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

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1. Introduction

In April 2015, the NMIJ was re-organized and 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 measurement are related to the 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.

2. Acoustics

Activities after last CCAUV meeting

(1) Sound power level standards

Japanese manufacturers of electrical products, such as copy machines, printers, and air conditioners, are required to precisely measure sound power level emitted from their own products to sell them worldwide. The main purpose of the measurement is that laws and regulations etc. in foreign countries require reliable measurement, and/or the manufactures need to get “eco-label” approvals to differentiate competitor manufacturers.

Practically, sound power measurement of the products is often made in comparison with reference sound sources (RSSs). Thus the calibration of the RSSs is essential and has an important

Fig. A1: Hemisphere frame for fixing microphones and RSS located in anechoic chamber

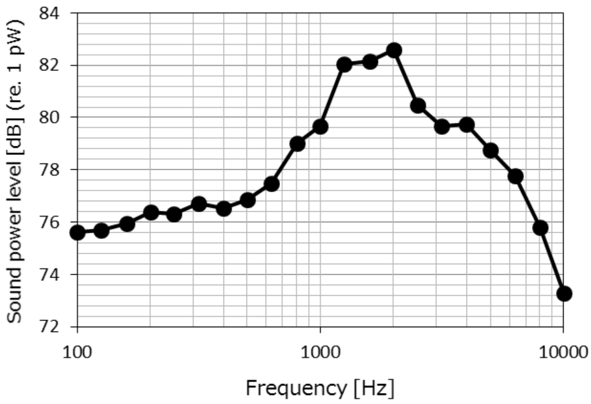

Fig. A2: Sound power level of RSS determined by our calibration system (Brüel and Kjær Type 4204)

role in the sound power measurement. The calibration procedure for RSS is standardized in ISO 6926, but there was no calibration laboratories in Japan except for NMIJ having anechoic room that satisfies the requirements of ISO standard. The RSS users in Japan were keen for NMIJ to calibrate them.

Under these background, we had developed the RSS calibration system, and in April 2015 we started the RSS calibration service from 100 Hz to 10 kHz with 1/3 octave sequence. The expanded uncertainties of the calibration (k=2) are from 0.4 dB to 0.9 dB.

Fig. A1 shows a photo of our calibration system, composed of hemisphere frame for fixing microphones and the RSS. The NMIJ does not have hemi-anechoic room and the hemi-anechoic environment is realized by underlying wooden plates in the anechoic room. The influence of the wooden board floor was investigated in detail by experiments and we found that it can be precisely corrected in the calibration [1-3]. **Fig. A2** shows an example of sound power level of RSS determined by our system.

To meet with customer requirements, we keep improving the calibration system to expand the frequency range, covering from 50 Hz to 20 kHz.

(2) Calibration of free-field sensitivity levels for type WS3 microphones in audible frequency

Since 2009, we have provided primary standards for airborne ultrasound by the free-field sensitivity levels of WS3 microphones from 20 kHz to 100 kHz. In recent years, WS3 microphones have been gradually used for acoustic measurements in audible frequencies because they are relatively small and do not disturb sound fields as compared with WS2 microphones. Furthermore, microphone array systems are made up of many small microphones such as type WS3 and often used for acoustic source localization. To cope with customer requirements and ensure the reliable acoustic measurement in audible frequencies, we decided to expand calibration frequencies of WS3 microphones down to 20 Hz. We use the reciprocity technique to calibrate WS3 microphones at airborne ultrasound range but it cannot be applied in audible frequencies because sufficient signal-to-noise ratio cannot be achieved. Following to IEC 61094-8, the sensitivities of WS3 microphones in audible frequencies are determined by comparing with reference LS2 microphones whose sensitivities are previously determined[4,5]. The calibration service was started in April 2015. The expanded uncertainties of the calibration (k=2) are from 0.4 dB to 0.8 dB.

(3) Research works

After the free-field sensitivity level calibration service for airborne ultrasound was started in 2009, we continue to improve the calibration system and decrease the measurement uncertainty. Particularly in airborne ultrasound range, we found some problem about microphone preamplifier for insert voltage technique and thus made it by ourselves. Our preamplifier is quarter inch in diameter and can be directly connected to the WS3 microphone without any adaptor. Other research activity includes examining the consistency of pressure sensitivities of LS microphones determined by using a large volume coupler and plane wave coupler, measuring and evaluating an airborne ultrasound emitted from electrical appliances, and developing optical microphones.

Calibration services

NMIJ has developed calibration systems to provide the national standards of sound pressure in air.

1) Primary calibration of pressure sensitivity level of laboratory standard microphones (LS1P & LS2P) by using the pressure reciprocity technique (20 Hz to 20 kHz).
2) Primary calibration of free-field sensitivity level of laboratory standard microphones (LS1P & LS2P) by using the free-field reciprocity technique (1 kHz to 20 kHz).
3) Comparative calibration of free-field sensitivity level of working standard microphones (WS1, WS2 & WS3, 20 Hz to 20 kHz).
4) Comparative calibration of free-field response level of sound level meters (20 Hz to 12.5 kHz).
5) Determination of sound pressure level of sound calibrators (31.5 Hz to 16 kHz).
6) For airborne ultrasound, the microphone calibration system by the free-field reciprocity technique in the compact anechoic chamber (**Fig. A3**) was established. The calibration frequency range of WS3 microphones is from 20 kHz to 100 kHz. This standard is essential for human safety evaluation and for testing equipment which radiates air-borne ultrasound.
7) For infrasound, the pressure sensitivity calibration system by “laser pistonphone method” was established (**Fig. A4**), Calibration frequency range of LS1P microphones is from 1 Hz to 20 Hz. This standard is essential for low frequency noise analysis and evaluation.

8) Calibration of sound power level of RSS (100 Hz to 10 kHz with 1/3 octave sequence)

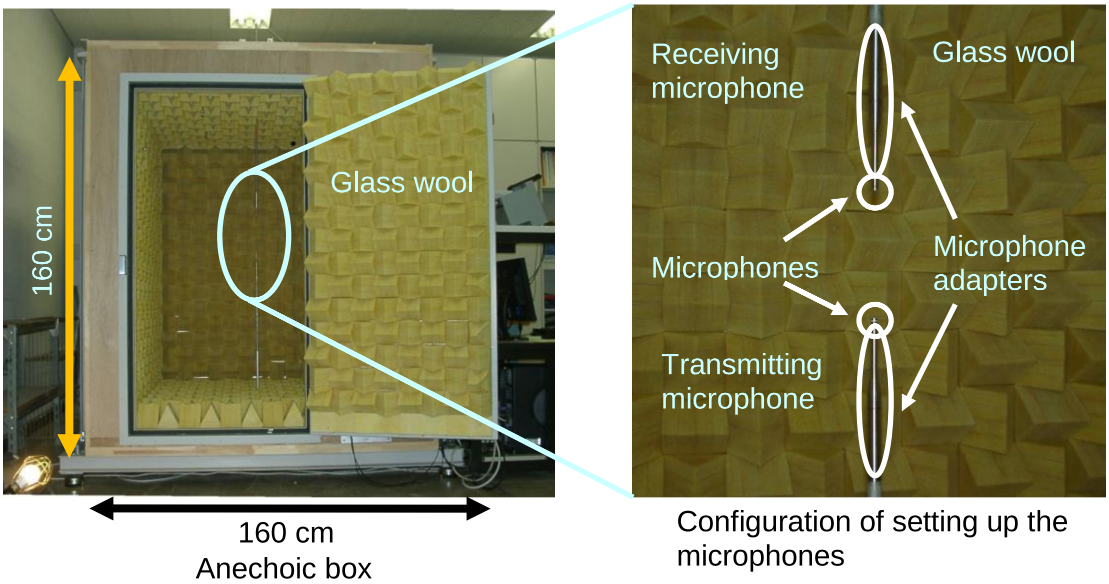

Fig A3: Compact anechoic chamber used for the calibration of airborne ultrasound by the reciprocity technique.

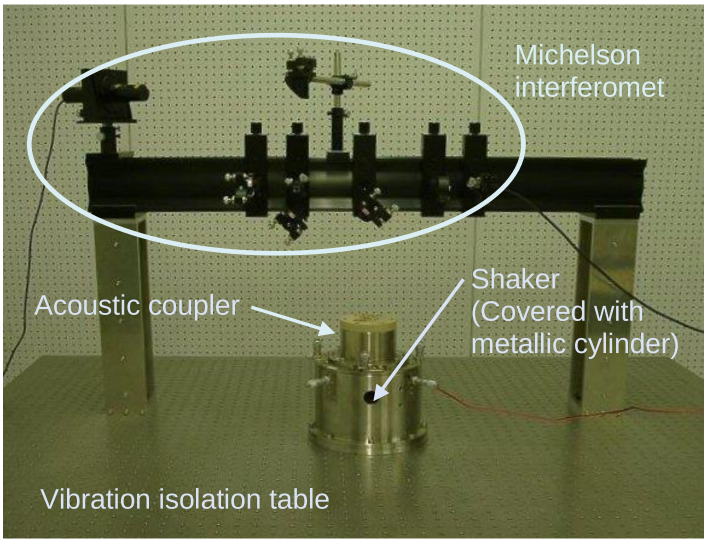

Fig. A4: "Laser pistonphone" which composes the microphone calibration system for infrasound.

Key comparisons and peer review

There are no international key comparison since last CCAUV meeting. Technical competence in our calibration system was confirmed by the peer review in Dec. 2012, and our calibration services for acoustics were re-accredited in May 2013.

CMCs

There are no changes in CMCs since last meeting.

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3. Ultrasound

We have established three kinds of ultrasonic standard.

1) Ultrasonic power

The radiation force balance (RFB) system of NMIJ is shown as **Fig. U1**. The primary standard of ultrasonic power using RFB has been started up to 500 mW in 2005. In 2009, the power range has been expanded up to 15 W. The frequency range and the power range are as follows;

1 mW ~ 15 W (0.5 MHz ~ 15 MHz)

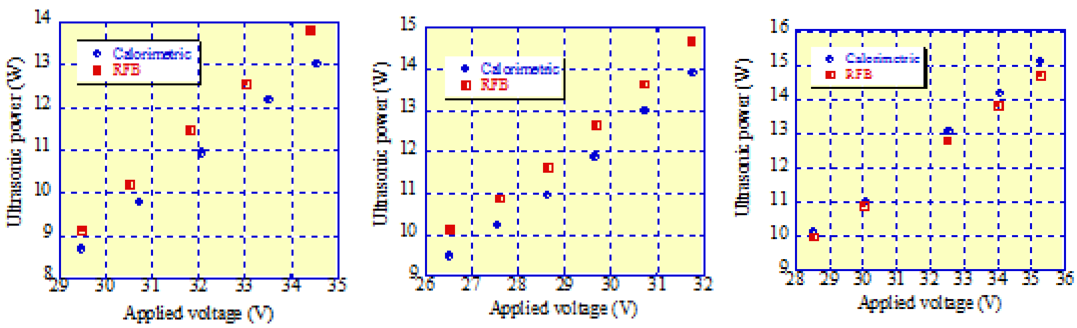
1 mW ~ 500 mW (15 MHz ~ 20 MHz)

The measurement uncertainties are 5 % ~ 12 % (95 % level of confidence).

Ultrasonic high power standard was developed by using "calorimetric method" with water as heating material for applying HITU (High Intensity Therapeutic Ultrasound). In this measurement, water bath is one of the important key elements. We have developed "free field" water bath. **Fig. U2** shows the photograph of the water bath. The radiated ultrasound repeats reflections at the water bath wall, and finally, circulates one-way in the water bath. We had already achieved ultrasonic power measurement up to 100 W in frequency range from 1 MHz and 3 MHz. The deviations between ultrasonic power measurement using calorimetric and RFB methods are within 5 %, as shown in **Fig. U3**. An ultrasonic power calibration service from 15 W to 100 W using "calorimetric method" was started in 2014. The corresponding expanded uncertainty is 9 % for 95 % level of confidence.

Fig. U1: A photograph of recovered ultrasonic power measurement system.

Fig. U2: A "free field" water bath.



1 MHz 2 MHz 3 MHz

Fig. U3: Relationship between applied voltage to the transducers and ultrasonic power obtained by calorimetric and RFB method. Operating frequencies are 1 MHz, 2 MHz, and 3 MHz, respectively.

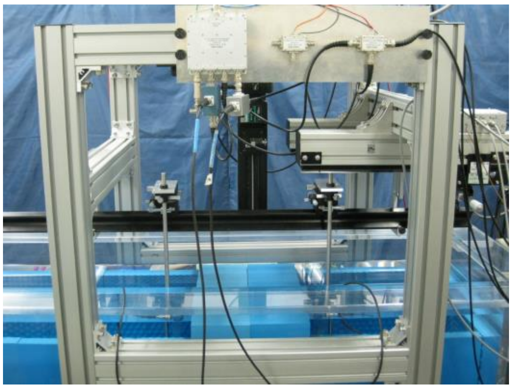


Fig. U6: A photograph of measurement system for reciprocity technique

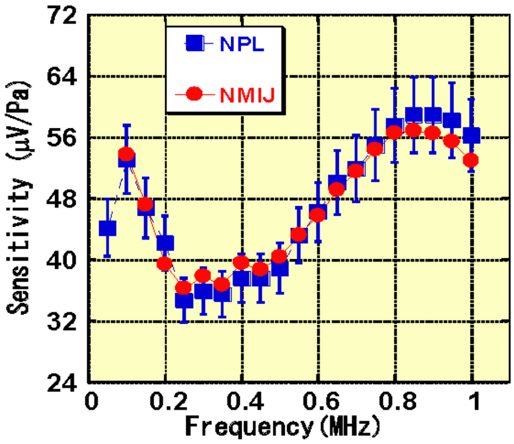


Fig. U7: Measured hydrophone sensitivity between 1 kHz and 1 MHz by reciprocity technique.

2) **Hydrophone sensitivity**

The primary calibration system for sensitivity of the standard membrane hydrophone (CPM04, Precision Acoustic Ltd.) using the laser interferometry has been established in 2005. The frequency range of the calibration is 0.5 MHz to 20 MHz. We have also established comparative calibration system for calibrating end-user hydrophones. Typical values of the expanded uncertainties are 6.1 % ~ 8.8 % (95 % level of confidence).

We are going to expand the higher frequency range up to 40 MHz by using laser interferometry, and lower frequency range between 100 kHz and 1 MHz by using reciprocity technique.

One of the most serious problems of high frequency calibration is the ultrasonic attenuation in water. So, we have to achieve "ultrasonic far-field" at near distance from the transducer as possible. One of the solutions of this problem is to develop an ultrasonic transducer whose active element size is as small as possible as shown in **Fig. U4.** And for the practical reason, it should have wideband frequency characteristics. We are developing this type of transducers by using PVDF-TrFE whose nominal active element diameter is 2 mm. As the result, we achieved the calibration up to 40 MHz as shown in **Fig. U5**. The discrepancy between the calibration results measured using the developing system and those measured using our current calibration system were within the uncertainties of our current calibration system at frequencies of 10–20 MHz. We estimated the expanded uncertainty for the calibration as 13 % above 20 MHz to 30 MHz and 17 % up to 40 MHz. We started the hydrophone sensitivity calibration up to 40 MHz using laser interferometry in 2014.

We are also developing the hydrophone sensitivity calibration system whose frequency range is 100 kHz to 1 MHz by reciprocity technique according to IEC 60565. The photograph of measurement system is shown in **Fig. U6**. A calibration result using this system was validated in comparison with that in NPL as shown in **Fig. U7**. The expanded uncertainties for the calibration are 10 % to 13 % (95 % level of confidence). We have started the calibration service of hydrophone sensitivity for frequency range between 100 kHz and 1 MHz in 2014.

3) Ultrasonic field parameters

For the evaluation of performance and safety of ultrasonic medical equipment, measurement of ultrasonic fields is required in related IEC standards. Manufacturers of the equipment will be able to achieve validation of their measurement by comparing given references of ultrasonic field with their measurement results. We have already started the calibration service of three kinds of ultrasonic field parameters characterizing an ultrasonic field radiated from a reference transducer in 2007. The schematic diagram of the measurement system is shown in Fig. U8. Uncertainties of these ultrasonic field parameters, such as the peak-rarefactional acoustic pressure p_R, the spatial-peak temporal average intensity I_{SPTA}, and the spatial-average temporal average intensity I_{SATA}, from 500 kHz to 20 MHz in our calibration are as follows (95 % level of confidence);

p_R: 7 % ~ 10 %

I_{SPTA}: 14 % ~ 20 %

I_{SATA}:14 % ~ 21 %

Furthermore, we intend to append the effective radiating area A_{ER} and the beam non-uniformity ratio R_{BN} required for the evaluation of ultrasonic physiotherapy systems in IEC 61689 to our ultrasonic field parameter calibration in a few years.

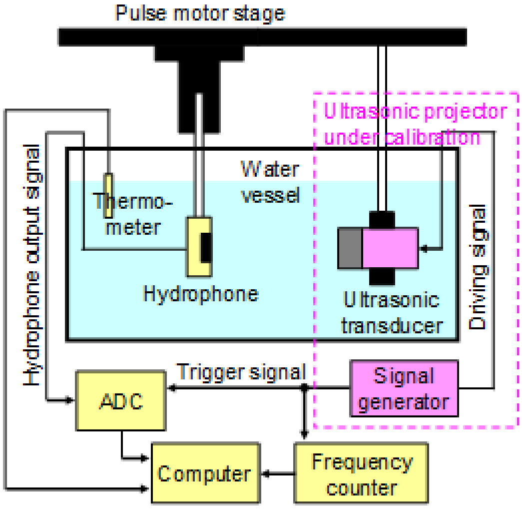


Fig. U8: A block diagram of the measurement system for ultrasonic field parameters.

4) Key comparisons

We participate in key comparisons of CCAUV.U-K3.1 and CCAUV.U-K4 that are for calibrations of ultrasonic power and hydrophone sensitivity, respectively. CCAUV.U-K3.1 is scheduled from March 2014 to March 2015. Our ultrasonic power calibration was finished in April and we reported the results in June 2014. CCAUV.U-K4 is scheduled from March 2014 to April 2015. NMIJ conducted hydrophone sensitivity calibration in September 2014, and we reported the results in November 2014.

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4. Vibration and acceleration standards

NMIJ has developed six calibration systems for the national standard of vibration, shock and angular velocity [1]-[12]. The four systems for vibration calibration are in compliance with ISO 16063-11 (Methods for the calibration of vibration and shock pick-ups. Part 11: Primary vibration calibration by laser interferometry) [13]. The system for shock calibration is in compliance with ISO 16063-13 (Methods for the calibration of vibration and shock transducers. Part 13: Primary shock calibration using laser interferometry) [14]. They are classified for their calibration range as follows.

Fig. V1 System 1: Very low-frequency vibration calibration system

Fig. V2 System 2: Low-frequency vibration calibration system
(CMC not published yet for 1 Hz to 40 Hz)

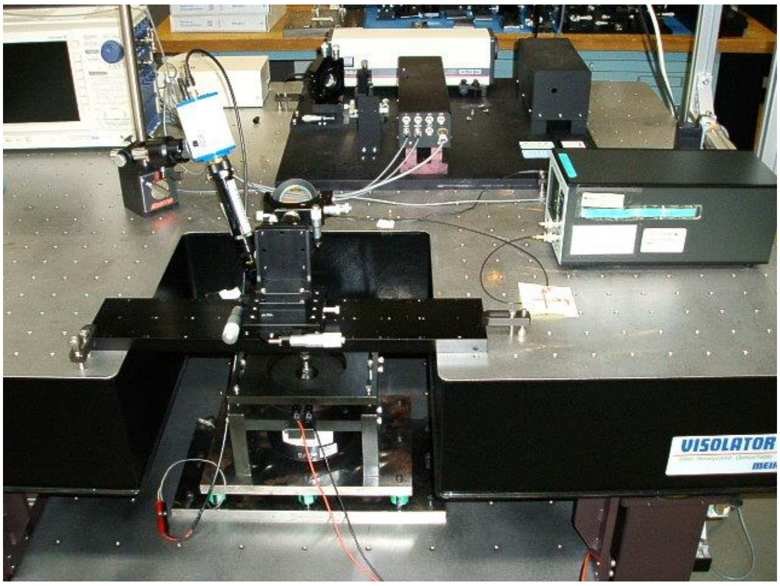

Fig. V3 System 3: Middle-frequency vibration calibration system
(CMC already published except for 20 Hz to 40 Hz)

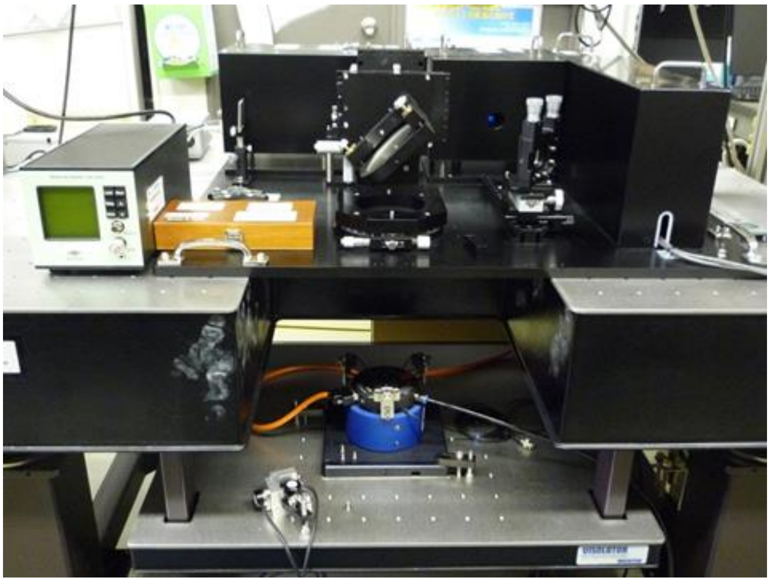

Fig. V4 System 4: High-frequency vibration calibration system

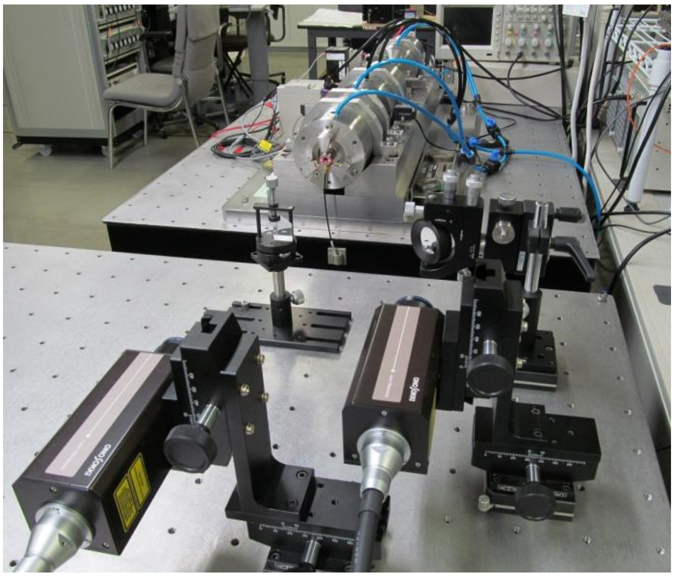

Fig. V5 System 5: Low-shock calibration system

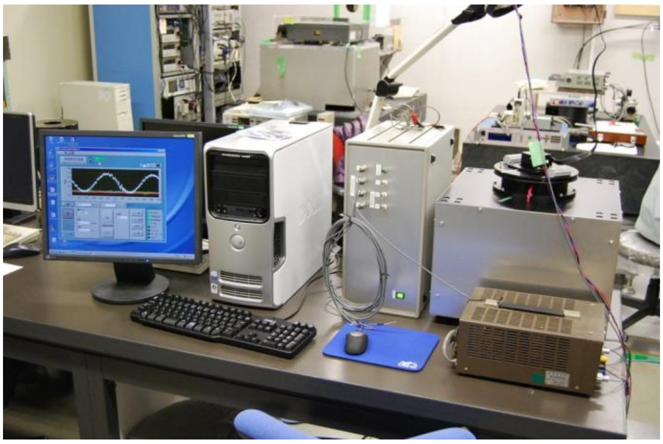

Fig. V6 System 6: Angular velocity calibration system

System 1 is realized by a combination of modified homodyne Michelson laser interferometer for fringe-counting method in compliance with ISO-16063-11 and an electro dynamic vibrator with air-born slider which maximum stroke is 36 cm in horizontal direction. In 2015, some improvements with signal processing and good-performance digitizers were carried out to reduce the expanded uncertainty down to 0.2 %.

System 2 is realized by a combination of Michelson laser interferometer for fringe-counting method in compliance with ISO 16063-11. The vibrator can generate rectilinear motion with horizontal or vertical direction by changing its posture.

System 3 is realized by a combination of modified homodyne Michelson laser interferometer both for fringe-counting method (20 Hz to 80 Hz) and sine approximation method (100 Hz to 5 kHz) in compliance with ISO 16063-11. The motion of vibrator is vertical direction.

System 4 is realized by a combination of modified homodyne Michelson laser interferometer with double optical path and an electro dynamic vibrator with air-borne slider. The motion of vibrator is vertical direction.

System 5 is the shock calibration system for high acceleration amplitude. The shock exciter generates pulse-like acceleration which is monitored by two heterodyne laser interferometers. In order to calibrate shock sensitivity more precisely, the investigation has been done together with PTB [15, 16].

System 6, an angular velocity calibration system, for gyroscopes from 5 deg/s to 300 deg/s was developed with the use of a self-calibratable rotary encoder (selfA) as shown in **Fig. V6** [11]. Its expanded uncertainty is around 1.2×10^{-2} ° /s.

Technical competence in five systems from system 1 to 5 has been confirmed by peer-reviews in 2002, 2007 and 2013. But, the system 6 was not peer-reviewed yet, because it was just established in 2014.

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Figure	System	Calibration Range	Uncertainty (%)	CMC
Fig. V1	Very low frequency	0.1 Hz – 2 Hz	1.0 – 6.0	Not yet
Fig. V2	Low frequency	1 Hz– 200 Hz	0.3 – 2.0	Not yet
Fig. V3	Middle frequency	20 Hz – 5 kHz	0.3 – 0.8	Registered
Fig. V4	High frequency	5 kHz – 10 kHz	0.5 – 0.8	Not yet
Fig. V5	Low shock	50 m/s^2 – 10000 m/s^2	0.6	Not yet
Fig. V6	Angular velocity	5 deg/s – 300 deg/s	1.2×10^{-2} °/s	Not yet

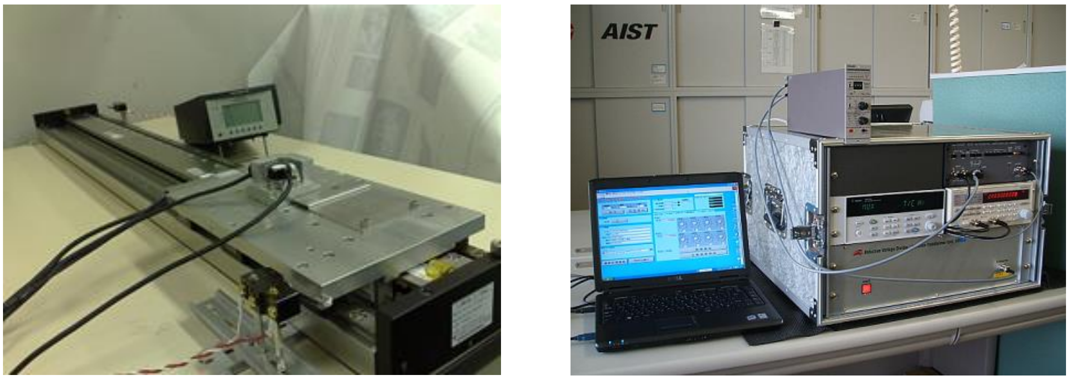

Fig. V7 Transportable calibration equipments

Fig. V8 Digital demodulator for laser vibrometer standard

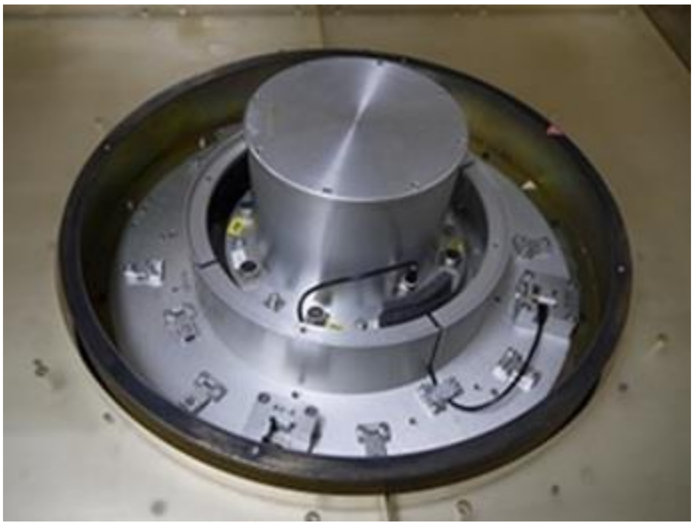

Fig. V9 Centrifuge calibration system for comparison to shock

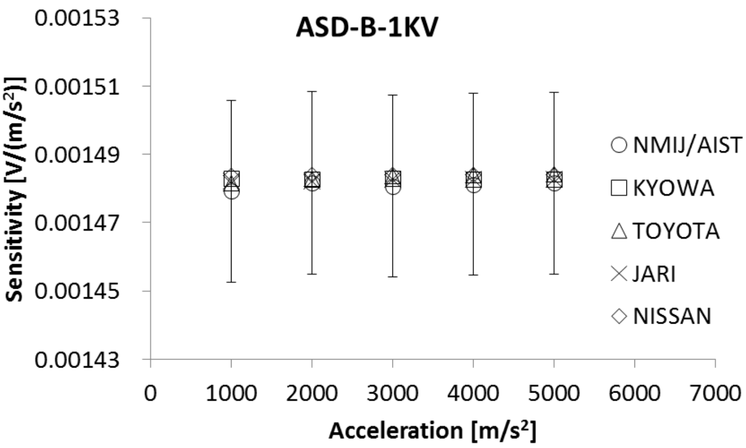

Fig. V10 Comparison result between shock and centrifuge among five participants

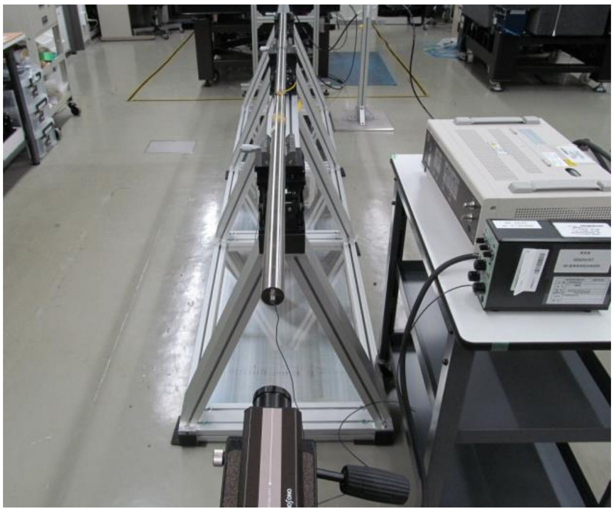

Fig. V11 High-shock calibration system

Now, NMIJ has been developing transportable calibration system for on-site calibration as shown in **Fig. V7** [17, 18, 19]. A reference laser vibrometer standard in compliance with ISO 16063-41 is also under development in cooperation with Japanese private manufacturer as shown in **Fig. V8** [20, 21]. In order to confirm the validity of shock measurements in car crash test, NMIJ evaluated some piezoresistive accelerometers by comparing shock calibration system with centrifuge calibration system (**Fig. V9**) through a round robin test among 5 participants of manufacturers and users [22, 23]. **Fig. V10** shows the result of the round robin test. **Fig. V11** is the high-shock calibration system with heterodyne-type laser measurement for fast velocity up to 20 m/s.

NMIJ as a pilot laboratory implements the International key comparison of APMP.AUV.V.K-1.1 which is in progress among NMIJ, A*Star, NIMT and CMS/ITRI. In this comparison, two kinds of accelerometers BK8305 (back-to-back type) and BK8305-001 (single-ended type) are evaluated on sinusoidal accelerations in the frequency range from 40 Hz to 5 kHz. The calibration results of the BK8305 and BK8305-001 among participated NMIs will be compared and linked to the CIPM comparison, CCUAV.V.K-1 in 2001 and CCAUV.V-K2 in 2012. The draft B reporting is in progress.

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