered ultrasonic transducers as circulated devices for the pilot study in July 2019.

IEC/TC87

- M. Yoshioka attended on meetings of Plenary, WG6, and WG8 in Olomouc, June 2018.
- M. Yoshioka attended on meeting of WG8 in Rio de Janeiro, February 2019.

Transfer of calibration technique

- Y. Matsuda and M. Yoshioka worked out a technical transfer of hydrophone calibration by comparison from 0.5 MHz to 20 MHz to a domestic calibration institute in August 2019.

Research in operation

- Expansion of ultrasonic power calibration range up to 200 W
- Expansion of calibration frequency range for amplitude response of hydrophone sensitivity from 50 kHz to 60 MHz
- Development of calibration system for phase response of hydrophone sensitivity from 1 MHz to 40 MHz by comparison
- Addition of calibrated ultrasonic field parameters of "effective radiating area" and "beam non-uniformity ratio"
- Precise measurement technique of instantaneous acoustic pressure for broadband ultrasonic wave using frequency response of amplitude and phase of hydrophone sensitivity
- Quantitative measurement technique for cavitation
- Evaluation about thermal effect by medical ultrasonic equipment

Others

- 2 measurement services of ultrasonic field and cavitation to an university hospital and a manufacturer

- Promotion for ultrasonic measurement techniques of NMIJ in 6 domestic exhibitions and meetings

References

[1] T. Uchida, M. Yoshioka, Y. Matsuda, and R. Horiuchi, Measurement on Ultrasonic Power by Calorimetric Method -Comparison between Saturated and Degassed Water-, Proceedings of Symposium on Ultrasonic Electronics, Vol. 38, p. 3P2-1 (2017).

[2] T. Uchida, M. Yoshioka, R. Horiuchi, Effect of Dissolved Oxygen Level of Water on Ultrasonic Power Measured Using Calorimetry, Jpn. J. Appl. Phys. 57, p. 07LC04 (2018).

[3] Y. Chiba, M. Yoshioka, and R. Horiuchi, Measurement of instantaneous acoustic pressure for diagnostic ultrasound using frequency characteristics of amplitude and phase of hydrophone sensitivity, Proceedings of Symposium on Ultrasonic Electronics, Vol. 39, p. 1P5-7 (2018).

4. Vibration and acceleration standards

Established calibration services

Quantity	Calibration and Measurement Capabilities			Participated international comparison
	Instrument or Artefact	Measurement conditions Independent Variable	Expanded Uncertainty (k = 2)	
Voltage sensitivity	Acceleration measuring chain	0.1 Hz to 200 Hz	0.2 %	CCAUV.V-K3 APMP.AUV.V-K3
		>200 Hz to 4 kHz	0.4 %	CCAUV.V-K1 CCAUV.V-K2 CCAUV.V-K5 APMP.AUV.V-K1 APMP.AUV.V-K2
		>4 kHz to 10 kHz	0.5 %	
Phase shift		1 Hz to 5 kHz	0.1 deg to 0.37 deg	CCAUV.V-K2 CCAUV.V-K5
Charge sensitivity	Accelerometer	20 Hz to 4 kHz	0.4 %	CCAUV.V-K1 CCAUV.V-K2 CCAUV.V-K5 APMP.AUV.V-K1 APMP.AUV.V-K2
		>4 kHz to 10 kHz	0.5 %	

Shock voltage sensitivity	Acceleration measuring chain	50 m/s^2 to 10000 m/s^2	0.6 %	CCAUV.V-K4
Angular velocity	Gyroscope	-300 deg/s to 300 deg/s	1.2×10^{-2} deg/s	

The number of accredited labs：6 accredited laboratories

The number of calibration service to accredited labs：5 calibration services from Sep. 2017 to present

Latest peer-reviewed assessment

Quantity	Calibration and Measurement Capabilities				Date of Accreditation
	Instrument or Artefact	Measurand Level or Range	Measurement conditions / Independent Variable (Optional)	Expanded Uncertainty (Level of Confidence Approximately 95 %)	
Voltage sensitivity (Modulus)	Acceleration measuring chain		0.1 Hz to 200 Hz	0.2 %	29th Mar. 2019
			>200 Hz to 4 kHz	0.4 %	
			>4 kHz to 10 kHz	0.5 %	
Charge sensitivity (Modulus)	Accelerometer		20 Hz to 4 kHz	0.4 %	
			>4 kHz to 10 kHz	0.5 %	
Shock voltage sensitivity (Modulus)	Acceleration measuring chain		50 m/s^2 to 10000 m/s^2	0.6 %	

Current CMC

Quantity	Calibration and Measurement Capabilities				Approved on
	Instrument or Artefact	Measurand Level or Range	Measurement conditions / Independent Variable (Optional)	Expanded Uncertainty (Level of Confidence Approximately 95 %)	
Voltage sensitivity (Modulus)	Acceleration measuring chain		40 Hz to 80 Hz	0.3 %	1st Aug. 2004
			100 Hz to 200 Hz	0.5 %	
			250 Hz to 2 kHz	1.0 %	
			2.5 kHz to 5 kHz	1.5 %	

Activities (conferences and ISO committee, APMP etc.) [Sep. 2017 to present]

IMEKO World Congress 2017

- H. Nozato *et al*., “Time delay evaluation for laser interferometer using electro-optical modulator”

ITRI-AIST 6th Joint Symposium

- W. Kokuyama, “Vibration metrology for infrastructure”

Dresden Metrologists Summit 2019

- H. Nozato, “Frequency response evaluation of laser Doppler vibrometer using electro-optic modulator”
- H. Nozato, “Evaluation of seismometer by low-frequency calibration facility at NMIJ”

ISO/TC108/WG33 & WG34

- H. Nozato attended on both the working groups 33 & 34 as the alternative head of delegates in Berlin, March 2019.

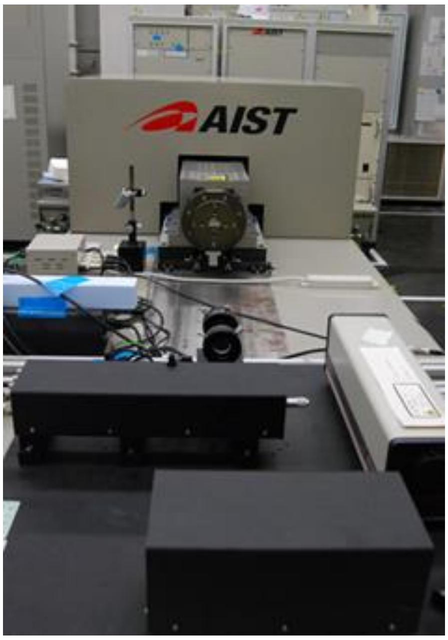
APMP TCAUV

- A. Ota and W. Kokuyama attended MEDEA training course on seismometer calibration at low frequency as trainer in Taiwan 2017.
- H. Nozato attended on APMP TCAUV and its workshop in India 2017.
- H. Nozato attended on APMP TCAUV and its workshop in Singapore 2018.

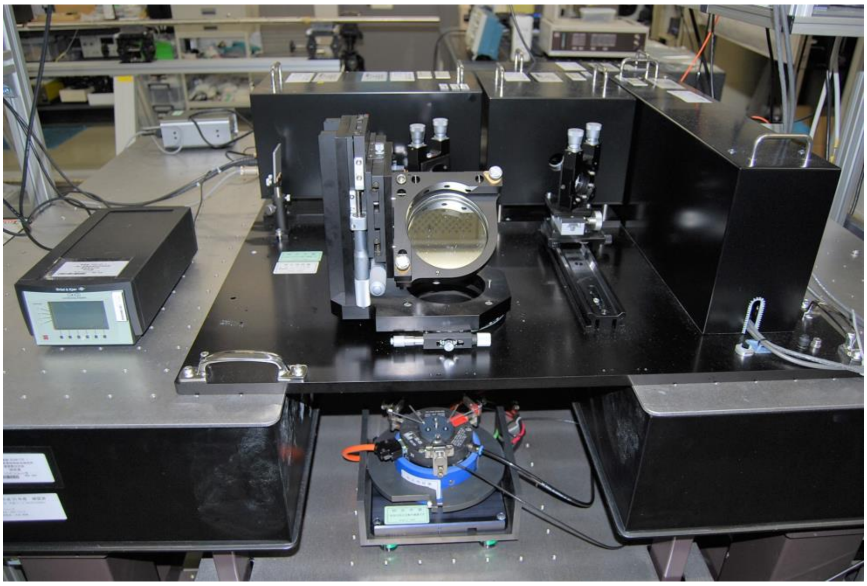
Other activities

- W. Kokuyama studies from Jan. 2019 to Apr. 2020 at Colorado university of United States.

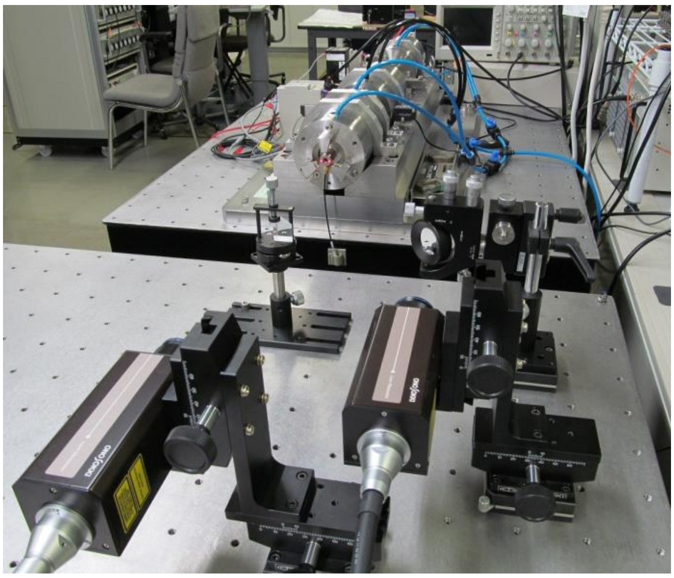
Calibration facilities



Facility name	Low-frequency calibration system[1]
Range	0.1 Hz to 200 Hz
Exp. uncertainty	0.2 %
Exciter	Electro dynamic exciter with air bearing
Standard	Homodyne laser interferometer
In compliance with	ISO 16063-11



Facility name	High-frequency calibration system[2][3][4]
Range	20 Hz to 10 kHz
Exp. uncertainty	0.3 % to 0.5 %
Exciter	Electro dynamic exciter with air bearing
Standard	Homodyne laser interferometer with double optical path
In compliance with	ISO 16063-11



Facility name	Low-shock calibration system[5][6]

Range	50 m/s^2 to 10,000 m/s^2
Exp. uncertainty	0.6 %
Exciter	Collision between two rigid bodies with air bearing
Standard	Two heterodyne laser interferometers
In compliance with	ISO 16063-13

Facility name	Angular velocity calibration system[7]
Range	-300 deg/s to 300 deg/s
Exp. uncertainty	1.2×10^{-2} deg/s
Exciter	Servo motor with air bearing
Standard	Self-calibratable rotary encoder
In compliance with	None

References

[1] W. Kokuyama, T. Ishigami, H. Nozato, A. Ota, "Improvement of very low-frequency primary vibration calibration system at NMIJ/AIST", Proceedings of XXI IMEKO World Congress, Prague, Czech Republic (2015).

[2] T. Usuda and T. Kurosawa, "Calibration methods for vibration transducers and their uncertainties", Metrologia, Vol.36, 375-383 (1999).

[3] A. Oota, T. Usuda, H. Aoyama, S. Sato, "Development of primary calibration system for vibration and acceleration standard in high frequency range with laser interferometer with multifold optical path", IEEJ Trans. SM, Vol.126, No.11, 612-620 (2006).

[4] A. Oota, T. Usuda, H. Nozato, “Correction and evaluation of the effect due to parasitic motion on primary accelerometer calibration”, Measurement, Vol.43, No.5, 714-725 (2010).

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[7] W. Kokuyama, T. Watanabe, H. Nozato, A. Ota, “Angular velocity calibration system with a self-calibratable rotary encoder”, Measurement, Vol.82, 246-253 (2016).